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Risk factors for a radiolucent line around the acetabular component with an interface bioactive bone cement technique after primary cemented total hip arthroplasty

PROGNOSTIC FACTORS FOR A RADIOLUCENT LINE AND IMPROVEMENT OF THE CEMENT-BONE INTERFACE AROUND CEMENTED ACETABULAR COMPONENT WITH AN INTERFACE BIOACTIVE BONE CEMENT TECHNIQUE

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Aims

The main aims were to identify risk factors predictive of a radiolucent line (RLL) around the acetabular component with an interface bioactive bone cement (IBBC) technique in the first year after THA, and evaluate whether these risk factors influence the development of RLLs at five and ten years after THA.

Methods

A retrospective review was undertaken of 980 primary cemented THAs in 876 patients using cemented acetabular components with the IBBC technique. The outcome variable was any RLLs that could be observed around the acetabular component at the first year after THA. Univariate analyses with univariate logistic regression and multivariate analyses with exact logistic regression were performed to identify risk factors for any RLLs based on radiological classification of hip osteoarthritis.

Results

RLLs were detected in 27.2% of patients one year postoperatively. In multivariate regression analysis controlling for confounders, atrophic osteoarthritis (odds ratio (OR) 2.17 (95% confidence interval (CI), 1.04 to 4.49); p = 0.038) and 26 mm (OR 3.23 (95% CI 1.85 to 5.66); p < 0.001) or 28 mm head diameter (OR 3.64 (95% CI 2.07 to 6.41); p < 0.001) had a significantly greater risk for any RLLs one year after surgery. Structural bone graft (OR 0.19 (95% CI 0.13 to 0.29) p < 0.001) and location of the hip centre within the true acetabular region (OR 0.15 (95% CI 0.09 to 0.24); p < 0.001) were significantly less prognostic. Improvement of the cement-bone interface including complete disappearance and poorly defined RLLs was identified in 15.1% of patients. Kaplan-Meier survival analysis for the acetabular component at ten years with revision of the acetabular component for aseptic loosening as the end point was 100.0% with a RLL and 99.1% without a RLL (95% CI 97.9 to 100). With revision of the acetabular component for any reason as the end point, the survival rate was 99.2% with a RLL (95% CI 97.6 to 100) and 96.5% without a RLL (95% CI 93.4 to 99.7).

Conclusion

This study demonstrates that acetabular bone quality, head diameter, structural bone graft, and hip centre position may influence the presence of the any RLL.

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Introduction

Total hip arthroplasty (THA) is one of the most successful orthopaedic interventions in the 20th century. It relieves pain and improves function and health-related quality of life. Cemented THA procedures were introduced in 1961 and have evolved since low friction arthroplasty was reported by Sir John Charnley.[1-3] The longevity of cemented THA shown by more than 20 years of data is excellent.[4-6] Furthermore, despite seven to ten national hip arthroplasty registries having reported that cemented fixation in patients older than 75 years results in the lowest risk of revision, increasing use of uncemented THA is a worldwide phenomenon.[7,8] To improve the survival rate of the cemented component, it is critically important to construct well-fixed cement-bone interfaces for both acetabular and femoral components.[9] It is generally accepted that a solid, well-fixed cement-bone interface reduces the micromigration of the acetabular component and protects it against wear debris and fluid accumulation at the interface.[10-12] Progression of cementing techniques including pressurizers, suction aspirators, preparation of the subchondral bone plate, and introduction of flanged components has improved the clinical results of cemented acetabular components, with the aim of constructing a well-fixed interface.[13-16] As a result of recent advances in cementing techniques, there is good evidence of acetabular component survival of 97.8% for all causes of revision 12.5 years postoperatively.[17] Given these results, there might be no room for further improvement in this modern cementing technique. In 1982, Oonshi et al[18] reported an interface bioactive bone cement (IBBC) technique to augment cement-bone bonding. The basic philosophy behind this technique is to achieve additional physicochemical bonding by interposing osteoconductive crystal hydroxyapatite (HA) granules at the cement-bone interface. Excellent survival rates have been reported for THA cemented using this IBBC technique.[18-20]

On the other hand, several previous studies have reported that any postoperative radiolucent line (RLL) at the bone-cement interface around the acetabular component profoundly affects later loosening of the component.[10,12,21-24] Furthermore, RLLs in the first year postoperatively are associated particularly with loosening of the acetabular component.[12,21,22] We therefore analyzed a large cohort of patients with any postoperative RLL around the acetabular component. The main goals of the present study were to identify risk factors predictive of RLL in the first year after THA and evaluate whether these risk factors influenced the expansion of RLLs five and ten years after THA.

Methods

This retrospective study was conducted between November 2001 and March 2019 in Matsudo City General

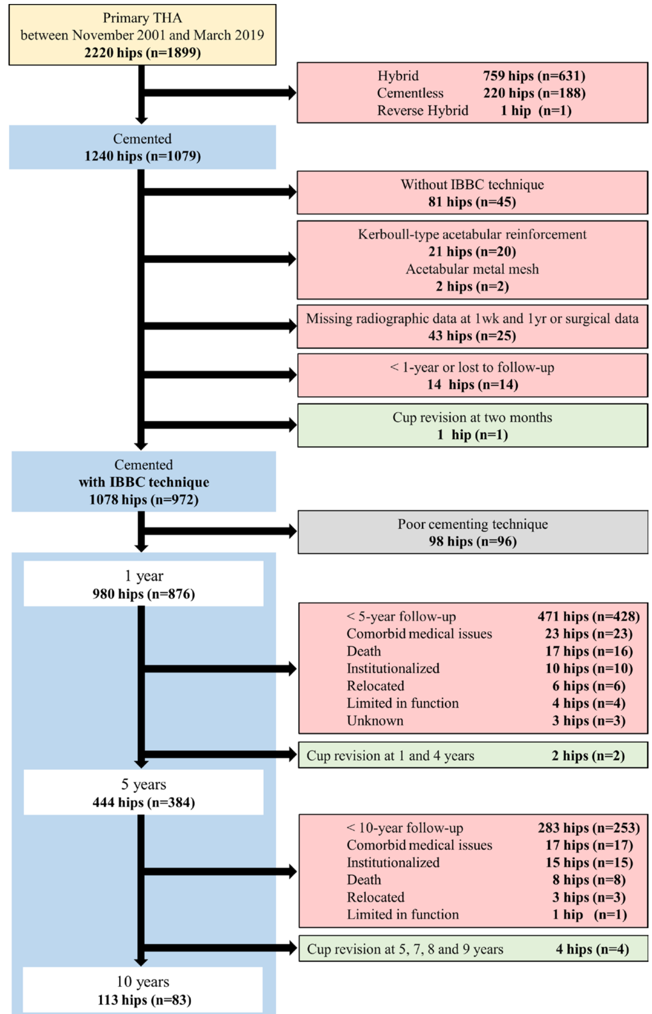

Fig. 1

Flow diagram for the study. IBBC, interface bioactive bone cement; THA, total hip arthroplasty.

Hospital. All procedures performed in these studies involving human participants were in accordance with the ethical standards of the 1964 Helsinki Declaration and its later amendments or comparable ethical standards and approved by the institutional review board.[25] All baseline characteristics and clinical data including radiography were obtained retrospectively from the hospital records.

Study population. Eight surgeons (SM, SI, CS, TN, YK, MT, SY, KI) performed 2,220 primary THAs in 1,899 patients between November 2001 and March 2019. The patients included in the study had undergone primary cemented THA using the IBBC technique and were radiologically followed for a minimum of one year after surgery (Figure 1). A total of 980 hips in 876 patients were enrolled in this study from this period. A total of 444 hips in 384 patients and 113 hips in 83 patients were followed for a minimum of five years and ten years after surgery, respectively. Radiological examination was performed in

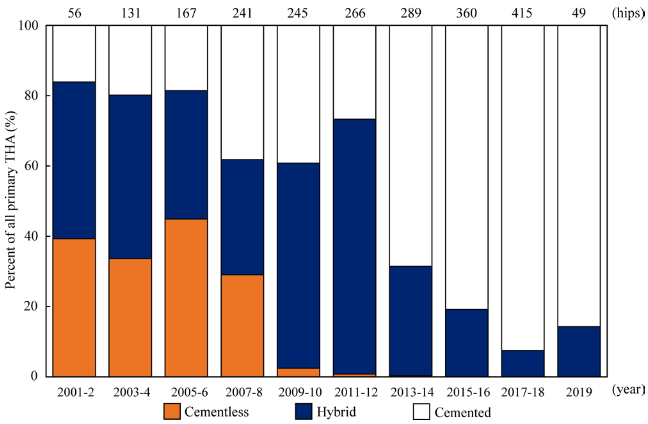

Fig. 2

The transition of fixation method for primary total hip arthroplasty between November 2001 and March 2019. THA, total hip arthroplasty.

all patients one week and one year postoperatively, and at the final follow-up. All follow-up radiographs taken at our institution used the same protocol during this study. In all patients, anteroposterior (AP) and lateral pelvic radiographs with the patella facing forward and the patient in the supine position were obtained immediately and every year postoperatively. The x-ray tube was positioned 1.2 metres from and perpendicular to the table. Radiological assessments were performed by two hip surgeons (SM and IS) from an AP view. Patients' demographics and surgical details were analyzed from their medical records retrospectively. Baseline data included age, sex, BMI at the time of surgery, mean follow-up term, diagnosis, surgical approach, femoral head diameter, acetabular component outer/internal diameters, and the use of structural bone graft. There were 162 hips in 107 patients excluded from the study. The reasons for exclusion were as follows: THA without the IBBC technique (81 hips); with Kerboull-type acetabular reinforcement (21 hips); with acetabular metal mesh (two hips); missing radiological and surgical data (43 hips); < one year or lost to follow-up (14 hips); and revision of the acetabular component (one hip) (Figure 1).

