JSES International 8 (2024) 119–125

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

Bone mineral density around cementless short stems after reverse shoulder arthroplasty: changes over time and its relationship to stem positioning

Katsumasa Nakazawa, MD[a], Tomoya Manaka, MD, PhD[a,*], Yoshihiro Hirakawa, MD, PhD[b], Yoichi Ito, MD, PhD[c], Ryosuke Iio, MD[a], Naoki Oi [c], Hiroaki Nakamura, MD, PhD[a]

[a]*Department of Orthopaedic Surgery, Osaka Metropolitan University Graduate School of Medicine, Osaka, Japan*
[b]*Ishikiriseiki hospital, Higashiosaka, Japan*
[c]*Osaka Shoulder Center, Ito Clinic, Osaka, Japan*

ARTICLE INFO

Keywords:
Bone mineral density
Cementless short stem
Reverse shoulder arthroplasty
Stem alignment
Filling ratio
Dual-energy X-ray absorptiometry

Level of Evidence: Level IV; Case Series; Treatment Study

Background: There are numerous reports of bone adaptation observed on plain radiography studies after the use of cementless short stems in reverse shoulder arthroplasty. However, reports on changes in bone mineral density (BMD) around the stem using dual-energy X-ray absorptiometry (DEXA) are prominently absent. In the present study, we measured BMD around the stem using DEXA and investigated changes over time from postoperative year 1 to year 2. Additionally, the relationship between BMD changes, filling ratio, and stem alignment was examined.
Methods: Forty-seven patients with short cementless stems who could be assessed via DEXA at 1-2 years postoperatively were included. After dividing the zones around the stem into 5, the BMD in each zone was measured, in addition to BMD changes and amount of change from postoperative year 1 to year 2. The relationship between filling ratio and stem alignment on postoperative plain radiography was assessed.
Results: A significant decrease in BMD in zone 3 was observed between postoperative year 1 and year 2 ($P = .02$). Regarding filling ratio and stem alignment, a negative correlation between valgus stem alignment and BMD change observed in zone 1 ($r = -0.470$, $P < .01$). In addition, stem valgus greater than 6° correlated with a significant decrease in BMD in zone 1. ($P = .01$). No significant differences were found in the other zones. Furthermore, there was no correlation between filling ratio and BMD change.
Conclusion: In reverse shoulder arthroplasty cementless short stems, changes that that occurred between postoperative year 1 to year 2 demonstrated a decrease in BMD in zone 3. In addition, a decrease in BMD in zone 1 was observed with a stem alignment of valgus 6° or higher, suggesting that stem alignment within valgus 6° is required to prevent a decrease in BMD.

Reverse shoulder arthroplasty (RSA) is an effective treatment for cuff-tear arthropathy and shoulder osteoarthritis.[3,20] Reverse shoulder arthroplasty (RSA) implants have improved over the years, especially with regard to stems; the use of cementless short stems has steadily increased owing to the concept of preserving bone stock.[1] Notwithstanding its popularity, a common problem with cementless short stems is that bone adaptation increases in cases with higher filling ratios (FR) of the stem.[21,24]

In particular, Schnetzke et al[24] reported that regarding the relationship between FR and high bone adaptations around the stem, there were no obvious signs at postoperative year 1; however, at postoperative year 2, high bone adaptations were significantly more common in patients with higher FR. However, these observations were qualitative in nature because they were based on plain radiography.

In total hip arthroplasty (THA), bone mineral density (BMD) around the stem is measured using dual-energy X-ray absorptiometry (DEXA) to quantitatively evaluate changes over time.[4,6,15] Applying this method to RSA, we aimed to measure the BMD around the stem of the RSA using DEXA to facilitate quantitative evaluation.

This study received approval by the Osaka City University Institutional Review Board (2021-277).

*Corresponding author: Tomoya Manaka, MD, PhD, Department of Orthopaedic Surgery, Osaka Metropolitan University Graduate School of Medicine, 1-4-3, Asahimachi, Abeno-ku, Osaka, 545-8585, Japan.
E-mail address: manaka@med.osaka-cu.ac.jp (T. Manaka).

https://doi.org/10.1016/j.jseint.2023.08.015
2666-6383/

We hypothesized that BMD changes around the stem over time might be related to stem positioning. Particularly, we considered the changes to be related to stem positioning, especially changes that occur from postoperative year 1 to year 2.

Thus, the objectives of this study included measuring BMD around the stem of RSA using DEXA, investigating BMD changes from postoperative year 1 to year 2, and exploring the relationship of these changes to the FR of the stem and stem alignment.

Materials and methods

Patients

As a retrospective study, informed consent was obtained from each patient and ethical approval was obtained from the authors' institutional review board (Approval No: 2021-277).

