



## Original Research

## Radiological Evaluation of the Relationship Between Cortical Hypertrophy and Stress Shielding After Total Hip Arthroplasty Using a Cementless Stem

Makoto Kanto, MD <sup>a,\*</sup>, Shigeo Fukunishi, MD <sup>b</sup>, Tomokazu Fukui, MD <sup>a</sup>, Shoji Nishio, MD <sup>a</sup>, Yuki Fujihara, MD <sup>a</sup>, Shohei Okahisa, MD <sup>a</sup>, Yu Takeda, MD <sup>b</sup>, Shinichi Yoshiya, MD <sup>b</sup>, Toshiya Tachibana, MD <sup>a</sup>

<sup>a</sup> Department of Orthopedic Surgery, Hyogo College of Medicine, Nishinomiya City, Hyogo, Japan

<sup>b</sup> Nishinomiya Kaisei Hospital, Nishinomiya City, Hyogo, Japan

## ARTICLE INFO

## Article history:

Received 12 May 2020

Received in revised form

23 September 2020

Accepted 27 September 2020

Available online xxx

## Keywords:

Total hip arthroplasty

Stress shielding

Cortical hypertrophy

## ABSTRACT

**Background:** Unloading of the proximal medial femoral cortex is usually associated with an increased bone strain at the distal part of the prosthesis, which may cause distal femoral cortical hypertrophy (CH). The objective of this study was to determine the factors that may be considered a predisposition to distal femoral CH and its effect on the stress shielding (SS) or durability of the fixation of the stem.

**Methods:** A total of 240 total hip arthroplasties were performed between January 2006 and December 2016, with all hips implanted with a Bicontact stem. The minimum follow-up period was more than 2 years, and the mean follow-up period was 7.2 years. The radiographic outcome was assessed on an anteroposterior hip radiograph. CH and SS were assessed on postoperative radiographs in the Gruen zone. We defined CH that appeared in zone 3 or 5 as 'the focal type' and defined CH that appeared in zones 2, 3, 4, 5, and 6 as 'the diffuse type.' SS followed the procedures from the Engh classification.

**Results:** CH was found in 72 hips (30% of the 240 hips), the focal type was found in 23 hips (9.6% of the 240 hips), and the diffuse type was found in 49 hips (20.4% of the 240 hips). SS was found in 41 hips (17.1% of 240 hips), including 32 hips with SS, which was found after the development of CH. One hip was from the focal-type CH and 31 hips were from the diffuse-type CH. SS, which is typically found in Engh classification types 1 and 2 developed in 13 hips, and SS, which is widely seen in Engh classification types 3 and 4 developed in 19 hips. All 19 hips with progressed SS were found after the diffuse-type CH had developed. In addition, among the 19 hips with progressed SS, Dorr type A was found in 0 hips, Dorr type B in 8 hips, and Dorr type C in 11 hips.

**Conclusions:** According to the results of our radiological evaluation, development of the diffuse-type CH after total hip arthroplasty using Bicontact stems is one of the critical causes of the later development of SS and could be predicted to progress to SS. To prevent the development of the diffuse-type CH, the indication to choose a Bicontact stem for a Dorr type C with osteoporotic bone should be considered.

© 2020 The Authors. Published by Elsevier Inc. on behalf of The American Association of Hip and Knee Surgeons. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

## Introduction

Total hip arthroplasty (THA) is considered an orthopaedic procedure with a high success rate [1,2]. On the other hand, various

bone reactions around the femoral stem after THA may affect its long-term survival [3,4]. Cementless hip components have been used to encourage biological fixation by allowing bone integration, which ensures long-term survivorship of the prosthesis [5,6]. Cementless THA has been exhibiting excellent long-term outcomes in both functional and radiographic aspects [7]. We used a cementless stem (Bicontact, B/Braun-Aesculap, Germany) for all patients in this study (Fig. 1). This implant is a straight-flanged collarless stem made of titanium alloy. The proximal portion is

\* Corresponding author. Department of Orthopedic Surgery, Hyogo College of Medicine, 1-1 Mukogawa-cho, Nishinomiya City, Hyogo, Japan 653-8501. Tel.: +81 798 45 6111.