Operative technique and postoperative treatment. The fixation method for primary THA in our institution between November 2001 and March 2019 has changed over time for the following reasons (Figure 2). On the acetabular side, the quality of polyethylene has been a main priority. Highly cross-linked polyethylene (HXLPE) was introduced clinically in Japan earlier for the cementless acetabular component than for the cemented acetabular component.[26] Moreover, insufficient initial stability of cementless fixation for secondary osteoarthritis based on dysplasia was a major problem for revision at that time.[27,28] Hence, the rates of cemented acetabular fixation have increased from 2013 and account for more than 80% of THAs since 2017. On the femoral side, as a general rule, the cemented femoral stem was indicated for rheumatoid arthritis and for elderly patients with osteoporosis during the period of this study. The main indication for using a cementless femoral component was osteoarthritis with good bone quality. However, the cemented femoral stem has been indicated in almost all cases from 2009 to the present because thigh pain including occult fracture was a recognized problem after cementless THA.

The surgeries were performed using the Watson-Jones approach in the lateral position from November 2001 to November 2005 by one consultant hip surgeon (SI).[29] The direct anterior approach in the supine position for the purpose of improving accuracy of acetabular component positioning was used from December 2006 to July 2014 by two consultant hip surgeons (SI and CS) and three trainees. The anterolateral approach in the supine position to improve accuracy of both acetabular component positioning and stem alignment was used from August 2014 to March 2019 by three consultant hip surgeons (SI, CS, SM) and two trainees.[30] The trans-trochanteric approach[31] or Hardinge approach[32] with a subtrochanteric shortening osteotomy was employed during the study period for patients who had a severely dislocated hip diagnosed as type IV based on the Crowe classification,[33] stiff hip diagnosed as Crowe type III, or osteoarthritis after the femoral osteotomy by two consultant hip surgeons (SI, CS).

HXLPE was defined as polyethylene that was irradiated above 50 kGy.[34] Acetabular components with conventional polyethylene were used from November 2001 to June 2013. HXLPE was introduced in July 2013 and Vitamin E-stabilized highly crosslinked polyethylene was also used in combination with HXLPE since May 2014. As a general rule of preoperative planning, the acetabulum was usually reamed from 2 mm to 4 mm more than the planning diameter size, and a trial component was temporarily placed. The acetabular component was trimmed to fit the acetabulum within 40° to 45° of inclination and 20° of anteversion based on the anatomical plane. In patients who had insufficient superolateral bone coverage, structural autologous bone graft using the resected femoral head was shaped and fixed with screws. Morcellized bone without subchondral bone, which was produced by the reaming of the acetabulum, was placed on the grafting side of the femoral head autograft. The subchondral bone plate was not removed but was slightly bleeding, and multiple anchor holes were drilled in DeLee and Charnley zones 1 and 2,[35] and in the pubis and ischial bones in zone 3.[35] After haemostasis was achieved by compressive gauze packing into the bleeding area, all components were implanted with bone cement using a third generation cementing technique. Hydroxyapatite (1 g to 2 g) was smeared on the bone surface just before cementing by using an IBBC technique.[18,19] Osteograft-S (average porosity 40%, 0.3 to 0.7 mm diameters, Japan Medical Materials, Japan), Neobone (average porosity 72% to 78%, 0.5 to 1.0 mm diameters, Aimedic MMT) and Boneceram-P (average porosity 35% to 48%, 0.9 to 1.5 mm diameters, Olympus Terumo Biomaterials, Japan) were used as HA granules. Acetabular components used were the following: Exceed ABT cemented components (Biomet, UK) in 446 hips (45.5%); Charnley-Marcel-Kerboull original concept components (Biomet, France) in 170 hips (17.3%); the K-MAX CLHO components (KYOCERA Medical, Japan) in 116 hips (11.8%); Charnley Elite plus Ogee components (Depuy International, UK) in 60 hips (6.1%); Exeter Contemporary flanged components (Stryker Howmedica, France) in 58 hips (5.9%); Mars components (Matsumoto Medical, Japan) in 49 hips (5.0%); Exeter X3 Rimfit components (Stryker Orthopaedics, USA) in 46 hips (4.7%); Charnley Ogee components (Depuy International in 22 hips (2.2%); Bio-Clad polyethylene acetabular components (Biomet Orthopedics, USA) in 11 hips (1.1%); and PHS FL socket components (Japan Medical, Japan) in two hips (0.2%).

The drainage tube was inserted and removed one day postoperatively. To prevent deep venous thromboembolism, all patients had chemical prevention of thromboembolism for three to four weeks and were encouraged to mobilize as soon as possible without restriction, and to walk with full weight-bearing after drain removal. In the patients who underwent THA by trans-trochanteric approach or Hardinge approach with subtrochanteric shortening osteotomy, weight-bearing was gradually increased to full weight-bearing from six to eight weeks postoperatively. One or two grams of prophylactic cephazolin was administered preoperatively, followed by another dose postoperatively.

Exposure variables and measures assessed. We aggregated baseline data and perioperative factors, such as age at the time of surgery (< 60, 60 to 79, and ≥ 80 years), BMI (< 30 kg/m^2 and ≥ 30 kg/m^2), diagnosis (primary osteoarthritis, secondary osteoarthritis, rheumatoid arthritis, avascular necrosis, rapidly destructive coxopathy, and femoral neck fracture), surgical approach (anterolateral supine, direct anterior, trans-trochanteric osteotomy,[31] anterolateral,[29] direct lateral,[32] and direct lateral with shortening osteotomy), and radiological classification of hip osteoarthritis (Crowe classification,[33] Tönnis classification,[36] and biological-reaction based on the classification of Bombelli).[37] The biological-reaction classification as shown in Figure 3 is based on the original publication by Bombelli.[37] Surgeon volume was classified as low (0 to 10 cases per year), medium (11 to 25 cases per year), or high (26 cases per year).[38] Hip centre position was classified as within the true acetabular region (TAR) or outside TAR.[39]

Outcome. All patients were followed for a minimum of one year postoperatively. RLL was defined as more than a 2 mm lucency adjacent to a sclerotic line at the cement-bone interface, modifying the criteria described by Kobayashi et al.[40] The primary outcome measure was

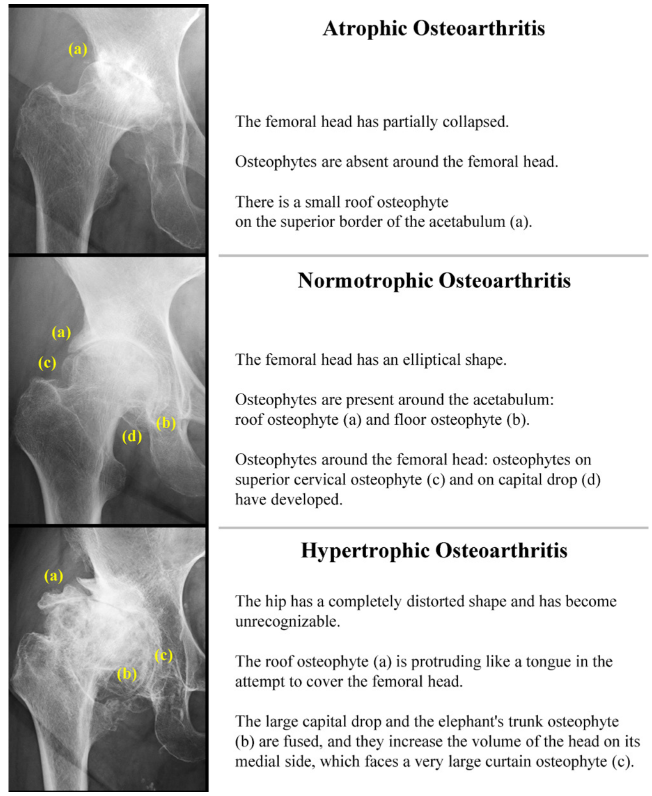

Fig. 3

The biological-reaction classification of hip osteoarthritis according to Bombelli.[37]

any RLL around the acetabular component in the first year after THA, and any RLL detected within one week postoperatively was excluded from the primary outcome to take into consideration a poor cementing technique (Figure 1). The location and frequency of the RLLs were evaluated according to the zones described by DeLee and Charnley.[35] The definition of periprosthetic joint infection (PJI) was obtained from the scoring-based criteria.[41]

Clinical outcome was assessed at the one-, five, and ten-year follow-up postoperatively using the Japanese Orthopaedic Association hip score (JOAHS),[42] which is composed of four factors: pain, range of motion, walking, and activities of daily living (ADL).[42] The modified Harris Hip Score (mHHS) was also used. It is composed of eight factors: pain, limp, support, distance walked, stairs, shoes/socks, sitting, and public transportation.[43] Total scores for the JOAHS and the mHHS range from 0 to 100 and from 0 to 91 (worst to best), respectively.

