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Quarter Century Outcomes of Alumina Ceramic-on-Ceramic Total Hip Arthroplasty

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ABSTRACT

Background: Alumina ceramic-on-ceramic (CoC) bearings were widely used in total hip arthroplasty (THA) due to their superior wear resistance and inert properties, making them ideal for young, active patients who require long-lasting implants. This study aimed to synthesize findings from previous reports, providing a comprehensive follow-up of at least 25 years on the clinical and radiologic outcomes, the prevalence of osteolysis, and implant survivorship in patients undergoing primary cementless CoC THA.

Methods: We have previously reported 5- to 10-year outcomes following the implementation of third-generation alumina-on-alumina bearings in a consecutive series of 100 primary cementless THAs. This report updates those results with a minimum follow-up of 25 years. Of the original cohort, 58 patients who had 67 hips were available for the latest follow-up. Clinical assessments were performed using the Harris Hip Score and pain questionnaires. Radiographic evaluations were employed to assess implant fixation and osteolysis.

Results: At the final follow-up, the implant survival rate was an impressive 96.3%, with revision of the implant as the end point. The mean Harris Hip Score improved significantly from preoperative values to 90.1, indicating excellent functional outcomes. The incidence of ceramic-related noise increased over time, with three cases of ceramic head fractures requiring a change of bearings. Notably, the extent of stem notching observed in earlier reports did not show further progression. Radiologically, all implants demonstrated bony ingrowth with no signs of aseptic loosening or major osteolysis.

Conclusions: The long-term (minimum 25-year) follow-up of alumina-on-alumina bearings in primary cementless THA demonstrates outstanding implant survivorship, excellent functional outcomes, and minimal adverse effects over 25 years. Despite some issues like ceramic-related noise and component fractures, the overall performance of CoC bearings remains highly encouraging, particularly suitable for young, active patients. Surgeons should provide appropriate education to both potential THA candidates and patients who already have THAs with CoC bearings.

Level of Evidence: Therapeutic Level IV.

Total hip arthroplasty (THA) is a highly successful surgical procedure, providing major benefits to both patients and surgeons [1,2]. However, long-term outcomes can be compromised by mechanical failures and aseptic loosening, primarily due to osteolysis induced by wear debris particles [3,4]. To mitigate these complications, alumina-on-alumina (CoC) ceramic bearings have been introduced, known for their superior wear resistance and inert biological properties, making them particularly suitable for young, active patients requiring durable implants [5,6].

No author associated with this paper has disclosed any potential or pertinent conflicts which may be perceived to have impending conflict with this work. For full disclosure statements refer to https://doi.org/10.1016/j.arth.2024.10.009.

Ethical statement: The present study was approved from Seoul National University Hospital Institutional Review Board review.

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Numerous studies have documented the long-term success of third-generation CoC bearings, reporting excellent survival rates and minimal adverse effects [7–10]. However, these studies often involve limited follow-up periods, necessitating further research. We have previously reported results at a minimum of 5 and 10 years following the implantation of third-generation ceramic-on-ceramic (CoC) bearings (BIOLOX forte; CeramTec, Plochingen, Germany) in a consecutive series of 100 primary alumina-on-alumina cementless THAs performed in 84 patients by a single surgeon at our institution [11,12]. The purpose of this study was to provide a comprehensive follow-up of at least 25 years on the clinical and radiologic outcomes, prevalence of osteolysis, and implant survivorship in patients who had primary cementless CoC THA. Building on our previous work, which reported 5- and 10-year outcomes, we now present an updated analysis with a minimum follow-up of 25 years in the same cohort. This long-term follow-up aimed to ascertain the true longevity and performance of CoC bearings, offering insights into their suitability for young, active patients. Especially, we focused on the ceramic-related complications such as ceramic-related noises, stem neck notching, and ceramic component fractures.

Methods

Cohorts

We evaluated a consecutive series of 100 primary cementless alumina-on-alumina THAs performed between November 4, 1997, and April 30, 1998, in 84 patients. Patients who had less than 25 years of follow-up were excluded. Institutional review board approval was obtained before this study.