E-mail address: [makoto.k0919@gmail.com](mailto:makoto.k0919@gmail.com)



**Figure 1.** Photograph of the Bicontact stem.

sprayed with plasma, and the stem has an anatomical shape with a wide border in the middle, which is supported anteroposteriorly by the flanges and lateral derotational wings [8]. Bicontact stems have been reported to have excellent clinical and radiological outcomes in the last 10 to 15 years [9]. However, development of hypertrophy in the distal femoral cortex, which is called cortical hypertrophy (CH), has been reported after THA using Bicontact stems. Generally, CH is a fusiform enlargement of the cortical bone in the femoral stem tip [10–14], and no reports have been made that examine the relationship between clinical outcomes and long-term survivorship

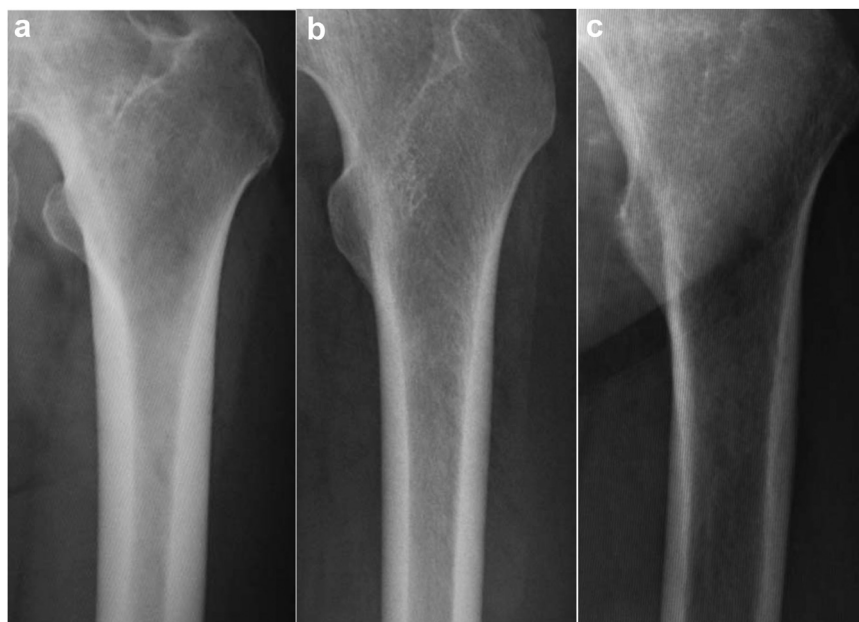
of the implant. Previous studies have demonstrated that an unloading of the proximal medial femoral cortex, which is usually associated with an increased bone strain at the distal part of the prosthesis, may cause distal femoral CH [15–17]. Subsequently, this pattern of abnormal loading might cause calcar resorption, known as stress shielding (SS) [11,16,14]. CH and SS may be caused by a large and stiff femoral stem [18–20]. However, there have been no reports made regarding the relationship between SS and CH. In our clinical experience, we have found some cases that SS later progressed after the development of CH in cases that underwent THA using Bicontact stems. We hypothesized that there is a possible correlation between CH and the later development of SS. The objective of this study was to determine the factors that may be considered predispositions to distal femoral CH and to examine the relationship between the development of CH, SS, and the durability of the stem fixation.

### Material and methods

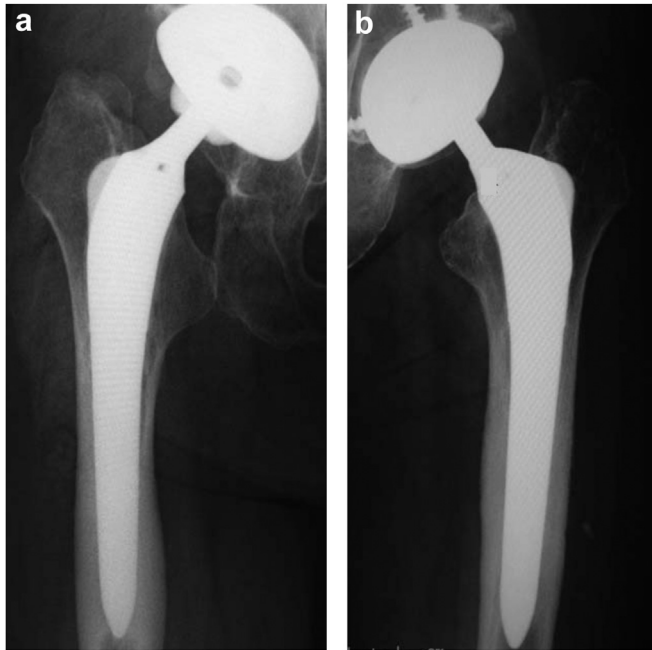
This study was approved by the Institutional Review Board of Hyogo College of Medicine. We explained our surgical concepts to the patients, and informed consent was obtained from all patients included in the study.