Statistical analysis. All variables were summarized as frequencies, percentages, means, and standard deviations (SDs). Univariate logistic regression analyses were used to determine the relationship between the presence of any RLL and sex, age, BMI, diagnosis, surgical approach, head diameter, tertiles of acetabular component polyethylene thickness, the use of structural bone graft, and HA. All factors with a p-value of < 0.05 in the univariate analysis and a priori variables based on previous literature that could have potentially influenced the clinical result of cemented acetabular component, including surgeon volume of practice and hip centre position,[38,39] were used in exact logistic regression controlling for the potential confounders. The Haldane-Anscombe correction (adding 0.5 to all zero cells in the contingency table) was used to calculate odds ratios (ORs) and corresponding confidence intervals (CIs). In the multivariate analysis, a value of $p < 0.05$ was considered significant and was designed to identify all influencing factors for the presence of the any RLL. C-statistics, the Hosmer-Lemeshow test and pseudo R-squared values were calculated to evaluate the calibration and goodness-of-fit of multivariate analysis. Categorical variables to examine the influence of the expansion of RLL five and ten years after THA were compared using Fisher's exact test. All results are expressed as the p-value, adjusted ORs, and corresponding CIs.

Postoperative clinical outcomes at one, five, and ten years between the two groups were compared using independent-samples t-tests. Kaplan-Meier survivorship analysis with 95% CIs was performed for the entire study and for two different outcomes: revision of the acetabular component for aseptic loosening and revision for any reason. The relationship between the presence of an RLL and survival was analyzed using a log-rank test; p-values of < 0.05 were considered significant. The kappa statistical analysis was used to analyze the reliability of RLL identification by different observers (SM and IS) on the same occasion (interobserver reliability) and by the same observer on separate occasions (intraobserver reliability). The Landis and Koch[44] scale was used to assess the strength of reliability: 0.01 to 0.20 (slight), 0.21 to 0.40 (fair), 0.41 to 0.60 (moderate), 0.61 to 0.80 (substantial), and more than 0.81 (almost perfect). The analysis of inter- and intraobserver reliability was based on the first and the second set of observations, with the second set four to six weeks after the first set. All calculations were performed using R software, version 3.6.1 (R Development Core Team, Austria) and SAS, version 9.4 (SAS Institute, USA).

Results

A total of 980 hips (876 patients) underwent primary cemented THA using the IBBC technique and were followed for a minimum of one year after surgery. The mean patient age was 66.6 years (SD 10.3). The majority of the patients were female (91.0%, 892 of 980) and the most common preoperative diagnosis was secondary osteoarthritis (85.7%, 840 of 980). Nearly half of the patients (45.3%, 444 of 980) were followed for at least five years and 11.5% (113 of 980) were followed for at least ten years. Six hips that had acute PJI were treated with debridement, antibiotics, and implant retention without acetabular revision. Details of the reason for acetabular component revisions and treatments are summarized in Table I. Two hips with periprosthetic femoral fracture, Vancouver B2, were revised only on the femoral side after six and seven years, respectively. Six hips dislocated but no hips were revised due to recurrence of dislocation.

The baseline characteristics of the patients and surgical details are summarized in Table II. Interobserver reliabilities of RLL were 0.863 and 0.798, representing substantial agreement. Intraobserver reliabilities were 0.911 and 0.877 representing almost perfect agreement. RLLs were detected in 27.2% (267 of 980) of patients the first year after surgery, in 29.1% (129 of 444) at five-year follow-up and in 32.7% (37 of 113) at ten-year follow-up. The distribution of RLLs based on the zones described by DeLee and Charnley is shown in Table III. The change in distribution of RLLs with time is shown in Figure 4. Development of RLLs including any new appearance occurred in 14.9% (66 of 444) of patients between years one and five and in 10.6% (12 of 113) of patients from five to ten years postoperatively. Improvement of the cement-bone interface including complete disappearance and poorly defined RLLs was identified in 15.1% of patients (14 of 93). All improvements were detected within the first five years after surgery and did not progress (Figure 5).

Based on univariate logistic regression analyses of nine parameters for any RLLs one year after surgery, male sex (OR 3.88 (95% CI 2.48 to 6.08); $p < 0.001$), secondary osteoarthritis (OR 0.23 (95% CI 0.12 to 0.46); $p < 0.001$), rheumatoid arthritis (OR 0.33 (95% CI 0.13 to 0.81); $p = 0.016$), trans-trochanteric osteotomy (OR 0.34 (95% CI 0.13 to 0.87); $p = 0.025$), head diameter of 26 mm (OR 7.36 (95% CI 4.62 to 11.72); $p < 0.001$) or 28 mm (OR 5.60 (95% CI 3.74 to 8.37); $p < 0.001$), and structural bone graft (OR 0.14 (95% CI 0.10 to 0.20); $p < 0.001$) were significantly associated with any RLLs (Table IV) using univariate logistic regression analyses. All factors with a p-value of < 0.05 in the univariate analysis and a priori variables based on previous literature, such as surgeon volume and hip centre position, were included in a multivariate analysis using exact logistic regression. In the multivariate analysis controlling for potential confounders, atrophic osteoarthritis in biological-reaction based on the classification of Bombelli (OR 2.17 (95% CI 1.04 to 4.49); $p = 0.038$), 26 mm head diameter in Crowe classification (OR 3.23 (95% CI 1.85 to 5.66); $p < 0.001$), in Tönnis classification (OR 3.31 (95% CI 1.90 to 5.78); $p < 0.001$) and in Bombelli classification (OR 3.26 (95% CI 1.87 to 5.69); $p < 0.001$) or 28mm head diameter in Crowe classification (OR 3.64 (95% CI 2.07 to 6.41); $p < 0.001$), in Tönnis classification (OR 3.91 (95% CI 2.22 to 6.91); $p < 0.001$) and in Bombelli classification (OR 3.93 (95% CI 2.22 to 6.97); $p < 0.001$) had a significantly greater risk of developing any RLLs one year after surgery. Structural bone graft in Crowe classification (OR 0.19 (95% CI 0.13 to 0.29); $p < 0.001$), in Tönnis classification (OR 0.19 (95% CI 0.13

Table I. Details of the reason for acetabular component revisions and treatments.