Patients who had undergone RSA using the Aqualis Asend Flex (Stryker GmbH, Selzach, Switzerland) for cuff tear arthropathy or irreparable rotator cuff-tear who could be followed up for at least 2 years postoperatively and evaluated for BMD via DEXA at postoperative years 1 and 2 were included. Patients with revision RSAs, fracture sequelae, dislocation or infection, and acute proximal humeral fractures were excluded.

Among the 137 patients who underwent RSA between June 2019 and November 2020 at a single institution, we included 86 patients who underwent RSA using the Aqualis Asend Flex (Stryker GmbH, Selzach, Switzerland). Three patients died during the follow-up period and 18 were lost to follow-up. A total of 65 patients were followed up for > 2 years postoperatively. Of these, cemented stems were used in 10 patients (2 cases of revision, 5 cases of fracture sequelae, and 1 case of infection). After excluding these patients, BMD was measurable in 47 of the 47 patients at postoperative years 1 and 2. The mean follow-up period was 34.2 $\pm$ 7.2 months (range: 25-48).

The average age was 76.3 $\pm$ 4.5 years (range: 67-86 years), with 22 men and 25 women. RSA was performed on the right side in 29 patients and on the left side in 18 patients. The average height, weight, and body mass index were 154.4 $\pm$ 9.2 cm (range: 139.5-171.5), 55.9 $\pm$ 9.8 kg (range: 37.8-77.3), and 23.4 $\pm$ 3.1 kg/m^2 (range: 16.1-32.2), respectively.

Among the study participants, 2 had diabetes mellitus and 11 had hypertension or heart disease. Seven patients were treated for osteoporosis, including 2 patients receiving eldecalcitol, 1 patient receiving bazedoxifene acetate, 1 patient receiving minodronic acid hydrate, 1 patient receiving romosozumab, and 1 patient receiving denosumab. All of these drugs for osteoporosis were administered preoperatively, with no postoperative induction or discontinuation.

All patients showed a low level of shoulder usage in their daily lives. All procedures were performed using the standard deltopectoral approach by the 2 surgeons T.M and I.Y. The stem was used in all cases with an inclination of 132.5° and an inclination of 12.5° when using asymmetric polyethylene inserts for trays, resulting in a humeral inclination of 145°. All patients underwent the same postoperative protocol with a sling for 2 weeks. Assisted range of motion (ROM) exercise was initiated 2 days postoperatively, and free ROM exercise was initiated after weaning off the sling. The strengthening program began 3 months postoperatively.

Dual-energy X-ray absorptiometry (DEXA) measurement protocol

Bone mineral density (BMD) was measured using a Lunar Prodigy DEXA device (General Electric Healthcare Medical Systems, Chalfont St Giles, Buckinghamshire, UK), and the shoulder, lumbar spine, and femur were each scanned for evaluation. This device may cause measurement errors due to the positioning of the measurement site. All scans were performed in the supine position, and the abduction position was maintained using a 15^o abduction brace. The upper extremities were placed in external rotation with the palms facing outward (Fig. 1).

The imaging procedure involved obtaining images that included the area from the elbow joint to the supraclavicular border. Twenty centimeters were measured from the midpoint of the humeral osteotomy surface, and an area up to 20 cm was manually set as the bone area (Fig. 2*A*). A region of interest was then established, 2 cm proximal to the 20 cm point (Fig. 2*B*). Regarding zone classification, the distance from the osteotomy surface to the tip of the stem was measured on the bone axis and the length was divided into 2 equal parts; this length was used as the standard length. Using the length criterion, the circumference of the stem was then divided into 5 zones (Fig. 3). Bone mineral density (BMD) in these zones was measured. The bone mineral content (BMC, g), area (cm^2), and BMD (g/cm^2) were calculated. The interobserver error for BMD measurement was determined by the interclass correlation coefficient of the 3 assessors (3 musculoskeletal radiologists) blinded to the identity of the patients. The order of patients was randomized for

Figure 1 Measurement of bone mineral density around the stem using dual energy X-ray absorptiometry. The patient was placed supine with a 15^o abduction brace to maintain a constant abduction position. The affected upper limb was externally rotated with the palm facing outward.