### Study design and population

This study was a retrospective, nonrandomized observational study over the course of a decade. Inclusion criteria in this study were patients who underwent primary THA with a standardized surgical procedure, with the use of the same cementless cup (Plasma cup BTM, B/Braun-Aesculap, Germany) and cementless stem (Bicontact TM, B/Braun-Aesculap, Germany) implants. Two hundred forty patients who underwent primary THA between January 2006 and December 2016 were included in this study. We defined the exclusion criteria as patients who sustained an intraoperative fracture of the proximal femur and patients who developed a postoperative deep infection during the study period. Two patients with an intraoperative fracture of the proximal



**Figure 2.** Preoperative proximal femoral geometry categorized using the classification proposed by Dorr. (a) Dorr type A; (b) Dorr type B; (c) Dorr type C.



**Figure 3.** (a) The focal-type cortical hypertrophy (CH); (b) the diffuse-type CH.

femur and 2 patients with a postoperative deep infection were excluded from the study. In addition, we began the usage of short stem–type Bicontact stems since 2017, which had been introduced in Japan the previous year. This type of stem was excluded from the study.

Radiographic outcomes were independently assessed by one senior surgeon (S.H.) and one senior resident (M.K.) on an anteroposterior hip radiograph. Preoperative bony quality and proximal femoral geometry were categorized as type A, B, and C using the classification proposed by Dorr *et al* (Fig. 2).

### Surgical procedures

Surgeries were performed using the same technique for all patients. We used a modified Hardinge approach with a skin incision of 10 cm or less with the patient in the lateral position. All hips were implanted with a cementless cup (Plasma cup BTM, B/Braun-Aesculap, Germany) and a cementless stem (Bicontact TM B/Braun-Aesculap, Germany). This stem is designed to have a flat, square cross section that enables some allowance for rotational adjustment. Regarding cup positioning, inclination and anteversion angles were targeted at 40°–45° and 15°–20°, respectively, using imageless navigation (OrthoPilot; B/BRAUN-Aesculap, Germany). The stem anteversion was arbitrarily adjusted under manual control. In postoperative rehabilitation, postoperative gait exercise with full weight-bearing was allowed the day after surgery.

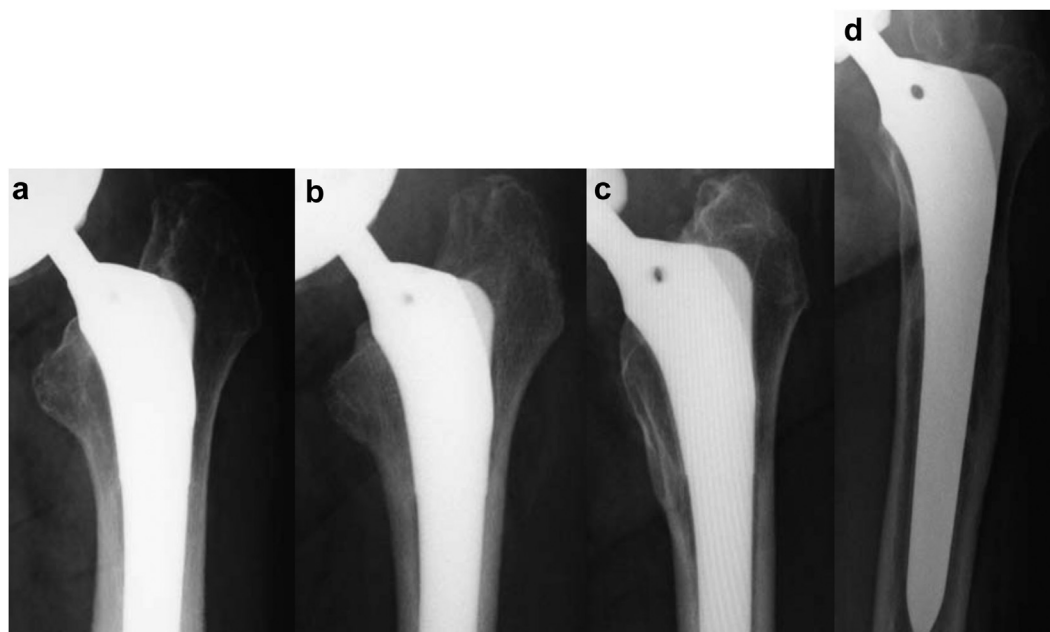
### Postoperative evaluation

Postoperative clinical assessments were made to determine the existence of complications, such as stem subsidence, deep venous thrombosis, and dislocation. All included patients underwent postoperative radiographic examinations immediately after surgery, at 1 week, 1 month, 3 months, 6 months, a year, and every other year after surgery.