Sex	Age, yrs	Original diagnosis	Time to revision, yrs	RLL at one wk (poor cementing technique)	RLL at 1 yr	Reason	Treatment
F	75	Secondary OA (dysplasial)	0.2	None	N/A	Posterior column fracture with central migration Dislocation	**1-stage cemented revision arthroplasty** Gap cup and structural allograft with antibiotic-loaded cement fixation **Internal fixation using reconstruction plate**
F	65	Secondary OA (dysplasial)	1.0	Yes	Yes	PJI	**2-stage cemented revision arthroplasty** Kerboull-type acetabular reinforcement and structural allograft with antibiotic-loaded cement fixation
F	72	RDC	1.5	None	None	Central migration	**1-stage cemented revision arthroplasty** Kerboull-type acetabular reinforcement and structural allograft with antibiotic-loaded cement fixation
F	61	Secondary OA (dysplasial)	4.0	Yes	Yes	PJI	**2-stage cemented revision arthroplasty** Kerboull-type acetabular reinforcement and structural allograft with antibiotic-loaded cement fixation
M	70	Primary OA	4.0	None	Yes	PJI	**2-stage cemented revision arthroplasty** strctual allograft with antibiotic-loaded cement fixation
F	63	Secondary OA (dysplasial)	5.0	None	None	Superior migration with collapse of structural autologous bone graft	**1-stage cemented revision arthroplasty** Kerboull-type acetabular reinforcement and structural allograft with antibiotic-loaded cement fixation
F	71	RA	7.0	None	None	Development of RLL in zoneS 1, 2, and 3 by DeLee and Charnley	**1-stage cemented revision arthroplasty** Kerboull-type acetabular reinforcement and structural allograft with antibiotic-loaded cement fixation
F	63	Secondary OA (CD)	8.0	None	None	PJI	**2-stage cemented revision arthroplasty** Kerboull-type acetabular reinforcement and structural allograft with antibiotic-loaded cement fixation
M	76	Secondary OA (dysplasial)	9.0	None	None	PJI	**2-stage cemented revision arthroplasty** Kerboull-type acetabular reinforcement and structural allograft with antibiotic-loaded cement fixation
F	62	Secondary OA (dysplasial)	10.0	None	None	PJI	**2-stage cemented revision arthroplasty** antibiotic-loaded cement fixation

CD, congenital dislocation; N/A, not available; OA, osteoarthritis; PJI, periprosthetic joint infection; RA, rheumatoid arthritis; RDC, rapidly destructive coxopathy; RLL, radiolucent line.

to 0.28); p < 0.001) and in Bombelli classification (OR 0.21 (95% CI 0.14 to 0.30); p < 0.001) and within TAR in Crowe classification (OR, 0.15 (95% CI 0.09 to 0.24); p < 0.001), in Tönnis classification (OR 0.14 (95% CI 0.09 to 0.23); p < 0.001) and in Bombelli classification (OR 0.13 (95% CI 0.08 to 0.22); p < 0.001) had a significantly lower risk (Table V). There was no relationship between these factors and progression of RLLs at five and ten years postoperatively (Table VI).

The JOAHS and mHHS at one, five, and ten years postoperatively in the groups with or without RLLs are shown in Table VII. A statistically significant difference was found in the JOA total and function scores between the groups five years postoperatively (p = 0.017 and 0.003, respectively) and ten years postoperatively (p = 0.008 and 0.001, respectively), and in the mHHS total and function scores ten years postoperatively (p = 0.029 and 0.023, respectively, all independent-samples *t*-test). Kaplan-Meier survival analysis for the acetabular component at ten years with revision of the acetabular component for aseptic loosening as the end point was 100.0% in the group with RLLs and 99.1% (95% CI 97.9 to 100) in the group without RLLs (Figure 6a). With revision of the acetabular component for any reason as the end point, the survival rate was 99.2% (95% CI 97.6 to 100) in the group with RLLs and 96.5% (95% CI 93.4 to 99.7) in the group without RLLs (Figure 6b). There was no statistically significant difference in acetabular revision for aseptic loosening and for any reason between the two groups (p = 0.354 and 0.698, respectively, log rank test; Figure 6a and b).

Discussion. It is true that both cemented and cementless THA can yield successful long-term results. Despite national hip arthroplasty registries in Australia, Denmark, England and Wales, Finland, the Netherlands, New Zealand, Romania, Norway, Sweden, and Switzerland have reported that cemented fixation in patients older than 75 years results in the lowest risk of revision, increasing use of cementless THA is a worldwide phenomenon.[7,8] The risk of revision for any reason using a cemented acetabular component is significantly lower than for cementless components,[45–47] and the cemented acetabular component is the gold standard. However, the optimum acetabular component fixation using cement still remains controversial. Several studies have shown that any postoperative RLL at the bone-cement interface around the acetabular component profoundly affects later loosening of the component.[10,12,21-24] Biomechanical reinforcement of

Table II. Baseline demographic data and surgical details of the study (876 patients with 980 hips).

Variable	Length of follow-up		
	≥ 1 yr	≥ 5 yrs	≥ 10 yrs
Hips, n (%)	980 (100)	444 (100)	113 (100)
Mean age, yrs (SD)	66.7 (10.3)	65.6 (9.9)	61.1 (11.0)
Mean follow-up, yrs (SD)	4.8 (3.2)	7.6 (2.6)	11.4 (1.5)
Sex, n (%)			
Male	88 (9.0)	34 (7.7)	10 (8.8)
Female	892 (91.0)	410 (92.3)	103 (91.2)
Side, n (%)			
Right	508 (51.8)	235 (52.9)	61 (54.0)
Left	472 (48.2)	209 (47.1)	52 (46.0)
Mean BMI, kg/m^2 (SD)	23.6 (4.0)	23.3 (3.8)	23.1 (3.7)
Preoperative diagnosis, n (%)			
Primary OA	38 (3.9)	16 (3.6)	0 (0)
Secondary OA	840 (85.7)	372 (83.8)	82 (72.6)
CD, Dysplasia, Subluxation	785 (80.1)	350 (78.8)	78 (69.0)
Pelvic osteotomy	21 (2.1)	7 (1.6)	1 (0.9)
Femoral osteotomy	18 (1.8)	10 (2.3)	2 (1.8)
Trauma	12 (1.2)	3 (0.7)	0 (0)
Femoral and pelvic osteotomy	3 (0.3)	2 (0.5)	1 (0.9)
Infection	1 (0.1)	0 (0)	0 (0)
RA	45 (4.6)	30 (6.8)	14 (12.4)
AVN	41 (4.2)	21 (4.7)	14 (12.4)
RDC	11 (1.1)	4 (0.9)	3 (2.7)
FNF	5 (0.5)	1 (0.2)	0 (0)
Approach, n (%)			
ALS	526 (53.7)	85 (19.1)	0 (0)
DA	369 (37.7)	289 (65.1)	77 (68.1)
TO	42 (4.3)	34 (7.7)	8 (7.1)
AL	24 (2.4)	19 (4.3)	17 (15.0)
DL	12 (1.2)	11 (2.5)	9 (8.0)
DL with SSO	7 (0.7)	6 (1.4)	2 (1.8)
Femoral head diameter, n (%)			
22 m	370 (37.8)	267 (60.1)	76 (67.3)
26 mm	171 (17.4)	129 (29.1)	35 (31.0)
28 mm	437 (44.6)	47 (10.6)	2 (1.8)
32 mm	2 (0.2)	1 (0.2)	0 (0)
Acetabular component, n (%)			
Outer/Internal diameter (mm)			
36/22	1 (0.1)	0 (0)	0 (0)
37/22	2 (0.2)	2 (0.5)	0 (0)
38/22	3 (0.3)	2 (0.5)	1 (0.9)
40/22, /26, /28	150 (15.3), 8 (0.8), 1 (0.1)	119 (26.8), 6 (0.2), 1 (0.2)	32 (28.3), 0 (0), 0 (0)
42/22, /26, /28	109 (11.1), 21 (2.1), 4 (0.4)	72 (16.2), 15 (3.4), 1 (0.2)	18 (15.9), 1 (0.9), 0 (0)
43/22, /26	5 (0.5), 14 (1.4)	5 (1.1), 10 (2.3)	3 (2.7), 3 (2.7)
44/22, /26, /28	67 (6.8), 34 (3.5), 120 (12.2)	45 (10.1), 20 (4.5), 3 (0.7)	12 (10.6), 4 (3.5), 0 (0)
46/22, /26, /28	20 (2.0), 37 (3.8), 184 (18.8)	17 (3.8), 32 (7.2), 30 (6.8)	6 (5.3), 6 (5.3), 1 (0.9)
47/26	33 (3.4)	28 (6.3)	16 (14.2)
48/22, /26, /28	8 (0.8), 5 (0.5), 42 (4.3)	4 (0.9), 3 (0.7), 6 (1.4)	3 (2.7), 1 (0.9), 0 (0)
50/22, /26, /28	5 (0.5), 13 (1.3), 27 (2.8)	1 (0.2), 12 (2.7), 2 (0.5)	1 (0.9), 3 (2.7), 1 (0.9)
52/26, /28, /32	3 (0.3), 44 (4.5), 2 (0.2)	2 (0.5), 4 (0.9), 1 (0.2)	0 (0), 0 (0), 0 (0)
53/26	2 (0.2)	0 (0)	0 (0)
54/26, /28	1 (0.1), 6 (0.6)	1 (0.2), 0 (0)	1 (0.9), 0 (0)
56/28	5 (0.5)	0 (0)	0 (0)
58/28	4 (0.4)	0 (0)	0 (0)
Structural bone graft, n (%)	590 (60.2)	266 (59.9)	67 (59.3)

Continued

Table II. Continued

AL, anterolateral; ALS, anterolateral in spine; AVN, avascular necrosis; CD, congenital dislocation; DA, direct anterior; DL, direct lateral; FNF, femoral neck fracture; OA, osteoarthritis; RA, rheumatoid arthritis; RDC, rapidly destructive coxopathy; SD, standard deviation; SSO, subtrochanteric shortening osteotomy; TO, trans-trochanteric osteotomy.

the interface is necessary to establish a well-fixed cement-bone interface. Despite progression of cementing techniques including pressurizers, suction aspirators, preparation of the subchondral bone plate, and introduction of flanged components that play a major role in mechanical reinforcement,[13–16] RLLs around the acetabular component are often found in postoperative radiography. From the viewpoint of biomechanical reinforcement, Oonshi et al[18] in 1982 reported an IBBC technique with the aim of additional physicochemical bonding augmenting the cement-bone interface by interposing osteoconductive crystal HA granules. Our study shows that poor bone quality is a significant risk factor for RLL around the acetabular component; these results are congruent with previous reports.[48,49] Contrary to expectation, we identified that structural bone graft, the position of the hip centre and head diameter also were significantly associated with the risk of RLL. However, these risk factors did not predict expansion of the RLL five and ten years after THA and the presence of an RLL by the first year was not associated with revision arthroplasty. Interestingly, it is quite apparent from our investigation that the cement-bone interface was improved over time by the complete disappearance or poorly defined RLLs in some cases. To our knowledge, no reports have been published showing the improvement of the cement-bone interface around cemented acetabular components.