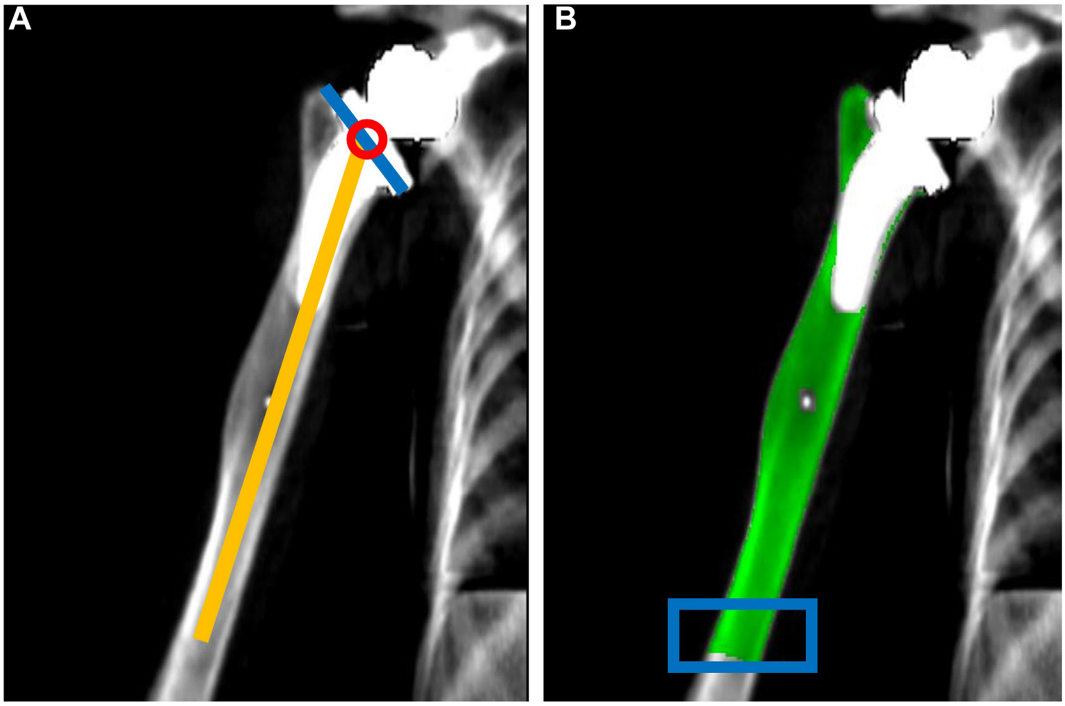


Figure 2 Setting up the region of interest (ROI). The imaging procedure obtained images to include the area from the elbow joint to the supraclavicular border. (A) Twenty centimeters were measured from the midpoint of the humeral osteotomy surface, and an area up to 20 cm was manually set as the bone area. The — represents humeral osteotomy surface, and ◯ is midpoint of humeral osteotomy surface. The — is 20 cm. (B) An ROI was then established, 2 cm proximal to the 20 cm point. The ▭ is the ROI.

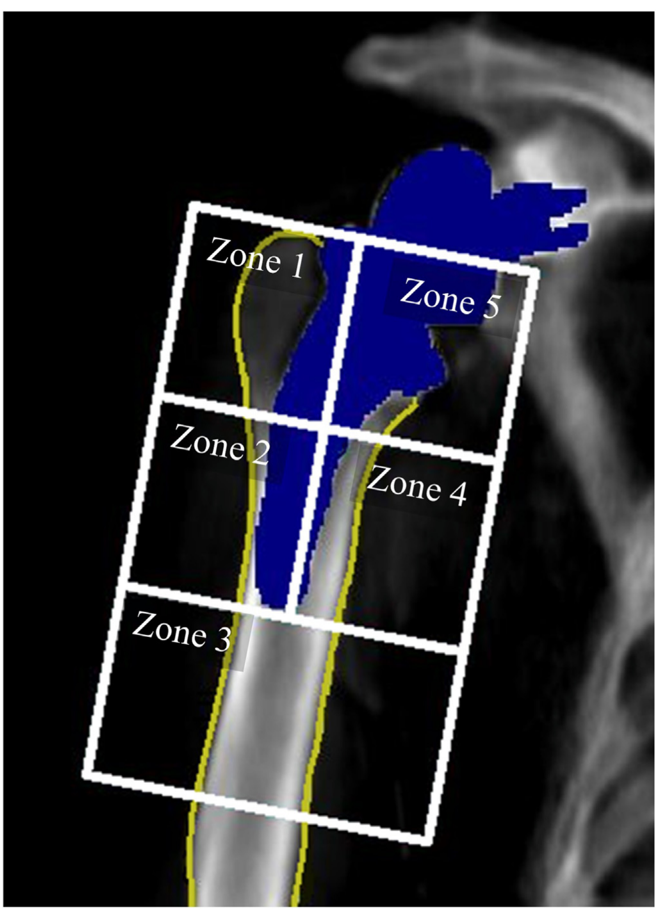


Figure 3 Classifying 5 zones around the stem. For zone classification, the distance from the osteotomy surface to the stem tip was measured on the bone axis and divided into 5 equal parts based on the length bisected.

each evaluation to avoid bias, and each reviewer was blinded to the measurements made by the other reviewers. Lumbar spine and femoral BMD were measured as a percentage of the mean for young adults (aged 20-44 years) and defined as YAM.