CH and SS were assessed on postoperative radiographs according to the Gruen zone [21]. We defined CH as fusiform enlargements of the cortical bone in the bone-implant region, which appeared in zones 3 or 5, and identified them as ‘the focal type,’ whereas we identified CH that appeared in zones 2, 3, 4, 5, and 6 as ‘the diffuse type’ (Fig. 3). SS was assessed according to the criteria of Engh *et al* (Fig. 4) [22,23].

### Statistical analysis

All statistical analyses were conducted using SPSS (version 19; IBM SPSS Statistics, Inc, Chicago, IL) for Windows. Categorical data



**Figure 4.** Classification of stress shielding (SS). (a) SS grade 1: rounding off of the proximal medial neck; (b) SS grade 2: loss of the medial cortex density around the minor trochanter; (c) SS grade 3: loss of the medial cortex density below the minor trochanter; (d) SS grade 4: cortical resorption into the diaphysis (all around the stem).

**Table 1**  
Patient demographics.

Parameters	Value
Gender (female/male)	208/32
Age at surgery (years)	61.6 ± 12.9(24-87) <sup>a</sup>
Follow-up period (years)	6.0 ± 2.7(2-12) <sup>a</sup>
Preoperative diagnosis (the number of hips)	
Developmental dysplasia	190
Osteonecrosis of the femoral head	32
Primary osteoarthritis	12
Rheumatoid arthritis	3
Femoral neck fracture	2
Rapidly destructive coxarthrosis	1

<sup>a</sup> Mean ± SD (range).

were analyzed using the chi-square test, and  $P < .05$  was considered significant.

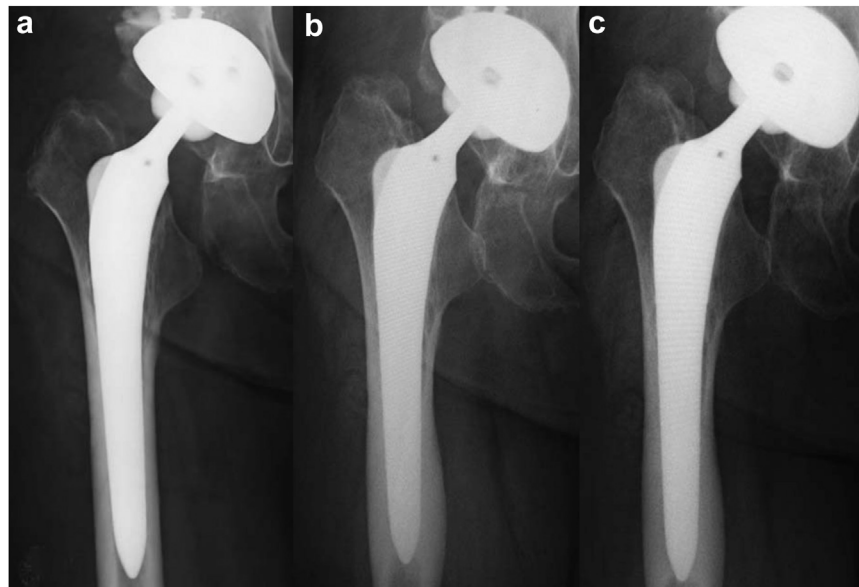
## Results

Two hundred forty total hip replacements were performed in the present study. The minimum follow-up period was defined as 2 years and averaged  $6.0 \pm 2.7$  years (range: 2-12 years). There were 32 male and 208 female patients with the mean age at surgery of  $61.6 \pm 12.9$  (range: 24 to 87) years. Preoperative diagnosis included developmental dysplasia in 193 hips, osteonecrosis of the femoral head in 30 hips, rheumatoid arthritis in 3 hips, and rapidly destructive coxarthrosis in one hip (Table 1). There were no major complications such as dislocation or deep venous thrombosis encountered during the study period. Two hips revealed stem subsidence of more than 3 mm. The stem subsidence was revealed within a month after surgery, and we determined that mismatched smaller size stems were implanted in these cases. At the time of the final follow-up, 2 patients (2 of 240: 0.83%) complained of thigh pain when walking, and 6 patients (6 of 240: 2.5%) complained of groin pain during deep flexion of the hip joint. However, these complaints were not severe; thus, none of these patients required additional surgery. No hips required revision surgery for any reasons. In radiographic examination, no stem revealed varus or valgus