Our findings should be interpreted in the context of several limitations. First, this was a non-randomized retrospective study performed by eight different surgeons who were familiar with acetabular cementing, using five different approaches and ten different acetabular components at a single institution. It is possible that our

Table III. The distribution of radiolucent lines at one, five, and ten years postoperatively.

	Hips, n (%)		
DeLee Charnley zones	**At 1 yr**	**At 5 yrs**	**At 10 yrs**
Total	980 (100)	444 (100)	113 (100)
None	713 (72.8)	315 (70.9)	76 (67.3)
1 only	142 (14.5)	59 (13.3)	17 (15.0)
2 only	22 (2.2)	13 (2.9)	4 (3.5)
3 only	30 (3.1)	9 (2.0)	4 (3.5)
1 + 2	25 (2.6)	18 (4.1)	4 (3.5)
1 + 3	21 (2.1)	19 (4.3)	5 (4.4)
2 + 3	24 (2.4)	9 (2.0)	0 (0)
1 + 2 + 3	3 (0.3)	2 (0.5)	3 (2.7)
Any zone	267 (27.2)	129 (29.1)	37 (32.7)

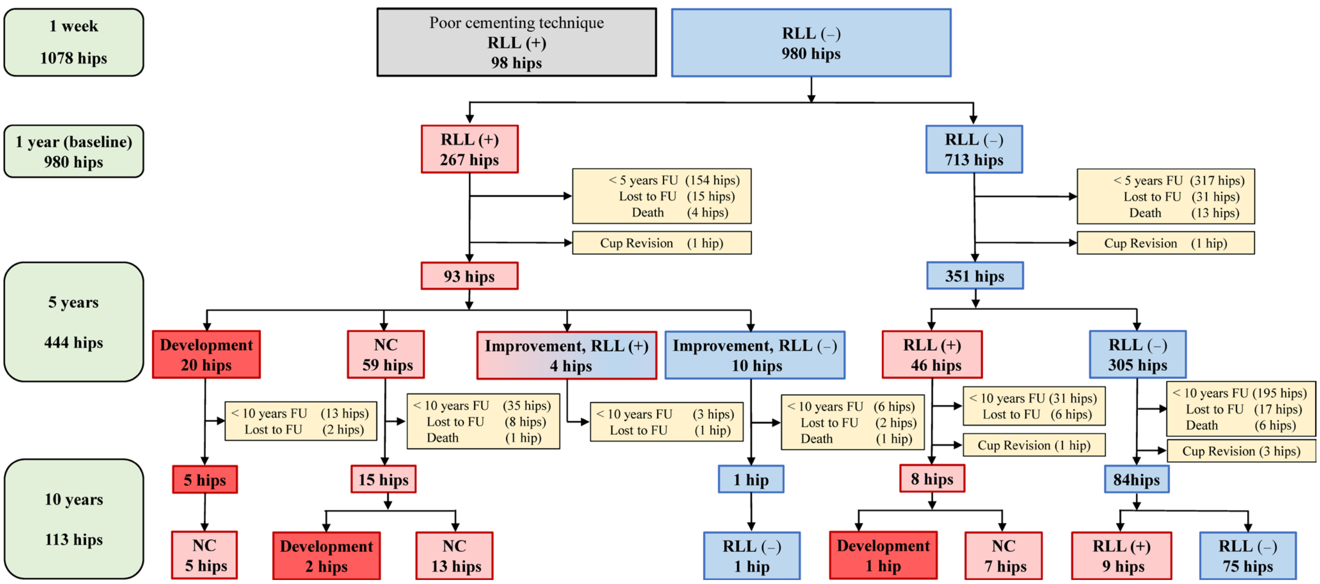

Fig. 4

Flowchart depicting the change in distribution of radiolucent lines at one, five, and ten years postoperatively. FU, follow-up; RLL, radiolucent line; NC, no change.

estimates were not generalizable from the national registries because of these diversities based on surgeon or institutional bias. Second, in the present study, 80.1% of patients had secondary osteoarthritis based on congenital dislocation or dysplasia.[50,51] Therefore, our findings might not apply to European or American patients who mostly have primary hip osteoarthritis. In addition, all the acetabular components were not selected from the same manufacturer as the femoral components. The proportion of patients lost to follow-up also may have created a selection bias. However, the National Joint Registry of England and Wales found mixing of components from different manufacturers was not associated with increased overall revision rates,[52] therefore this is the best evidence currently available from one institute because all clinical and radiological data of patients between the first year and ten years of follow-up were available. Third, the study did not include a control group without the IBBC technique. It will be necessary to verify the effectiveness of the IBBC technique by comparing it with other modern cementing techniques in future studies. Fourth, we investigated and classified radiologically hip osteoarthritis based on the Crowe, Tönnis, and biological reaction of Bombelli classifications. Atrophic osteoarthritis was one risk factor for any RLL. However, we did not evaluate bone quality around the acetabular component objectively and or the effects of medications for osteoporosis. Fifth, although radiographs of the hip joint were used at each follow-up timepoint, the sequential relationship in sagittal balance between the hip and the whole spine may influence the description of RLL. The description of RLL in various positions should be taken into consideration in future studies. Sixth, although we identified 26 mm and 28 mm head diameters as a potential risk factor specific to any RLLs and the most common head diameter in THA is 32 mm in several national joint registries,[53–56] our study did not

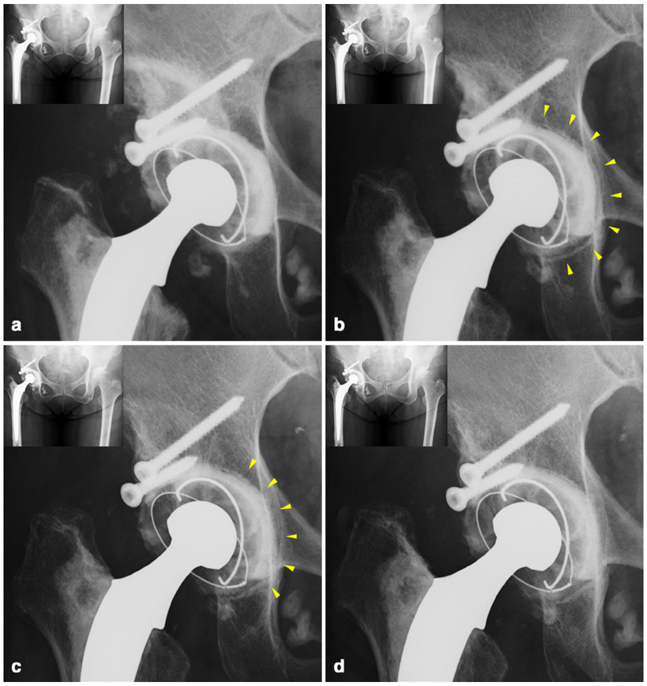

Fig. 5

Postoperative radiographs of a 61-year-old woman with primary cemented total hip arthroplasty. a) One week postoperatively; b) one year postoperatively, the yellow arrow indicates a radiolucent line at the cement-bone interface in DeLee Charnley zones 2 and 3; c) five years postoperatively, the yellow arrow indicates the improvement in the radiolucent line at the cement-bone interface in DeLee Charnley zone 2 and part of zone 3; and d) nine years postoperatively, improvement of the cement-bone interface was maintained.

include the larger diameter femoral heads (> 32 mm), which caused two patients to be excluded. In addition, all polyethylene acetabular components had a thickness of at least 6 mm. Accordingly, the effects of a large diameter femoral head on friction torque at the cement-bone interface, and of polyethylene thickness on stress concentrations at the interface, were not examined. Finally, the influence of medications for rheumatoid arthritis or osteoporosis should be investigated because these may interfere with additional physicochemical bonding, which is the philosophy behind the IBBC technique. Rheumatoid arthritis patients with any RLL in the first year constituted 5.2% (14 of 267) of the patient sample. Medications for rheumatoid arthritis patients in the first year included: prednisolone (78.6%, 11 of 14), methotrexate (35.7%, 5 of 14), salazosulfapyridine (35.76%, 5 of 14), bucillamine (7.1%, 1 of 14), tacrolimus (7.1%, 1 of 14), and biological medications in 21.4% (3 of 14). RLLs was not identified in rheumatoid arthritis patients between years one and five. Furthermore, antiosteoporosis medications in patients with improvement of RLL constituted 28.6% (4 of 14) of this patient population. Medications included: bisphosphonates (14.3%, 2 of 14), selective oestrogen receptor modulators (14.3%, 2 of 14), and active vitamin D3 (7.1%, 1 of 14). However, it is extremely difficult to examine the time to initiation of medication in this retrospective study.

