Preoperative Factors Predicting the Severity of BMD Loss Around the Implant after Total Hip Arthroplasty

Akira Morita  
Yokohama City University

Kobayashi Naomi (naomik58@aol.com)  
Yokohama City University Medical Center

Hyonmin Choe  
Yokohama City University

Taro Tezuka  
Yokohama City University

Shota Higashihiro  
Yokohama City University

Yutaka Inaba  
Yokohama City University

Research Article

Keywords: total hip arthroplasty, bone mineral density, canal flare index, Zweymüller

DOI: https://doi.org/10.21203/rs.3.rs-129646/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License
Abstract

Background

Stress shielding after total hip arthroplasty (THA) leads to the loss of bone mineral density (BMD) around the femoral implants, particularly in the proximal area. BMD loss around the implant is likely to occur within 1 year after THA, but its severity depends on patient characteristics. This study evaluated preoperative factors associated with the severity of zone 7 BMD loss after THA.

Methods

This retrospective cohort study included 48 patients who underwent primary THA at our hospital from October 2011 to December 2015. All patients underwent implantation of a Zweymüller-type femoral component without any postoperative osteoporosis medications. The objective variable was change in zone 7 BMD after 1 year. Factors evaluated included age, body mass index (BMI), Japanese Orthopaedic Association (JOA) score, Harris Hip Score (HHS), Canal Flare Index (CFI), and lumbar BMD on the frontal and lateral sides. Factors associated with loss of zone 7 BMD were identified by univariate and multivariate regression analyses.

Results

Univariate regression analysis showed that CFI (P=0.003) and preoperative lumbar BMD on the frontal (P=0.003) and lateral (P<0.001) sides were significantly correlated with loss of zone 7 BMD. Multivariate regression analysis showed that CFI (P=0.014) and lumbar BMD on the lateral side (P<0.001) were independently correlated with loss of zone 7 BMD.

Conclusion

Lower preoperative lumbar BMD on the lateral side and lower CFI were significantly associated with zone 7 BMD loss after THA. Patients with these characteristics should be carefully monitored for severe BMD loss after THA.

Introduction

Total hip arthroplasty (THA) is an established surgical method for patients with hip joint diseases, such as osteoarthritis and osteonecrosis of the femoral head, resulting in stable long-term clinical outcomes, including pain relief and improvements in activities of daily living (ADL) [1, 2]. THA, however, can result in a reduction in bone mineral density (BMD) around the implant, especially in the proximal part such as Gruen's zones 1 and 7 [3–5]. Although BMD loss around the implant has not been found to directly worsen clinical outcomes, this loss of BMD has been associated with periprosthetic fracture risk and late loosening [6, 7], suggesting that maintenance of BMD around the implant results in stable long-term clinical outcomes.
The main cause of BMD loss around the implant is stress shielding, which results from changes in mechanical stress properties after implantation [4]. Several studies have assessed the ability of several drugs, including bisphosphonates and teriparatide, to prevent BMD loss around implants following THA [8–12]. Because BMD loss may also be associated with preoperative patient-specific factors, these findings suggest that such drug interventions should be initiated immediately after THA particularly in selected patients at higher risk of BMD loss. This study therefore sought to identify preoperative factors predicting the severity of BMD loss around implants after THA.

Patients And Methods

This retrospective cohort study evaluated patients diagnosed with osteoarthritis of the hip or osteonecrosis of the femoral head who underwent primary THA at our hospital from October 2011 to December 2015 (Fig. 1). Patients were excluded if they received non-target implants; were treated with drugs for osteoporosis or corticosteroids; or were diagnosed with a condition other than osteoarthritis of the hip or osteonecrosis of the femoral head. Patients were also excluded if all data, including BMD and X-rays, were not available 1 year after surgery. Preoperative patient activity levels were evaluated by measuring their activity score, Japanese Orthopaedic Association (JOA) hip score, and Harris Hip Score (HHS).