tilt of more than  $3^\circ$  in the postoperative coronal alignment. According to the classification proposed by Dorr *et al*, 12 hips were classified as type A, 185 hips as type B, and 43 hips as type C (Fig. 4). Regarding CH, 72 hips (30% of 240 hips) were determined as having CH, and we defined those 72 hips as ‘the CH group.’ CH is typically found in Gruen zones 3 and 5. We identified the focal type in 23 hips (9.6% of the 240 hips), and we identified the diffuse type, which is widely found in CH in 49 hips (20.4% of the 240 hips). Initial development of CH was identified within 2 years after surgery. On the other hand, SS was found in 41 of 240 (17.1%) hips. Thirty-two hips with SS were linked to the development of CH (44% of the 72 hips in the CH group), and 9 hips developed SS without CH (9 of 168 hips without development of CH: 5.5%). There was a significant difference between the CH group and the CH- group ( $P < .005$ ). Among the 32 hips with SS that later developed CH, one hip was from the focal-type CH (1 of 23 hips with the focal type CH: 4.3%) and 31 hips were from the diffuse-type CH. There was a significantly higher rate of SS in the diffuse-type CH than in the focal type ( $P < .05$ ). In addition, among the 31 hips that later developed SS after developing the diffuse-type CH, SS progressed to Engh type 3 or 4 during the follow-up period in 19 hips (19 of 31 hips: 61.2%) (Figs. 5-7). These hips that later developed SS after developing the diffuse-type CH revealed typical radiographic findings that showed the areas that once developed hypertrophy of the femoral cortex gradually led to bone resorption and subsequently the cortical bone became thinner as to make a hollow cylindrical shape. Among the 19 hips with progressive SS (Engh types 3 and 4), Dorr type A proximal femoral geometry was seen in 0 hips, Dorr type B in 8 hips, and Dorr type C in 11 hips. There was a significantly higher rate of progressed SS in Dorr type C ( $P < .05$ ). Inter-rater reliability of the radiographic assessment was analyzed using the kappa coefficient. The kappa coefficient was 0.87.

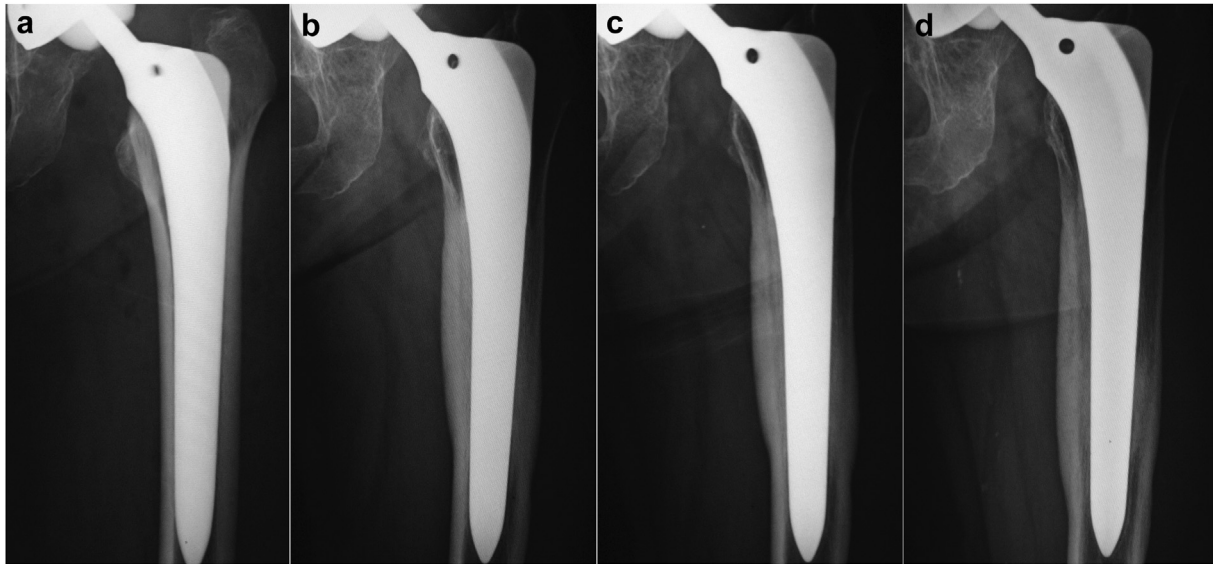
## Discussion

Several studies have reported excellent mid- or long-term outcomes using the Bicontact stem. In a previous study, Swamy *et al*. reported that no hips were revised because of aseptic loosening among the 116 THAs performed using Bicontact stems with a mean



**Figure 5.** The postoperative radiograph of a 56-year-old woman. (a) Postoperative radiograph; (b) 2 years after surgery, the focal-type CH was revealed; (c) 5 years after surgery, the focal-type CH with bony stability of the Bicontact stem was showing.