The well-fixed cement-bone interface is important to prevent micromigration and protect the acetabular component against wear debris and fluid accumulation at the cement-bone interface, which are caused by loosening.[10-12] According to previous reports, the incidence of any postoperative RLL is 2.0% to 7.0% immediately after surgery, 21.6% to 70.4% in the first year, 41.0% to 49.0% at five years, 36.0% to 57.3% at ten years, and 62.0% at 20 years postoperatively.[12,13,15,17,21,57] There is wide variation of RLL incidence in previous reports as cementing techniques have evolved over time. The presence of RLLs in this study was 24.8% (267 of 1,078) in the first year, similar to previous reports. However, RLLs in the first year were not associated with revision arthroplasty at later timepoints. Hence, it is possible that the IBBC technique may achieve additional physicochemical bonding at the cement-bone interface.

In the relationship between the presence of RLL and clinical outcome postoperatively, a statistically significant difference was found in JOAHS and mHHS between with and without RLL five and ten years postoperatively. One study evaluating the relationship between surgical technique and radiological and clinical outcomes postoperatively did not demonstrate any clinical advantage over modern cementing techniques.[57] Our results do not support these findings. One possibility for this difference is that patients without RLLs were significantly younger than those with RLLs at the five- and ten-year follow-up. Further examination is needed to clarify the relationship between the presence of RLLs and clinical outcomes postoperatively.

Bone quality for cement interdigitation plays a particularly critical role to establish an optimal mechanical stability. Kobayashi et al[48] conducted a multivariate analysis of 405 primary Charnley THAs to identify risk factors for aseptic loosening and found that the acetabular bone quality of atrophic osteoarthritis was not adequate to prevent fatigue failure or collapse of the cancellous bone. Similarly, Nixon et al[49] found revisions caused by aseptic loosening were more likely in patients who were diagnosed with atrophic osteoarthritis. The recent development of treatment for osteoporosis will influence the clinical results of cemented acetabular components including the appearance of RLLs. In the future, it will be necessary to examine the detailed bone quality around the acetabular component objectively, including bone mineral density.

In our study, 80.1% of patients had secondary osteoarthritis based on congenital dislocation, dysplasia, or subluxation. Almost all hip osteoarthritis in Japan is caused by these conditions,[50,51] and the acetabulum of these patients is small and shallow. Hence, structural bone graft was used in 67.9% (533 of 785) of these patients

Table IV. Univariate analyses of nine parameters for any radiolucent lines one year after surgery.

Variable	Frequency			OR (95% CI)	p-value*
	Total	RLL (+)	RLL (-)		
Hips, n (%)	980 (100)	267 (27.2)	713 (72.8)		
Sex, n (%)					
Female	892 (91.0)	218 (22.2)	674 (68.8)	1.00	
Male	88 (9.0)	49 (5.0)	39 (4.0)	3.88 (2.48 to 6.08)	< 0.001
Age, n (%)					
< 60 yrs	241 (24.6)	58 (5.9)	183 (18.7)	1.00	
60 yrs to 79 yrs	646 (65.9)	181 (18.5)	465 (47.4)	1.23 (0.87 to 1.73)	0.238
≥ 80 yrs	93 (9.5)	28 (2.9)	65 (6.6)	1.36 (0.80 to 2.31)	0.259
BMI, n (%)					
< 30 kg/m²	905 (92.3)	242 (24.7)	663 (67.7)	1.00	
≥ 30 kg/m²	75 (7.7)	25 (2.6)	50 (5.1)	1.37 (0.83 to 2.26)	0.219
Diagnosis, n (%)					
Primary OA	38 (3.9)	22 (2.2)	16 (1.6)	1.00	
Secondary OA	840 (85.7)	205 (20.9)	635 (64.8)	0.23 (0.12 to 0.46)	< 0.001
RA	45 (4.6)	14 (1.4)	31 (3.2)	0.33 (0.13 to 0.81)	0.016
AVN	41 (4.2)	21 (2.1)	20 (2.0)	0.76 (0.31 to 1.86)	0.552
RDC	11 (1.1)	4 (0.4)	7 (0.7)	0.42 (0.10 to 1.66)	0.215
FNF	5 (0.5)	1 (0.1)	4 (0.4)	0.18 (0.02 to 1.78)	0.143
Approach, n (%)					
ALS	526 (53.7)	151 (15.4)	375 (38.3)	1.00	
DA	369 (37.7)	101 (10.3)	268 (27.3)	0.94 (0.70 to 1.26)	0.662
TO	42 (4.3)	5 (0.5)	37 (3.8)	0.34 (0.13 to 0.87)	0.025
AL	24 (2.4)	9 (0.9)	15 (1.5)	1.49 (0.64 to 3.48)	0.356
DL	12 (1.2)	1 (0.1)	11 (1.1)	0.23 (0.03 to 1.76)	0.156
DL with SSO	7 (0.7)	0 (0)	7 (0.7)	0.17 (0.01 to 2.91)†	0.110
Femoral head diameter, n (%)					
22 mm	370 (37.8)	34 (3.5)	336 (34.3)	1.00	
26 mm	171 (17.4)	73 (7.4)	98 (10.0)	7.36 (4.62 to 11.72)	< 0.001
28 mm	437 (44.6)	158 (16.1)	279 (28.5)	5.60 (3.74 to 8.37)	< 0.001
32 mm	2 (0.2)	2 (0.2)	0 (0)	48.77 (2.29 to 1036.48)†	0.103
Polyethylene thickness, n (%)					
< 8 mm	14 (1.4)	4 (0.4)	10 (1.0)	1.00	
8 mm to 9 mm	528 (53.9)	141 (14.4)	387 (39.5)	0.91 (0.28 to 2.95)	0.876
≥ 10 mm	438 (44.7)	122 (12.5)	316 (32.2)	0.97 (0.30 to 3.14)	0.953
Structural bone graft	590 (60.2)	73 (7.4)	517 (52.8)	0.14 (0.10 to 0.20)	< 0.001
Hydroxyapatite, n (%)					
Osteograft-S	113 (11.5)	28 (2.9)	85 (8.7)	1.00	
Neobone	308 (31.4)	66 (6.7)	242 (24.7)	0.83 (0.50 to 1.37)	0.465
Boneceram-P	559 (57.0)	173 (17.7)	386 (39.4)	1.36 (0.86 to 2.16)	0.193

*Univariate logistic regression analyses.
†The Haldane-Anscombe correction was applied to calculate the odds ratios and corresponding confidence intervals.
AL, anterolateral; ALS, anterolateral in spine; AVN, avascular necrosis; CI, confidence interval; DA, direct anterior; DL, direct lateral; FNF, femoral neck fracture; IBBC, interface bioactive bone cement; OA, osteoarthritis; OR, odds ratio; RA, rheumatoid arthritis; RDC, rapidly destructive coxopathy; RLL, radiolucent line; SSO, subtrochanteric shortening osteotomy; TO, trans-trochanteric osteotomy

and 60.2% of all patients. Previous retrospective studies of primary total hip arthroplasty with acetabular reconstruction using a structural bone graft reported excellent clinical and radiological results.[58–62] Structural bone graft could play an important role to facilitate complete containment of the acetabular component, resulting in better cement penetration and reinforcing the cement-bone interface mechanically. Furthermore, structural bone graft of the acetabular component is necessary to restore the bone stock, which would be an advantage in future revision THA.

An acetabular anatomical reconstruction in patients with secondary osteoarthritis based on dysplasia is technically demanding and remains a challenge. Bone deficiency from the anterolateral to superior aspects of the acetabulum makes it difficult to achieve adequate host bone coverage.[27] On the other hand, in previous studies of patients with dysplasia undergoing cementless THA,

Table V. Multivariate analyses of seven parameters for any radiolucent lines one year after surgery.