All patients were operated direct lateral approach and implanted with the same cementless femoral component of a Zweymüller-type stem (SL-PLUS MIA, Smith and Nephew, Inc. Memphis, TN), a cementless acetabular component (REFLECTION, Smith and Nephew, Inc.), and a cross-linked polyethylene liner (XLPE liner, Smith and Nephew, Inc.). All patients started to use a wheelchair on the first postoperative day and started gait exercises with full weight bearing as soon as possible. Baseline periprosthetic BMD was measured 1 week after THA by dual-energy X-ray absorptiometry (DEXA) (QDR 2000, Hologic, Waltham, MA), followed by subsequent measurements at 1 year intervals. Regions of interest (ROIs) were centered on the periprosthetic zones described by Gruen (Fig. 2). Lumbar BMDs at L2 to L4 in the lumbar anterior-posterior (AP) and lateral directions were also measured 1 week preoperatively using DEXA.

The primary study outcome was change in zone 7 BMD 1 year after THA. Factors evaluated included age, body mass index (BMI), and preoperative JOA score, HHS, Canal Flare Index (CFI) (Fig. 3), and lumbar BMD on the frontal and lateral sides.

Univariate regression analysis and multivariate regression analysis were performed using SPSS II software (SPSS Japan, Inc., Tokyo, Japan). Factors significant on univariate analyses were included in stepwise multivariate regression analysis. A P-value < 0.05 was considered statistically significant.

Results
Of the 328 patients who underwent primary THA at our hospital from October 2011 to December 2015, 280 were excluded. Of the latter, 185 received non-target implants, 70 were taking medications for osteoporosis, two were diagnosed with a condition other than osteoarthritis of the hip or osteonecrosis of the femoral head, four were taking steroids, and 19 had missing data, such as the results of BMD measurements and X-rays.

The 48 included patients were of mean (± standard deviation) age 64.0 ± 12.0 years and mean BMI of 24.0 ± 4.2 kg/m² at the time of surgery. Table 1 shows their demographic and clinical characteristics, and Fig. 4 shows the periprosthetic changes in BMD for each zone at 1 year postoperatively. Relative to baseline, the mean percent changes in BMD for zones 1–7 at 1 year were −10.9%±9.7%, -9.3%±11.5%, -3.7%±8.6%, +0.9%±5.5%, +0.8%±6.1%, -12.9%±12.8%, and −32.8%±15.3%, respectively. Table 2 shows the results of univariate regression analysis of the association between change in zone 7 BMD and exploratory variables. Scatter plots showed that the percent change from baseline in zone 7 BMD at 1 year correlated significantly with preoperative CFI (R² = 0.177, R = 0.421, P = 0.003; Fig. 5), preoperative lumbar BMD on the frontal side (R² = 0.194, R = 0.440, P = 0.003; Fig. 6), and preoperative lumbar BMD on the lateral side (R² = 0.310, R = 0.557, P < 0.001; Fig. 7). Multivariate regression analysis showed that the percent change from baseline in zone 7 BMD correlated significantly with preoperative CFI (P = 0.014) and preoperative lumbar BMD on the lateral side (P < 0.001), but not with any other factors (Table 3).

| Variable                        | Average±SD |
|---------------------------------|------------|
| Age (yr)                        | 64.0±12.0  |
| Male/Female                     | 9/39       |
| BMI (kg/m²)                     | 24.0±4.2   |
| JOA score                       | 52.0±14.0  |
| HHS                             | 51.8±15.4  |
| CFI                             | 4.2±0.8    |
| Lumbar spine BMD AP side (g/cm²)| 1.0±0.2    |
| Lumbar spine BMD lateral side (g/cm²)| 0.7±0.1 |
| Change in BMD of zone 7 (%)     | -32.8±15.3 |