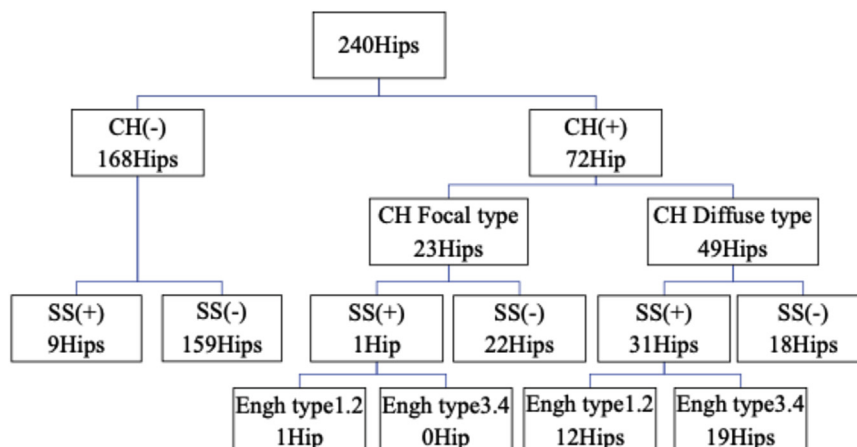




**Figure 6.** Postoperative radiograph of a 78-year-old woman. (a) Postoperative radiograph; (b) 2 years after surgery, the diffuse-type CH was revealed; (c) 3 years after surgery, the density of the CH was reduced; (d) 6 years after surgery, the width of the cortical bone around the stem became thinner. The hypertrophy of the femoral cortex revealed bone resorption, and SS progressed all around the stem.

follow-up of 12.9 years [24]. Furthermore, Tsukada and Wakui reported results of patients who underwent THA with a minimum 10-year follow-up using the cementless Bicontact N stem, and the stem survival rate was 94.4% at 15 years postoperatively [25]. There are multiple factors that affect bone remodeling, such as calcar resorption and CH after THA [26]. The development of CH is possibly due to the bony reaction to the stress overload around the distal part of the stem. The main cause of CH is abnormal load transmitted from the stem to bone [27]. Overload around the stem tip rather than at the calcar area can cause bone resorption in the calcar region and develop distal CH [11]. In addition, high bending stiffness of the cementless stem may be related to thigh pain and CH [28,29]. In a previous study, 49% and 27% of patients with straight stem and anatomic proximal porous-coated stems developed CH, respectively [30]. However, the clinical outcome of CH was controversial. Although Cho *et al.* reported that clinical outcomes and stem survival were not associated with CH [31], another study reported that CH correlated with worse clinical results [32]. In the present study, CH was found in 72 hips (30% of the 240 hips),

and the rate of the development of CH after THA was similar to other previous reports. Although progressed SS which is defined as Engh type 3 or 4 was found in 19 (7.9%) hips, no hips required revision surgery for any reason in the present study. In addition, in these 19 hips with progressive SS, 11 hips were categorized as the Dorr type C femur in proximal femoral geometry by preoperative radiographic examination. We hypothesized that Dorr type C could be a risk factor in developing distal fixation and proximal mismatch. In the present study, SS occurred in one hip from the focal-type CH, whereas SS occurred in 31 hips from the diffuse-type CH. In addition, progressed SS occurred in 19 hips after developing diffuse-type CH, whereas no hips developed progressed SS after developing focal-type CH. Following the results of our radiological evaluation, we theorized that the different mechanisms of developing CH in the focal-type CH and the diffuse-type CH could be explained. Whiteside reported radiographic and clinical results of cementless THA using a femoral stem designed to tightly fit the distal part of the stem and suggested that distal hypertrophy may be related to bending stress concentrating around the end of the



**Figure 7.** The flowchart of the postoperative radiographic assessment.

stiff implant [33]. In cases which developed diffuse-type CH, we hypothesized that the initial stability is different from the concept of the Bicontact stem, where the fixation is restricted to the metaphyseal portion. Bicontact stems require proximal fixation in the proximal coating area in a unique anatomical shape. Regarding surgical procedures and materials, the Bicontact system has 2 different types of rasps: the distal rasp and the proximal rasp. Surgical procedures with Bicontact stems should use the distal type rasp first. In cases of Dorr type C femurs with severe osteoporotic bone, the distal rasp could be gradually made bigger until stabilization at the distal femur is established. However, this might cause a proximal mismatch between the stem and the femur. In cases such as these, the Bicontact stem may not obtain the correct surgical outcome of establishing stability near the metaphyseal portion, and it may be suitable to choose other types of stems such as a cemented stem. In addition, another possible theory is that the distal fixation developed at the site of the smooth surface around the mid or distal area of the Bicontact stem; thus, the abnormal load transfer could have induced new bone formation around the smooth surface. However, bone integration did not develop around the smooth surface. Therefore, the area that developed hypertrophy of the femoral cortex later revealed bone resorption, and the width of the cortical bone in the mid or distal area around the stem became thinner. According to this theory, SS could progress and expand to the area all around the stem after developing diffuse-type CH.