	Crowe (980 hips)			Tönnis (958 hips)*			Bombelli (biological-reaction) (958 hips)*		
Variable		**Adjusted OR (95% CI)**	**p-value**		**Adjusted OR (95% CI)**	**p-value**		**Adjusted OR (95% CI)**	**p-value**
Sex									
Female		1.00			1.00			1.00	
Male		1.75 (0.98 to 3.12)	0.058		1.43 (0.80 to 2.56)	0.234		1.40 (0.78 to 2.52)	0.259
Diagnosis									
OA									
Primary		1.00	-	1 + 2	1.00		Hyper	1.00	
Secondary	I	1.05 (0.48 to 2.29)	0.909						
CD	II	1.05 (0.41 to 2.71)	0.914				Normo	1.30 (0.65 to 2.64)	0.460
Dysplasia	III	0.75 (0.19 to 2.87)	0.670	3	1.04 (0.64 to 1.68)	0.883			
Subluxation	IV	3.08 (0.35 to 27.27)	0.313				Atro	2.17 (1.04 to 4.49)	0.038
Other†		1.82 (0.61 to 5.41)	0.285						
RA		0.74 (0.25 to 2.19)	0.588		0.71 (0.29 to 1.75)	0.460		1.06 (0.38 to 2.96)	0.915
AVN		1.07 (0.37 to 3.05)	0.905		1.12 (0.45 to 2.75)	0.813		1.70 (0.60 to 4.80)	0.318
RDC		0.75 (0.14 to 4.08)	0.736		0.74 (0.15 to 3.58)	0.704		1.20 (0.23 to 6.33)	0.827
FNF		0.40 (0.05 to 3.50)	0.406		0.39 (0.05 to3.11)	0.372		0.60 (0.07 to 5.18)	0.641
Approach									
ALS		1.00	-		1.00	-		1.00	
DA		1.41 (0.88 to 2.26)	0.148		1.40 (0.87 to 2.23)	0.162		1.42 (0.88 to 2.28)	0.152
TO		0.81 (0.19 to 3.42)	0.772		0.91 (0.22 to 3.79)	0.895		1.15 (0.27 to 4.80)	0.852
AL		0.70 (0.22 to 2.18)	0.536		0.70 (0.23 to 2.21)	0.547		0.73 (0.23 to 2.31)	0.592
DL		0.38 (0.04 to 3.49)	0.395		0.48 (0.06 to 4.09)	0.504		0.49 (0.06 to 4.14)	0.509
DL with SSO		0.10 (0 to 4.47)	0.237		1.38 (0.01 to 157.33)	0.894		1.89 (0.02 to 183.38)	0.784
Femoral head diameter (mm)									
22		1.00			1.00			1.00	
26		3.23 (1.85 to 5.66)	< 0.001		3.31 (1.90 to 5.78)	< 0.001		3.26 (1.87 to 5.69)	< 0.001
28		3.64 (2.07 to 6.41)	< 0.001		3.91 (2.22 to 6.91)	< 0.001		3.93 (2.22 to 6.97)	< 0.001
32		5.32 (0.07 to 393.45)	0.446		8.95 (0.13 to 605.74)	0.308		7.84 (0.16 to 393.27)	0.303
Structural bone graft		0.19 (0.13 to 0.29)	< 0.001		0.19 (0.13 to 0.28)	< 0.001		0.21 (0.14 to 0.30)	< 0.001
Surgeon volume (cases/y)									
≤ 10		1.00			1.00			1.00	
11 to 25		0.83 (0.43 to 1.62)	0.587		0.80 (0.41 to 1.55)	0.502		0.81 (0.41 to 1.58)	0.534
> 25		0.67 (0.37 to 1.21)	0.180		0.68 (0.38 to 1.22)	0.190		0.73 (0.41 to 1.32)	0.296
Within TAR		0.15 (0.09 to 0.24)	< 0.001		0.14 (0.09 to 0.23)	< 0.001		0.13 (0.08 to 0.22)	< 0.001
C-statistics	0.840			0.835			0.842		
Hosmer-Lemeshow test	0.830			0.509			0.926		
Pseudo R-squared	0.277			0.271			0.278		

*Excludes 22 highly disloacted hips (indicated by Crowe type IV and Schanz osteotomy).
†Other indicated pelvic osteotomy, femoral osteotomy, both femoral and pelvic osteotomy, trauma, and infection.
AL, anterolateral; ALS, anterolateral in spine; AVN, avascular necrosis; CD, congenital dislocation; CI, confidence interval; DA, direct anterior; DL, direct lateral; FNF, femoral neck fracture; IBBC, interface bioactive bone cement; OA, osteoarthritis; OR, odds ratio; RA, rheumatoid arthritis; RDC, rapidly destructive coxopathy; SSO, subtrochanteric shortening osteotomy; TAR, true acetabular region; TO, trans-trochanteric osteotomy.

superior placement of the hip centre that was positioned a mean of 24.5 mm to 26.8 mm superior to the inter-teardrop line demonstrated excellent long-term clinical and radiological results.[63–65] Johnston et al[66] investigated the mechanical alterations associated with hip centre position to develop a mathematical model of the hip joint and suggested that placing the hip centre medially, inferiorly, and anteriorly improved mechanical function and

Table VI. Relationship between prognostic factors and development of radiolucent lines after five and ten years.

Follow-up	At 5 yrs (444 hips)				At 10 yrs (113 hips)			
RLL	Development (20 hips) RLL (+) (46 hips)	NC	OR (95% CI)	p-value*	Development (3 hips) RLL (+) (9 hips)	NC	OR (95% CI)	p-value*
Number of hips, n (%)	66 (100)	59 (100)			12 (100)	25 (100)		
Bombelli (Biological-reaction)								
Atrophic type	17 (25.8)	18 (30.5)	0.79 (0.34 to 1.86)	0.690	4 (33.3)	2 (8.0)	5.44 (0.64 to 71.21)	0.073
Femoral head diameter, mm								
26	34 (51.5)	34 (57.6)	0.78 (0.36 to 1.68)	0.590	7 (58.3)	16 (64.0)	0.79 (0.16 to 4.17)	> 0.999
28	15 (22.7)	7 (11.9)	2.17 (0.76 to 6.85)	0.158	1 (8.3)	1 (4.0)	2.13 (0.03 to 178.00)	> 0.999
Structural bone graft	24 (36.4)	12 (20.3)	2.22 (0.93 to 5.53)	0.074	4 (33.3)	3 (12.0)	3.52 (0.48 to 29.71)	0.183
Within TAR	56 (84.8)	44 (74.6)	1.90 (0.72 to 5.23)	0.182	10 (83.3)	21 (84.0)	0.95 (0.11 to 12.21)	> 0.999

*Fisher's exact test.
CI, confidence interval; NC, no change; OR, odds ratio; TAR, true acetabular region.

Table VII. Postoperative clinical score of radiolucent line (RLL) (+) and RLL (-).