Radiographic examination

A true anterior-posterior view of the glenohumeral joint was captured to investigate the FR of the stem and stem alignment based on the report of Raiss et al[21] The inclination of the stem relative to the humeral shaft axis was measured in degrees. The FR of the humeral shaft was measured at the level of the diaphysis and metaphysis. The relationship between changes in BMD, FR of the stem, and stem alignment was investigated. The intraobserver error for the FR of the stem and alignment was determined by the interclass correlation coefficient of 1 author (K.N.) blinded to the identity of the patients. The author repeated the measurement after 1 month to assess intraobserver reliability.

Statistics

The Shapiro–Wilk test was used to test for normality. Means and standard deviations were calculated for continuous variables. A paired *t*-test was used to compare differences in the BMD values by zone around the stem and BMD of the femur at postoperative years 1 and 2. Intraclass correlation coefficients (ICCs) for BMD were calculated according to the standard statistical methods (ICC 2, 1 for interobserver reliability), and ICCs for the FR of the stem and stem alignment were calculated according to the standard statistical methods (ICC 1, 1 for intraobserver reliability). The ICCs were reported as demonstrating slight (≤0.20), fair (0.21-0.40), moderate (0.41-0.60), substantial (0.61-0.80), or almost perfect agreement (0.81-1.00). The Shapiro–Wilk test showed a normal distribution of DEXA results; therefore, the paired *t*-test was used for statistical comparison of BMD changes. Correlations between BMD changes

Table I
Bone mineral density and bone mineral density changes at 1 and 2 years postoperatively.

	BMD (g/cm^2)		BMD change (%)	*P* value
	1 year postoperatively	2 years postoperatively		
Zone 1	0.49 ± 0.13 (0.279-0.815)	0.49 ± 0.13 (0.27-0.81)	1.02 ± 14.08 (−36.13-39.04)	.98
Zone 2	0.87 ± 0.28 (0.44-1.67)	0.88 ± 0.28 (0.38-1.66)	0.53 ± 9.94 (−22.47-19.50)	.97
Zone 3	0.89 ± 0.29 (0.53-1.87)	0.87 ± 0.27 (0.51-1.60)	−2.06 ± 7.40 (−24.36-18.01)	.02*
Zone 4	0.92 ± 0.23 (0.55-1.55)	0.90 ± 0.22 (0.52-1.48)	−1.87 ± 11.1 (−40.02-16.82)	.09
Zone 5	0.68 ± 0.24 (0.24-1.26)	0.65 ± 0.20 (0.29-1.11)	1.57 ± 39.86 (−0.51-37.67)	.21

BMD, bone mineral density.
Paired t-test.
$^*P < .05$.

Table II
Correlation of bone mineral density changes by zones with the stem filling ratios and stem alignment.

	FR met		FR dia		Stem alignment (Valgus)	
	r	*P* value	r	*P* value	r	*P* value
Zone 1	−0.07	.63	0.03	.85	−0.47	<.01*
Zone 2	−0.01	.94	0.21	.15	−0.16	.29
Zone 3	−0.17	.26	−0.11	.47	−0.21	.15
Zone 4	−0.19	.21	0.01	.94	−0.20	.18
Zone 5	−0.02	.88	0.19	.21	−0.15	.30

FR, filling ratio; *met*, metaphysis; *dia*, diaphysis.
Pearson's correlation coefficient.
$^*P < .05$.

and stem alignment and those between BMD changes and FR were analyzed using Pearson's correlation coefficient. The correlation coefficient was interpreted as weak (<0.35), moderate (0.35-0.70), or strong (>0.70). A post hoc power analysis was conducted using G*Power (version 3.0.3; Heinrich Heine Universität, Düsseldorf, Germany) to compare the BMD changes in zone 3. Optimal threshold points for stem alignment that predicted BMD changes were calculated using nonparametric receiver operating characteristic (ROC) analysis. The 2-sample t-test was used to compare the BMD changes in zone 1 higher and lower than 6° valgus. The level of significance was set at $P < .05$. Statistical analyses were performed using SPSS version 25.0 (IBM Corp., Armonk, NY, USA).

Results

The reliability of BMD around the stem was 0.97 (0.94-0.99), which was almost a perfect agreement. Similarly, the reliability of the FR of the stem and that of the stem alignment were 0.91 (0.83−0.95) and 0.95 (0.92-0.97) respectively, which were almost perfect agreements.

Study parameters

The mean BMD of the femur in 47 patients at postoperative year 1 was 83.5 ± 17.9% for %YAM and 83.1 ± 17.8% at postop year 2. The change from postoperative year 1 to year 2 was $P = .26$, with no significant difference.