Table 2. Univariate regression analysis of the association between change in zone 7 BMD and exploratory variables
### Table 3. Multivariate regression analysis of the association between change in zone 7 BMD and exploratory variables

| Variable                                      | Regression coefficient (B) | Standardized regression coefficients (β) | 95% CI       | P-value |
|-----------------------------------------------|----------------------------|------------------------------------------|--------------|---------|
| Age (yr)                                      | -0.226                     | -0.172                                   | ~-0.61–0.15  | 0.242   |
| BMI (kg/m²)                                   | -0.231                     | -0.063                                   | ~1.32–0.85   | 0.672   |
| JOA score                                     | 0.243                      | 0.223                                    | ~0.07–0.56   | 0.132   |
| HHS                                           | 0.133                      | 0.134                                    | ~0.16–0.43   | 0.369   |
| CFI                                           | 7.628                      | 0.421                                    | ~2.75–12.50  | 0.003   |
| Lumbar spine BMD AP side (g/cm²)              | 37.630                     | 0.440                                    | ~0.013–0.07  | 0.003   |
| Lumbar spine BMD lateral side (g/cm²)         | 83.027                     | 0.557                                    | ~0.04–0.12   | <0.001  |

### Discussion

This retrospective cohort study, which investigated preoperative factors associated with BMD loss in zone 7 after THA, found that preoperative CFI and lumbar BMD on the lateral side were significantly associated with periprosthetic BMD loss. These findings emphasize the importance of monitoring patients for severe BMD loss after THA, especially patients with lower lumbar BMD and a stovepipe-shaped proximal femur.

BMD loss around the implant has been frequently observed after THA [13, 14]. The most important cause of BMD loss is stress shielding, which is mainly influenced by stem design. A comparison of patients undergoing THA with Zweymüller stem and fit-and-fill stem implants found that both mechanical stress...
and zone 7 BMD loss around the implant were lower in the Zweymüller stem group than in the fit-and-fill stem group [4].

In addition to stem design, BMD loss may be associated with patient-specific or operative factors. For example, excessive stem anteversion mismatched with anatomical canal anteversion has been found to result in stem point contact with the cortical bone in the distal portion, affecting proximal periprosthetic zone 7 BMD loss after THA [15, 16]. An investigation of postoperative zone 7 BMD in groups of patients with normal preoperative lumbar BMD and patients with osteopenia and osteoporosis found that BMD loss was significantly higher in the osteopenia and osteoporosis groups than in the normal group [17], indicating that periprosthetic BMD loss is associated with bone quality as well as stress shielding [14].

Because zone 7 BMD loss occurs within 1 year postoperatively [17], it is important to take steps to prevent this BMD loss. Many drugs have been used to prevent BMD loss around the implant after THA. For example, bisphosphonate was reported to prevent BMD loss around the implant [10, 11, 18–23]. Moreover, bisphosphonate treatment was associated with a lower risk of aseptic revision in patients undergoing primary THA for osteoarthritis [21]. However, long-term continuous bisphosphonate treatment has been associated with atypical periprosthetic fractures [22, 23]. Periprosthetic fracture rates following primary THA were reported to be 1.1% in a large US cohort [22] and 0.64% over 10 years in the Swedish hip registry [23], with bisphosphonate use associated with a higher risk of periprosthetic fractures in younger patients with normal bone quantity [23]. Another effective agent that can prevent BMD loss around the implant is teriparatide. A randomized controlled trial found that teriparatide and alendronate were equally effective for preventing zone 7 BMD loss [11]. Moreover, switching from teriparatide to alendronate has been shown to be effective [12]. Although several drugs can prevent BMD loss around the implant after THA, care is necessary regarding the side effects and economic burden of these agents.

The shape of the femoral medullary cavity has been reported to be related to BMD loss around the implant. Postoperative zone 7 BMD was found to be significantly lower in stovepipe-shaped than in champagne-flute-shaped cavities when using taper-wedge-type stems [24]. The stovepipe-shaped type of medullary cavity has a small CFI, making these results similar to those of the present study. By contrast, a comparison of postoperative changes in BMD of any zone between three types of medullary cavities, stovepipe, normal, and champagne-flute shaped, using Zweymüller-type stems found no statistically significant differences in relative changes between the three groups [25]. Our study found that patients with low CFI, such as those with stovepipe-shaped medullary cavities, showed a greater reduction in postoperative zone 7 BMD than patients with high CFI, such as those with champagne-flute-shaped cavities.