There are several limitations in this study. First, the postoperative follow-up period was quite short, and the focus was only on the radiographic assessment. Therefore, it was not possible to determine the relationship between radiographic assessment and clinical outcomes, such as postoperative thigh pain or discomfort during daily activities. Two patients complained of thigh pain when walking at the time of the final follow-up period. One of those 2 patients was an 85-year-old woman who complained of thigh pain 12 years after surgery, and plain radiographs of the hip joint revealed SS grade 4. However, revision THA was not required as the thigh pain was not severe and did not progress during the follow-up period. Future observation is necessary to monitor the progress of thigh pain and SS. If SS progresses further, it could be associated with loosening of the stem, which may require future revision surgery.

Second, radiological evaluation used only anteroposterior radiographs. Therefore, we could not evaluate the sagittal alignment of the stem, the relationship between flexion and extension with the implantation of the stem, and the development of CH and SS. Stem malposition could be a potential risk of progression of SS, which is often associated with distal fixation and reducing load transfer at the proximal part of the femur [10,33]. In the present study, no stem revealed varus or valgus tilt of more than 3° in the postoperative coronal alignment. However, lateral radiographic or postoperative computed tomography evaluations will be needed for further detailed analysis of the stem fixation. Third, we used different types of stems during the same period: cemented stems and 2 types of cementless stems including Bicontact. Furthermore, this study was a retrospective observational study; therefore, stem selection was up to the surgeon before operation, and detailed indication of the stem choice was not available. Further analysis of radiographic assessment using other types of cementless stems and comparing them with Bicontact stems are necessary to obtain clear evidence of the relationship between CH and SS.

## Conclusions

According to the results of our radiological evaluation, the development of the diffuse-type CH after THA using Bicontact

stems could predict later development of SS. To prevent the distal fixation and development of the diffuse-type CH, the indication to choose Bicontact stems for Dorr type C femurs with osteoporotic bone should be considered.

## Conflict of interests

The authors declare there are no conflicts of interest.