The mean BMD of the spine at postoperative year 1 was 102.9 ± 27.2% for %YAM and 103 ± 28.2% at postoperative year 2. The change from postoperative year 1 to year 2 was $P = .79$, with no significant difference. In addition, there was no evidence of stem loosening at postoperative year 2.

Regarding the FR of the stem and stem alignment, the mean FR at the metaphysis (FR met) was 76.7 ± 9.1% (54.8%-92.8%), FR at diaphysis (FR dia) was 63.5 ± 10.2% (42.75%-88.8%), and stem alignment was at valgus 5.8° ± 3.1° (0.9-13.1 degrees) in all cases.

Bone mineral density by zones at postoperative years 1 and 2 and bone mineral density changes

Bone mineral density (BMD) per zone at postoperative years 1 and 2 is presented in Table I. The BMD changes by zone were significantly lower in zone 3 ($P = .02$). However, a post hoc power analysis revealed that the comparison of anteversion had a statistical power of 0.12.

Correlation between the stem filling ratio and bone mineral density changes

Bone mineral density (BMD) changes and their correlations with the FR of the stem are shown in Table II. The FR of the stem had no significant correlation with the BMD changes.

Correlation between stem alignment and bone mineral density changes

Bone mineral density (BMD) changes and their correlations with stem alignment are shown in Table II, with moderate correlation in zone 1 (Fig. 4). Receiver operating characteristic (ROC) analysis was performed with the increased BMD in zone 1 categorized as the increased group and the decreased group as the decreased group with an area under the curve of 0.698 ($P = .02$). Therefore, the threshold was determined to be 6° (Fig. 5). With 6° valgus or higher, BMD change was significantly reduced (Table III).

Discussion

To the best of our knowledge, this is the first study to measure BMD around the stem after RSA using DEXA. In the present study, a significant decrease in BMD from postoperative year 1 to year 2 was observed in zone 3. In relation to the FR of the stem and stem alignment, no association was found between the FR and correlation between valgus stem alignment and BMD in zone 1. Furthermore, the ROC curve results showed a significant difference in the BMD decrease when the stem alignment threshold was set at 6° valgus.

Recently, cementless short stems have been introduced to preserve the bone stock, reduce stress shielding, and improve vascularity and osteointegration.[14,22] In particular, the Aeqlis Asend Flex stem used in this study is a short stem with a proximal porous coating on the metaphyseal area for bone ingrowth. However, Schnetzke et al[24] reported that in a study of total shoulder arthroplasty (TSA) and RSA using the Aequalis Ascend Monolithic cementless monolithic short stem, 82.7% of recipients experienced cortical thinning and osteopenia in the medial proximal region (zone 5) and spot welds in 78.6% of the distal lateral region (zone 2) during a postoperative follow-up of 2 years. In total, 11.5% had condensation lines at the tip of the stem (zone 3). Furthermore, the

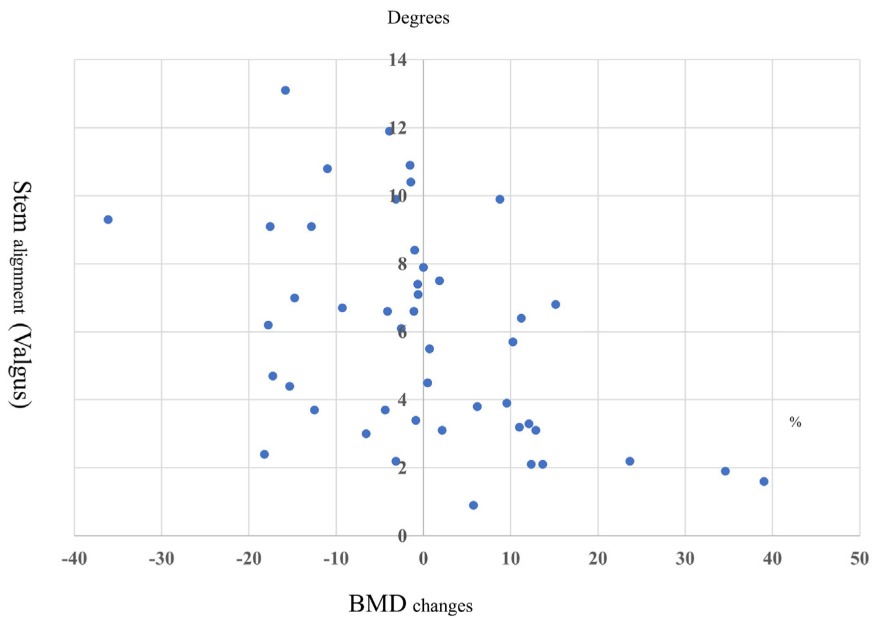
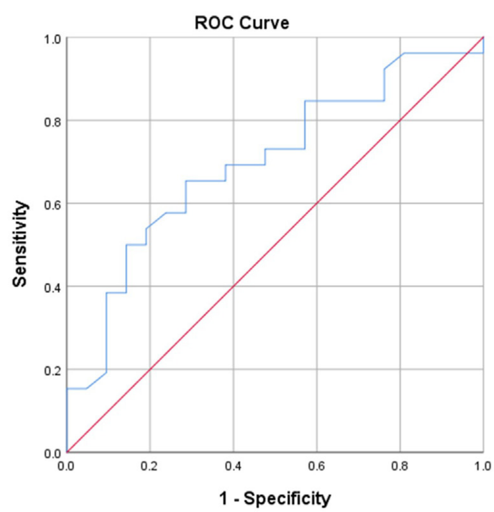