**Limitation**

This study had several limitations. First, this study only investigated patients with Zweymüller-type stems. Studies of other stem types, such as taper-wedge stems, may yield different results. Second, the total number of evaluated subjects was small, as many subjects had to be excluded.
Conclusion

Lower preoperative lumbar BMD on the lateral side and lower CFI were significantly associated with zone 7 BMD loss 1 year after THA. Patients at risk of BMD loss may benefit from pre- or postoperative drug treatment to prevent BMD loss.

Abbreviations

THA, total hip arthroplasty; BMD, bone mineral density; BMI, body mass index; JOA, Japanese Orthopaedic Association; HHS, Harris Hip Score; CFI, Canal Flare Index; ADL, activities of daily living; DEXA, dual-energy X-ray absorptiometry; ROIs, Regions of interest; AP, anterior-posterior.

Declarations

We conducted clinical studies according to the ICMJE guidelines.

Ethics approval and consent to participate

Ethical permission was acquired for this study from Yokohama City University ethical committee (number B191200033). Informed consent was obtained from all individual participants included in the study.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Authors' contributions

NK is Corresponding author. AM collected the patient data. HC and SH analyzed the patient data. TT and YI interpreted the patient data. All authors read and approved the final manuscript.
Acknowledgements

I would like to express my sincere appreciation to those who supported the research and cooperated in the preparation of the manuscript.

Authors' information (optional)

1. Department of Orthopaedic Surgery, Yokohama City University, Yokohama, Japan
2. Department of Orthopaedic Surgery, Yokohama City University Medical Center, Yokohama, Japan

References

1. Al Muderis M, Bohling U, Grittner U, Gerdesmeyer L, Scholz J (2011) Cementless total hip arthroplasty using the Spongiosa-I fully coated cancellous metal surface: a minimum twenty-year follow-up. J Bone Joint Surg Am 93:1039–44.
2. McLaughlin JR, Lee KR (2010) Uncemented total hip arthroplasty with a tapered femoral component: a 22- to 26-year follow-up study. Orthopedics 33:639.
3. Kröger H, Venesmaa P, Jurvelin J, Miettinen H, Suomalainen O, et al. (1998) Bone density at the proximal femur after total hip arthroplasty. Clin Orthop Relat Res 66–74
4. Hirata Y, Inaba Y, Kobayashi N, Ike H, Fujimaki H, et al. (2013) Comparison of Mechanical Stress and Change in Bone Mineral Density Between Two Types of Femoral Implant Using Finite Element Analysis. J Arthroplasty 28:1731–1735.
5. Ike H, Inaba Y, Kobayashi N, Hirata Y, Yukizawa Y, et al. (2015) Comparison between mechanical stress and bone mineral density in the femur after total hip arthroplasty by using subject-specific finite element analyses. Comput Methods Biomech Biomed Engin 18:1056–1065.
6. Leonardsson O, Kärrholm J, Åkesson K, Garellick G, Rogmark C (2012) Higher risk of reoperation for bipolar and uncemented hemiarthroplasty. Acta Orthop 83:459–466.
7. Aro HT, Alm JJ, Moritz N, Mäkinen TJ, Lankinen P (2012) 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 Orthopaedica
8. Knusten AR, Ebramzadeh E, Longjohn DB, Sangiorgio SN (2014) Systematic analysis of bisphosphonate intervention on periprosthetic BMD as a function of stem design. J Arthroplasty 29:1292–7.
9. Iwamoto N, Inaba Y, Kobayashi N, Ishida T, Yukizawa Y, et al. (2011) A Comparison of the Effects of Alendronate and Alfacalcidol on Bone Mineral Density Around the Femoral Implant and in the Lumbar Spine After Total Hip Arthroplasty. J Bone Jt Surgery-American Vol 93:1203–1209.
10. Arabmotlagh M, Pilz M, Warzecha J, Rauschmann M (2009) Changes of femoral periprosthetic bone mineral density 6 years after treatment with alendronate following total hip arthroplasty. J Orthop Res 27:183–188.
11. Kobayashi N, Inaba Y, Uchiyama M, Ike H, Kubota S, et al. (2016) Teriparatide Versus Alendronate for the Preservation of Bone Mineral Density After Total Hip Arthroplasty – A randomized Controlled Trial. J Arthroplasty 31:333–338.