At a minimum of 25 years postoperatively, of the original 84 patients, 13 patients who had 17 hips died and 13 patients who had 16 hips were lost to follow-up, which left 58 patients who had 67 hips (Figure 1). Of these patients, 54 patients (62 hips) had both clinical and radiological evaluations, while 4 patients (five hips) underwent only a clinical evaluation conducted by telephone and with a questionnaire sent by mail and e-mail (Table 1). The latest clinical and radiographic evaluations were performed at a mean of 25.8 years (range, 25.0 to 26.4) and 25.6 years (range, 25.0 to 26.4), respectively, after the operation. The study group included 32 men and 26 women. The mean age of these patients at the time of the index arthroplasty was 40 years (range, 18 to 63), and the mean body mass index (BMI) was 23.6. The most common diagnosis was osteonecrosis of the femoral head (48%), followed by primary coxarthrosis or coxarthrosis after hip dysplasia (16%) (Table 2).

Operative Details

The operations were performed by one high-volume senior surgeon. The procedures were performed using either a direct lateral approach or posterolateral approach. A direct lateral approach, with

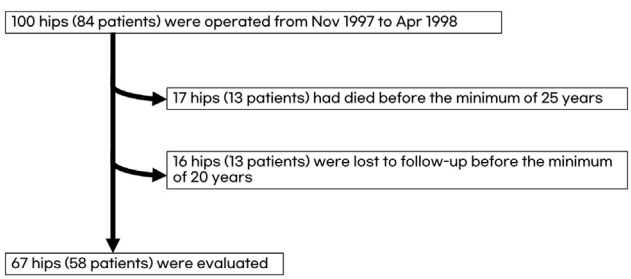

Figure 1. Flowchart of enrolled patients in this study.

Table 1
Data With a Minimum Follow-Up of 25 Years

Variable	No. of Patients	No. of Hips
Initial cohort	84	100
Died without 25-year data	13	17
Lost to follow-up before 25 years	13	16
Cohort with 25-year data	58	67
Clinical and radiographic data	54	62
Clinical data only	4	5

or without a trochanteric osteotomy, was utilized in cases of severe proximal femoral deformity, including patients who had sequelae of hip joint infection, fused hip, or sequelae of Perthes disease. The cementless acetabular component used was the Plasmacup SC (Aesculap, Tuttlingen, Germany), a hemispherical titanium cup. The cementless femoral component was the BiCONTACT (Aesculap), a slightly tapered, rectangular, collarless titanium-alloy femoral stem. A 28-mm modular alumina head (BIOLOX forte; CeramTec, Plochingen, Germany) was secured with a Morse taper, and the alumina liner (BIOLOX forte; CeramTec) was secured with a self-securing conical fit. Partial weight-bearing was allowed after 6 days, and full weight-bearing was allowed after 8 to 10 weeks. Patients were followed up at 6 weeks, 6 months, 12 months, and then annually after surgery.

Clinical and Radiological Evaluations

Clinical evaluations were performed with the use of the Harris Hip Score [13], the Western Ontario and McMaster Universities Osteoarthritis Index score [14], and a questionnaire that included items regarding any noise during daily activity.

Radiographs were evaluated by two independent observers (H.S.K. and J.J.Y.) with respect to component stability [15], radiolucent lines [11], calcar resorption [16], osteolysis [17], and loosening [18]. Zones described by Gruen et al. [19] and those described by DeLee and Charnley [20] were used to assess the location and extent of radiolucent lines and osteolysis. Osteolysis was defined as a periprosthetic cystic or scalloped lesion with a diameter exceeding 2 mm that had not been present on the immediate postoperative radiograph [17,21]. In addition, serial radiographs were reviewed for notching in the stem neck, and shoulder, which was called fretting in the previous studies [11,12].

Abduction and anteversion of the acetabular component were measured on 6-week radiographs. The abduction of the acetabular component was measured as the angle between the teardrop line and the long axis of the ellipse that projects the circular opening of the cup. We used the method described by Widmer [22] to measure anteversion.

Computed Tomography Examinations

We recommend that patients undergo a 3-dimensional computed tomography (CT) scan every 10 years after surgery [23]. Postoperative radiographs and CT scans were reviewed by two independent observers (H.S.K. and J.J.Y.) to assess the position of

Table 2
Initial Diagnosis Leading to Total Hip Arthroplasty.