Figure 4 Correlation between the valgus angle of the stem and the bone mineral density changes in zone 1. *BMD*, bone mineral density.



Area under the Curve

			Asymptotic 95% Confidence Interval	
Area	Std. Error *	Asymtotic Sig **	Lower Bound	Upper Bound
0.70	0.08	0.02	0.55	0.85

* Under the nonparametric assumption

** Null hypothesis: ture area = 0.5

Figure 5 Receiver operating characteristic curve for the valgus stem alignment as a predictor of BMD changes in zone 1. Area under the curve, 0.70; 95% confidence interval, 0.55-0.85; $P = .02$. *ROC*, receiver operating characteristic.

Comprehensive Reverse Shoulder System (Biomet, Warsaw, IN, USA) reported that at an average follow-up of 27 months, proximal bone remodeling occurred in approximately 30% of the patients.[9] These reports suggest that bone adaptation due to stress shielding occurs even when a short stem is used. However, these were qualitative evaluations that used plain radiography. Therefore, we utilized DEXA to conduct a quantitative assessment of BMD around the stem.

Table III
Valgus stem alignment and BMD changes when separated by 6°.

Zone 1	Stem alignment		P value
	<6 degrees valgus	≧6 degrees valgus	
BMD change (g/cm^2)	1.09 ± 0.05 (0.82-1.39)	0.49 ± 0.13 (0.64-1.15)	.01*

BMD, bone mineral density.
*P < .05 the 2-sample t-test.

In this study, BMD changes over time showed a 2.06% decrease in zone 3. Razfer et al[22] reported that finite element analysis of TSA showed that bone stresses are concentrated in the proximal trabecular bone, especially with an increase in the stem length. Therefore, they suggested that changes may occur in the proximal trabecular bone. However, in their study, the stem was designed to be in contact with the diaphyseal bone. In the present study, the FR at the diaphysis was set up to be noncontact (63.5%), and this difference may have influenced the study results. Furthermore, TSA and RSA have different prosthetic characteristics, which may have similarly influenced the results. In addition, because this study was a comparison between changes at postoperative year 1 and year 2, the changes at 2 years postoperatively may differ from those in the early postoperative period.

In THA, a decrease in BMD occurs mainly in the proximal part of the stem, particularly in zones 1 and 7 in Gruen's zone classification.[8,10,17,23,26] This trend was consistent even when the stem was short.[12] The initial stability of the cementless femoral stem requires fitting of the diaphysis to the femoral cortex, which is fixed distally and known to cause atrophy of the proximal femur with stress shielding.[13,25] However, our report showed a decrease in zone 3, which is in the distal part of the stem. This may be related to the fact that THA is performed on load-bearing joints, whereas RSA is performed on non–load-bearing joints. The effect size was 0.12 as the post hoc power of the test, which is a low result, and should be examined in future studies with a larger number of cases. Complications such as decreased BMD around the stem of THA have been reported to cause increased periprosthetic fractures and aseptic loosening.[2,16,19] Therefore, it is necessary to surveil and examine the possibility of a decrease in BMD, which could lead to periprosthetic humeral fractures in RSA, by long-term follow-up in the future.

In the correlation between the FR of the stem and stem alignment, the present study found a correlation between valgus stem alignment and BMD in zone 1. In a previous report on cemented and cementless stems on Delta III (DePuy International Ltd, Leeds, United Kingdom), Melis et al[18] reported that a higher FR was associated with condensation lines and spot welds. In addition, Raiss et al[21] reported an increase in the occurrence of bone adaptation when the diaphyseal FR exceeded 0.8. However, the present study found no correlation between BMD changes by zone and FR. Since the publication of the report by Raiss et al, our group has been cognizant of avoiding a high FR. The mean FR dia was low at 63.5 ± 10.2%, possibly because there were only 5 out of 47 cases (10.6%) with a mean FR dia greater than 0.8.