12. Morita A, Kobayashi N, Choe H, Ike H, Tezuka T, et al. (2020) Effect of switching administration of alendronate after teriparatide for the prevention of BMD loss around the implant after total hip arthroplasty, 2-year follow-up: a randomized controlled trial. J Orthop Surg Res 15:17.

13. Nishii T, Sugano N, Masuhara K, Shibuya T, Ochi T, et al. (1997) Longitudinal Evaluation of Time Related Bone Remodeling After Cementless Total Hip Arthroplasty. Clin Orthop Relat Res 339:121–131.

14. Venesmaa PK, Kröger HPJ, Miettinen HJA, Jurvelin JS, Suomalainen OT, et al. (2001) Monitoring of Periprosthetic BMD After Uncemented Total Hip Arthroplasty with Dual-Energy X-Ray Absorptiometry: a 3-Year Follow-Up Study. J Bone Miner Res 16:1056–1061.

15. Hayashi S, Hashimoto S, Matsumoto T, Takayama K, Nishida K, et al. (2017) Stem anteversion mismatch to the anatomical anteversion causes loss of periprosthetic bone density after THA. J Orthop Surg 25:230949901773947.

16. Hayashi S, Hashimoto S, Kanzaki N, Kuroda R, Kurosaka M (2016) Stem anteversion affects periprosthetic bone mineral density after total hip arthroplasty. HIP Int 26:260-264.

17. Alm JJ, Mäkinen TJ, Lankinen P, Moritz N, Vahlberg T, et al. (2009) Female patients with low systemic BMD are prone to bone loss in Gruen zone 7 after cementless total hip arthroplasty. Acta Orthop 80:531–537.

18. Kinov P, Tivchev P, Doukova P, Leithner A (2006) Effect of risedronate on bone metabolism after total hip arthroplasty: a prospective randomised study. Acta Orthop Belg 72:44–50

19. Yamaguchi K, Masuhara K, Yamasaki S, Nakai T, Fuji T (2003) Cyclic therapy with etidronate has a therapeutic effect against local osteoporosis after cementless total hip arthroplasty. Bone 33:144–9.

20. Yamasaki S, Masuhara K, Yamaguchi K, Nakai T, Fuji T, et al. (2007) Risedronate reduces postoperative bone resorption after cementless total hip arthroplasty. Osteoporos Int 18:1009–15.

21. Teng S, Yi C, Krettek C, Jagodzinski M (2015) Bisphosphonate Use and Risk of Implant Revision after Total Hip/Knee Arthroplasty: A Meta-Analysis of Observational Studies. PLoS One 10:e0139927.

22. Erviti J, Alonso Á, Oliva B, Gorricho J, López A, et al. (2013) Oral bisphosphonates are associated with increased risk of subtrochanteric and diaphyseal fractures in elderly women: a nested case–control study. BMJ Open 3:e002091.

23. Goh S-K, Yang KY, Koh JSB, Wong MK, Chua SY, et al. (2007) Subtrochanteric insufficiency fractures in patients on alendronate therapy. J Bone Joint Surg Br 89-B:349–353.

24. Oba M, Inaba Y, Kobayashi N, Ike H, Tezuka T, et al. (2016) Effect of femoral canal shape on mechanical stress distribution and adaptive bone remodelling around a cementless tapered-wedge stem. Bone Joint Res 5:362–9.

25. Nakamura S, Minoda Y, Ohta Y, Sugama R, Yamamura K, et al. (2019) Preoperative morphology of the proximal femoral canal did not affect the postoperative bone mineral density change around the
Figures

Figure 4

Time course of percent change in BMD from baseline in each Gruen zone over 1 year.
Figure 7

Scatter plot showing the relationship between percent change from baseline in zone 7 BMD and preoperative BMD on the lateral side at 1 year postoperatively (R²=0.310, R=0.557, P<0.001).