Score (possible range)	RLL (+)			RLL (-)			
	Mean (SD)	Median (IQR)	Range	Mean (SD)	Median (IQR)	Range	p-value*
Score at 1 yr (hips)	263			702			
Age, yrs	67.6 (11.0)	70.0 (15.0)	16.0 to 87.0	66.2 (9.9)	66.0 (15.0)	23.0 to 89.0	0.063
JOA-total (0 to 100)	90.7 (5.5)	92.0 (7.8)	71.0 to 100.0	91.0 (5.5)	92.0 (7.0)	74.0 to 100.0	0.369
JOA-pain (0 to 40)	39.2 (1.8)	40.0 (0)	35.0 to 40.0	39.4 (1.6)	40.0 (0)	35.0 to 40.0	0.063
JOA-function: walking and ADL (0 to 40)	32.4 (4.3)	33.0 (4.0)	16.0 to 40.0	32.7 (4.2)	33.0 (5.0)	16.0 to 40.0	0.385
mHHS-total (0 to 91)	81.6 (5.9)	81.0 (8.8)	66.0 to 95.0	82.2 (5.6)	83.0 (8.0)	62.0 to 91.0	0.144
mHHS-pain (0 to 44)	43.4 (1.4)	44.0 (0)	40.0 to 44.0	43.6 (1.3)	44.0 (0)	40.0 to 44.0	0.084
mHHS-function (0 to 47)	38.3 (5.5)	39.0 (7.0)	22.0 to 51.0	38.7 (5.2)	39.0 (9.0)	22.0 to 47.0	0.297
N/A	4			11			
Score at 5 yrs (hips)	129			313			
Age, yrs	72.9 (11.1)	75.0 (15.3)	37.0 to 92.0	69.6 (9.2)	70.0 (13.0)	28.0 to 88.0	0.001
JOA-total (0 to 100)	89.2 (6.2)	91.0 (8.0)	72.0 to 98.0	90.7 (5.7)	92.0 (8.0)	71.0 to 100.0	0.017
JOA-pain (0 to 40)	39.3 (1.8)	40.0 (0)	35.0 to 40.0	39.4 (1.6)	40.0 (0)	35.0 to 40.0	0.405
JOA-function: walking and ADL (0 to 40)	31.3 (4.8)	32.0 (6.0)	16.0 to 38.0	32.7 (4.3)	33.0 (5.0)	16.0 to 40.0	0.003
mHHS-total (0 to 91)	80.8 (5.9)	79.0 (8.0)	62.0 to 95.0	82.0 (5.6)	83.0 (6.0)	62.0 to 91.0	0.051
mHHS-pain (0 to 44)	43.4 (1.4)	44.0 (0)	40.0 to 44.0	43.5 (1.3)	44.0 (0)	40.0 to 44.0	0.405
mHHS-function (0 to 47)	37.4 (5.6)	37.0 (6.3)	22.0 to 51.0	38.5 (5.2)	39.0 (7.0)	22.0 to 47.0	0.061
N/A	0			2			
Score at 10 yrs (hips)	37			76			
Age, yrs	75.6 (13.2)	77.0 (18.5)	45.0 to 97.0	70.4 (9.7)	71.0 (12.0)	33.0 to 93.0	0.020
JOA-total (0 to 100)	87.2 (6.4)	88.0 (9.3)	72.0 to 98.0	90.7 (6.4)	92.0 (9.0)	75.0 to 98.0	0.008
JOA-pain (0 to 40)	39.5 (1.6)	40.0 (0)	35.0 to 40.0	39.5 (1.5)	40.0 (0)	35.0 to 40.0	0.964
JOA-function: walking and ADL (0 to 40)	29.1 (5.5)	31.0 (9.0)	16.0 to 38.0	32.7 (5.0)	33.0 (4.5)	16.0 to 38.0	0.001
mHHS-total (0 to 91)	80.7 (5.7)	81.0 (6.5)	68.0 to 91.0	83.2 (5.7)	85.0 (7.0)	62.0 to 91.0	0.029
mHHS-pain (0 to 44)	43.6 (1.3)	44.0 (0)	40.0 to 44.0	43.6 (1.2)	44.0 (0)	40.0 to 44.0	0.964
mHHS-function (0 to 47)	37.1 (5.8)	37.0 (6.3)	24.0 to 47.0	39.6 (5.2)	41.0 (7.0)	22.0 to 47.0	0.023

*Independent-samples *t*-test.
ADL, activities of daily living; IQR, interquartile range; JOA, Japanese Orthopaedic Association; mHHS, modified Harris hip score; N/A, not available; RLL, radiolucent line; SD, standard deviation.

reduced muscle effort and joint contact force. Moreover, prior clinical studies demonstrated that anatomical

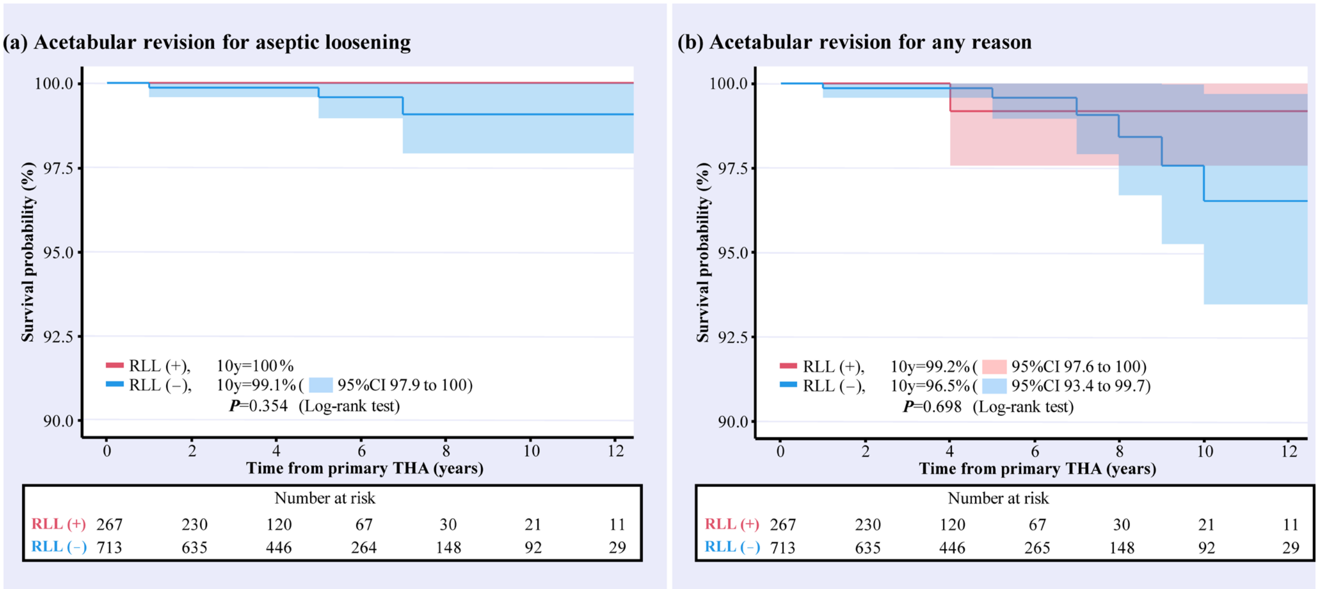

Fig. 6

Kaplan-Meier survivorship curve showing acetabular component survival at ten years with an end point of a) acetabular revision for aseptic loosening and b) acetabular revision for any reason. CI, confidence interval; RLL, radiolucent line; THA, total hip arthroplasty.

reconstruction of the acetabular components improved the long-term survival rate not only of the cemented acetabular component but also the femoral component in patients with dysplasia.[39,67] A RLL was depicted radiologically as the sign of demarcation between cement and bone. These findings strongly suggested that anatomical placement of the hip centre can decrease the biomechanical stress at the cement-bone interface around the acetabular component in cemented fixation.

A variety of femoral head sizes are currently available, and the optimal size was decided by the individual surgeon's strategy. Several national joint registries reported the most common head diameter in THA is 32 mm.[53–56] The most common reason for using a large-diameter femoral head is to increase the impingement-free range of motion[68] and jumping distance required for the head to dislocate by implant impingement.[69,70] In theory, the friction torque also increases as femoral head diameter size increases, as large heads are associated with increased contact area and a longer lever arm. In a mechanical simulation model, the mean frictional torque was greater in the larger 36 mm and 40 mm diameter metal femoral heads articulating against highly cross-linked polyethylene liners, compared with 28 mm and 32 mm diameter heads.[71] Similarly, a finite element analysis of the relationship between the stress on the cement-bone interface around a cemented acetabular component and femoral head size showed that stress on the bone-cement interface increased with femoral head diameter, providing insight into the increased risk of aseptic loosening and ultimately joint failure associated with larger prosthetic femoral heads.[72,73] Although all femoral head diameters except for two patients in this study were 22 mm, 26 mm, and 28 mm, our results are congruent with these prior reports. From this standpoint, it is possible that the small difference in femoral head diameter may be responsible for increased stress on the bone-cement interface.

To the best of our knowledge, no reports have been published on the improvement of the cement-bone interface around the acetabular component. It should be noted that the rate of improvement including complete disappearance and poorly defined RLLs was 15.1% and all of them were detected within the first five years after surgery. Furthermore, there was no evidence of development until ten years after surgery. This finding suggests that the IBBC technique may provide additional physicochemical bonding because of its osteoconductive activity, and prevent the development of RLLs.

In conclusion, this retrospective review of 980 primary cemented THAs with the IBBC technique indicates that atrophic osteoarthritis based on the biological-reaction classification of Bombelli, and 26 mm and 28 mm femoral head diameter were associated with a statistically significantly greater higher risk of any RLLs. In contrast, with structural bone graft and within the true acetabular region, the risk was significantly lower. On the other hand, these prognostic factors did not affect the progression of RLLs five and ten years after THA. Interestingly, improvement of the cement-bone interface was detected in 15.1% of patients within the first five years after surgery. Identifying and recognizing these prognostic factors is important for the surgical strategy and for longevity of primary cemented acetabular fixation.

Take home message

- Acetabular bone quality, head diameter, structural bone graft and hip centre position were influenced the presence of the any radiolucent line.
- Improvement of the cement-bone interface including complete disappearance and poorly defined radiolucent lines was rarely identified around the acetabular component with the interface bioactive bone cement technique.

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