In the present study, BMD change in zone 1 was correlated with the stem alignment of the valgus. When the threshold was set at 6° based on the ROC curve results, the BMD was significantly lower when the 6° valgus was exceeded. Previous studies of shoulder arthroplasty have not reported an association between bone adaptation and stem alignment. However, a THA article reported that varus-valgus stem alignment was associated with BMD in the Gruen zone 1, the greater trochanter.[7,11] Thus, stem alignment may have a significant effect on BMD changes in RSA. Despite maintaining a low FR as that in the present study, previous reports have demonstrated that small stems are more likely to cause malpositioning of the stem and increased endocortical contact. As a result, incidences of bone resorption have been reported.[1] Therefore, we believe that stress shielding caused by malpositioning of the stem at the valgus reduced BMD in zone 1. It has also been reported that increased endocortical contact can lead to aseptic loosening of the humeral stem, and a decrease in BMD in zone 1 may also lead to aseptic loosening. Therefore, it is necessary to place implants within 6° valgus.[5]

This study had some limitations. First, although the early postoperative period is often regarded as the baseline when examining BMD changes, BMD during the early postoperative period was not evaluated. Thus, investigating changes at postoperative years 1 and 2 may have not been sufficient. In addition, BMD around the stem may change over time, and long-term follow-up is necessary in the future. Second, this was a retrospective study, and only 1 stem model was studied. Third, the number of patients examined was small. Fourth, the clinical evaluation of ROM and other parameters was not performed. Fifth, the effect of osteoporosis drugs was not considered.

Conclusions

In the present study, a significant decrease in BMD from postoperative year 1 to year 2 was observed in zone 3. Regarding the correlation between BMD changes, filling ratios, and stem alignment, a correlation was found between stem alignment and BMD changes in zone 1. Furthermore, BMD in zone 1 decreased significantly at 6° valgus or greater. Therefore, we recommend that the stem should be placed within valgus 6° to prevent a decrease in BMD.

Disclaimers:

Funding: No funding was disclosed by the authors.
Conflicts of interest: The authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Abdic S, Athwal GS, Wittmann T, Walch G, Raiss P. Short stem humeral components in reverse shoulder arthroplasty: stem alignment influences the neck-shaft angle. Arch Orthop Trauma Surg 2021;141:183-8. https://doi.org/10.1007/s00402-020-03424-4.
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;83:107-14. https://doi.org/10.3109/17453674.2012.678798.
3. Boileau P, Sinnerton RJ, Chuinard C, Walch G. Arthroplasty of the shoulder. J Bone Joint Surg Br 2006;88:562-75. https://doi.org/10.1302/0301-620X.88B5.16466.
4. Brodner W, Bitzan P, Lomoschitz F, Krepler P, Jankovsky R, Lehr S, et al. Changes in bone mineral density in the proximal femur after cementless total hip arthroplasty. A five-year longitudinal study. J Bone Joint Surg Br 2004;86:20-6. https://doi.org/10.1302/0301-620x.86b1.14637.