## References

- [1] Harris WH. The first 50 years of total hip arthroplasty: lessons learned. *Clin Orthop Relat Res* 2009;467:28.
- [2] Learmonth ID, Young C, Rorabeck C. The operation of the century: total hip replacement. *Lancet* 2007;370:1508.
- [3] Engh CA, McGovern TF, Bobyn JD, Harris WH. A quantitative evaluation of periprosthetic bone-remodeling after cementless total hip arthroplasty. *J Bone Joint Surg Am* 1992;74:1009.
- [4] Bugbee WD, Culpepper 2nd WJ, Engh Jr CA, Engh Sr CA. Long-term clinical consequences of stress-shielding after total hip arthroplasty without cement. *J Bone Joint Surg Am* 1997;79:1007.
- [5] Zwartele R, Peters A, Brouwers J, Olsthoorn P, Brand R, Doets C. Long-term results of cementless primary total hip arthroplasty with a threaded cup and a tapered, rectangular titanium stem in rheumatoid arthritis and osteoarthritis. *Int Orthop* 2008;32(5):581.
- [6] Maheshwari AV, Ranawat AS, Ranawat CS. The use of hydroxyapatite on press-fit tapered femoral stems. *Orthopedics* 2008;31(9):882.
- [7] Kiran M, Yadav A. Comparative analysis of different total hip replacement implants used in a single health region of the United Kingdom - minimum 15 years follow-up. *Acta Orthop Belg* 2019 Jun;85(2):192.
- [8] Badhe NP, Quinnell RC, Howard PW. The uncemented Bi-Contact total hip arthroplasty. *J Arthroplasty* 2002;17(7):896.
- [9] Girish S, Alistair P. The Bicontact cementless primary total hip arthroplasty: long-term results. *Int Orthop* 2012;36:915.
- [10] Ritter MA, Fechtman RW. Distal cortical hypertrophy following total hip arthroplasty. *J Arthroplasty* 1988;3:117.
- [11] Lewis JL, Askew MJ, Wixson RL, Kramer GM, Tarr RR. The influence of prosthetic stem stiffness and of a calcar collar on stresses in the proximal end of the femur with a cemented femoral component. *J Bone Joint Surg Am* 1984;66:280.
- [12] Sumner DR, Galante JO. Determinants of stress shielding: design versus materials versus interface. *Clin Orthop Relat Res* 1992;274:202.
- [13] Engh CA, Hooten Jr JP, Zettl-Schaffer KF, et al. Porous-coated total hip replacement. *Clin Orthop Relat Res* 1994;298:89.
- [14] Sarmiento A, Gruen TA. Radiographic analysis of low-modulus titanium-alloy femoral total hip component. *J Bone Joint Surg Am* 1985;67:48.
- [15] Huiskes R. The various stress patterns of press-fit, ingrown, and cemented femoral stems. *Clin Orthop Relat Res* 1990;261:27.
- [16] Decking R, Puhl W, Simon U, Claes LE. Changes in strain distribution of loaded proximal femora caused by different types of cementless femoral stems. *Clin Biomech (Bristol, Avon)* 2006;21:495.
- [17] Lanyon LE, Paul IL, Rubin CT, et al. In vivo strain measurements from bone and prosthesis following total hip replacement. An experimental study in sheep. *J Bone Joint Surg Am* 1981;63:989.
- [18] Katsimihias M, Katsimihias G, Lee MB, Learmonth ID. Distal femoral cortical hypertrophy: predisposing factors and their effect on clinical outcome. *Hip Int* 2006;16:18.
- [19] Huiskes R, Weinans H, van Rietbergen B. The relationship between stress shielding and bone resorption around total hip stems and the effects of flexible materials. *Clin Orthop Relat Res* 1992;274:124.
- [20] Head WC, Bauk DJ, Emerson Jr RH. Titanium as the material of choice for cementless femoral components in total hip arthroplasty. *Clin Orthop Relat Res* 1995;311:85.
- [21] Gruen T, McNeice M, Amstutz H. "Modes of failure" of cemented stem-type femoral components: a radiographic analysis of loosening. *Clin Orthop Relat Res* 1979;141:17.
- [22] 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;69:45.
- [23] Engh CA, Glassman AH, Suthers KE. The case for porous-coated hip implants. The femoral side. *Clin Orthop Relat Res* 1990;261:63.
- [24] Swamy G, Pace A, Quah C, et al. The Bicontact cementless primary total hip arthroplasty: long-term results. *Int Orthop* 2012;36:915.
- [25] Tsukada S, Wakui M. A case series of total hip arthroplasty using cementless hip stem customized for patients of a specific race: 10- to 15-year results. *J Arthroplasty* 2016;31(1):190.
- [26] Sychterz CJ, Engh CA. The influence of clinical factors on periprosthetic bone remodeling. *Clin Orthop Relat Res* 1996;322:285.
- [27] Van Rietbergen B, Huiskes R, Weinans H, Sumner DR, Turner TM, Galante JO, ESB Research Award. The mechanism of bone remodeling and resorption around press-fitted THA stems. *J Biomech* 1992;1993(26):369.

- [28] Hartzband MA, Glassman AH, Goldberg VM, et al. Survivorship of a low-stiffness extensively porous-coated femoral stem at 10 years. *Clin Orthop Relat Res* 2010;468:433.
- [29] Brown TE, Larson B, Shen F, Moskal JT. Thigh pain after cementless total hip arthroplasty: evaluation and management. *J Am Acad Orthop Surg* 2002;10:385.
- [30] Laine HJ, Puolakka TJ, Moilanen T, Pajamaki KJ, Wirta J, Lehto MU. The effects of cementless femoral stem shape and proximal surface texture on 'fit-and-fill' characteristics and on bone remodeling. *Int Orthop* 2000;24:184.
- [31] Cho YJ, Chun YS, Rhyu KH, Baek JH, Liang H. Distal femoral cortical hypertrophy after hip arthroplasty using a cementless double tapered femoral stem. *J Orthop Surg (Hong Kong)* 2016;24(3):317.
- [32] Tapadiya D, Walker RH, Schurman DJ. Prediction of outcome of total hip arthroplasty based on initial postoperative radiographic analysis. Matched, paired comparisons of failed versus successful femoral components. *Clin Orthop Relat Res* 1984;186:5.
- [33] Whiteside LA. The effect of stem fit on bone hypertrophy and pain relief in cementless total hip arthroplasty. *Clin Orthop Relat Res* 1989;247:138.