5. Casagrande DJ, Parks DL, Torngren T, Schrumpf MA, Harmsen SM, Norris TR, et al. Radiographic evaluation of short-stem press-fit total shoulder arthroplasty: short-term follow-up. J Shoulder Elbow Surg 2016;25:1163-9. https://doi.org/10.1016/j.jse.2015.11.067.
6. Cohen B, Rushton N. Accuracy of dexa measurement of bone mineral density after total hip arthroplasty. J Bone Joint Surg Br 1995;77:479-83.
7. Fujita M, Hayashi S, Hashimoto S, Kuroda Y, Kuroda R, Matsumoto T. The influence of stem alignment on the bone mineral density around the Polarstem following total hip arthroplasty. Arch Orthop Trauma Surg 2022;143:3621-7. https://doi.org/10.1007/s00402-022-04607-x.
8. Gibbons CER, Davies AJ, Amis AA, Olearnik H, Parker BC, Scott JE. Periprosthetic bone mineral density changes with femoral components of differing design philosophy. Int Orthop 2001;25:89-92.
9. Giuseffi SA, Streubel P, Sperling J, Sanchez-Sotelo J. Short-stem uncemented primary reverse shoulder arthroplasty: clinical and radiological outcomes. Bone Joint Lett J 2014;96B:526-9. https://doi.org/10.1302/0301-620X.96B3.32702.
10. 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;17–27.
11. Hayashi S, Hashimoto S, Kanzaki N, Kuroda R, Kurosaka M. Stem anteversion affects periprosthetic bone mineral density after total hip arthroplasty. Hip Int 2016;26:260-4. https://doi.org/10.5301/hipint.5000363.
12. Jahnke A, Engl S, Altmeyer C, Jakubowitz E, Seeger JB, Rickert M, et al. Changes of periprosthetic bone density after a cementless short hip stem: a clinical and radiological analysis. Int Orthop 2014;38:2045-50. https://doi.org/10.1007/s00264-014-2370-6.
13. Kwon DG, Lee TJ, Kang JS, Moon KH. Correlation between stress shielding and clinical outcomes after total hip arthroplasty with extensively porous coated stems. J Arthroplasty 2013;28:1728-30. https://doi.org/10.1016/j.arth.2013.06.036.
14. Lädermann A, Chiu JCH, Cunningham G, Hervé A, Piotton S, Bothorel H, et al. Do short stems influence the cervico-diaphyseal angle and the medullary filling after reverse shoulder arthroplasties? Orthop Traumatol Surg Res 2020;106:241-6. https://doi.org/10.1016/j.otsr.2019.12.010.
15. Lawrie CM, Barrack RL, Nunley RM. Modular dual mobility total hip arthroplasty is a viable option for young, active patients: a mid-term follow-up study. Bone Joint Lett J 2021;103-B:73-7. https://doi.org/10.1302/0301-620X.103B7.BJJ-2021-0145.R1.
16. Leonardsson O, Kärrholm J, Åkesson K, Garellick G, Rogmark C. Higher risk of reoperation for bipolar and uncemented hemiarthroplasty. Acta Orthop 2012;83:459-66. https://doi.org/10.3109/17453674.2012.727076.
17. Lerch M, Kurtz A, Windhagen H, Bouguecha A, Behrens BA, Wefstaedt P, et al. The cementless Bicontact® stem in a prospective dual-energy X-ray absorptiometry study. Int Orthop 2012;36:2211-7. https://doi.org/10.1007/s00264-012-1616-4.
18. Melis B, Bonnevialle N, Neyton L, Lévigne C, Favard L, Walch G, et al. Glenoid loosening and failure in anatomical total shoulder arthroplasty: is revision with a reverse shoulder arthroplasty a reliable option? J Shoulder Elbow Surg 2012;21:342-9. https://doi.org/10.1016/j.jse.2011.05.021.
19. Morita A, Kobayashi N, Choe H, Tezuka T, Misumi T, Inaba Y. Effect of implant composition on periprosthetic bone mineral density after total hip arthroplasty. Arch Orthop Trauma Surg 2023;143:2763-71. https://doi.org/10.1007/s00402-022-04537-8.
20. Raiss P, Schmitt M, Bruckner T, Kasten P, Pape G, Loew M, et al. Results of cemented total shoulder replacement with a minimum follow-up of ten years. J Bone Joint Surg 2012;94:1-10. https://doi.org/10.2106/JBJS.K.00580.
21. Raiss P, Schnetzke M, Wittmann T, Kilian CM, Edwards TB, Denard PJ, et al. Postoperative radiographic findings of an uncemented convertible short stem for anatomic and reverse shoulder arthroplasty. J Shoulder Elbow Surg 2019;28:715-23. https://doi.org/10.1016/j.jse.2018.08.037.
22. Razfar N, Reeves JM, Langohr DG, Willing R, Athwal GS, Johnson JA. Comparison of proximal humeral bone stresses between stemless, short stem, and standard stem length: a finite element analysis. J Shoulder Elbow Surg 2016;25:1076-83. https://doi.org/10.1016/j.jse.2015.11.011.
23. Schmidutz F, Graf T, Mazoochian F, Fottner A, Bauer-Melnyk A, Jansson V. Migration analysis of a metaphyseal anchored short-stem hip prosthesis. Acta Orthop 2012;83:360-5. https://doi.org/10.3109/17453674.2012.712891.
24. Schnetzke M, Coda S, Raiss P, Walch G, Loew M. Radiologic bone adaptations on a cementless short-stem shoulder prosthesis. J Shoulder Elbow Surg 2016;25:650-7. https://doi.org/10.1016/j.jse.2015.08.044.
25. Smolders JMH, Hol A, Rijnders T, Van Susante JLC. Changes in bone mineral density in the proximal femur after hip resurfacing and uncemented total hip replacement: a prospective randomised controlled study. J Bone Joint Surg Br 2010;92 B:1509-14. https://doi.org/10.1302/0301-620X.92B11.24785.
26. Yan SG, Weber P, Steinbrück A, Hua X, Jansson V, Schmidutz F. Periprosthetic bone remodelling of short-stem total hip arthroplasty: a systematic review. Int Orthop 2018;42:2077-86. https://doi.org/10.1007/s00264-017-3691-z.