Diagnosis	No. of Hips (N = 67)
Osteonecrosis of the femoral head	32
Primary coxarthrosis or coxarthrosis after hip dysplasia	11
Sequelae of hip-joint infection	7
Sequelae of Legg-Calvé-Perthes disease	6
Ankylosis of the hip joint	4
Rheumatoid arthritis	2
Miscellaneous conditions	5

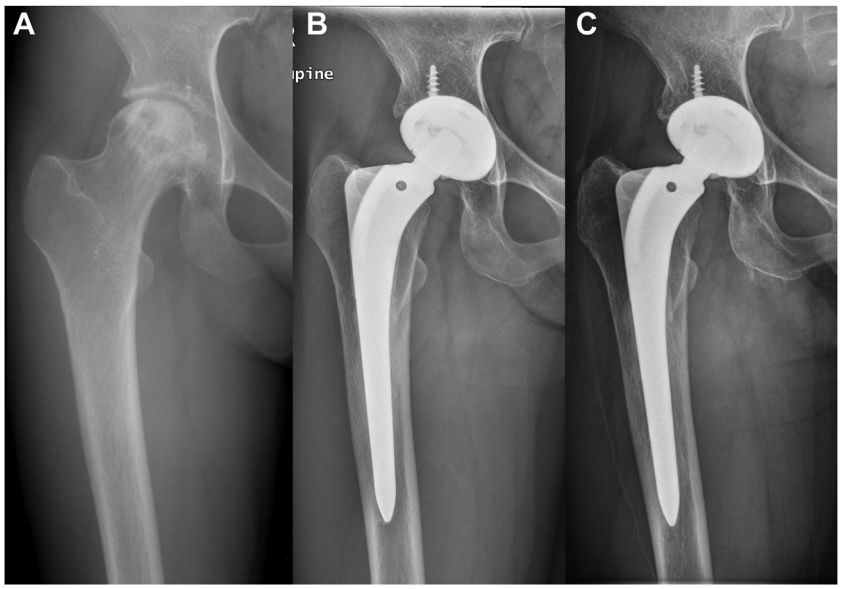

Figure 2. A 27-year-old young woman who had osteonecrosis underwent total hip arthroplasty with a 28-mm short-neck ceramic head. (A) Preoperative simple radiographs showed a collapse of right femoral head. (B and C) A hip radiograph was taken postoperative 10 years and 26 years, respectively. There is no evidence of prosthetic loosening, wear, osteolysis, or ceramic fracture.

the prosthesis, neck notch, osteolysis, loosening, and implant failure.

Data Analysis

Paired *t*-tests were used to assess the clinical outcomes. *P* values < 0.05 indicated statistical significance. We performed a Kaplan-Meier survival analysis with two end points: revision of any implant for any reason and reoperation for any reason [24]. Statistical analyses were performed using IBM Statistical Package for Social Sciences (SPSS) Statistics for Windows, version 27.0. (IBM Corp., Armonk, New York).

Results

Implant and Cup Position

A short-neck modular ceramic femoral head component was used in 34 (51%) hips. A medium-neck component was used in 28 (42%) hips and a long-neck component was used in 5 (7%) hips.

The average abduction and anteversion of the cup were 40.6° (range, 29 to 48) and 18.4° (range, 8 to 28), respectively.

Clinical and Radiological Outcomes

The mean preoperative Harris Hip Score for the entire series was 59 points (range, 30 to 84), and the mean postoperative score for the 67 hips with a minimum follow-up of 25 years was 90 points (range, 49 to 100, $P < 0.001$). At the last follow-up evaluation, the mean Western Ontario and McMaster Universities Osteoarthritis Index score was 15.3 points (range, 0 to 38).

All 62 hips assessed radiographically exhibited bone ingrowth, with no signs of loosening observed at the latest follow-up. Radiolucent lines were identified in 10 hips (11%), specifically in Gruen zones 3, 4, or 5, at a minimum of 5 years [11]; however, there was no progression noted at the most recent follow-up. The frequent occurrence of rounding off the sharp medial edge of the resected femoral neck was observed at a minimum of 10 years [12], and no changes were noted in the latest radiographs. No further calcar resorption was detected in any of the hips. Additionally, no periprosthetic osteolysis was detected around any cups or stems on standard radiographs (Figure 2).

Complications

There were two dislocations that occurred during the follow-up period. A dislocation involved the right hip and occurred 7.3 years postoperatively in a patient and had osteonecrosis and had undergone bilateral THA via a posterolateral approach. An open reduction was performed without exchanging the bearing, and no recurrence of dislocation was observed. The other dislocation occurred 12 years postoperatively following a fall in a patient who had undergone THA via a posterolateral approach due to osteonecrosis of the femoral head. This patient was treated with closed reduction and abduction bracing, with no further dislocations reported during the follow-up period.

There were four patients who experienced periprosthetic femoral fractures. A patient sustained a fracture around a well-fixed stem 11 months postoperatively, resulting in abrupt stem subsidence. This fracture healed with nonoperative treatment, and no further subsidence was detected. Another fracture occurred 6.2 years postoperatively after a fall from a height of 3 meters. This fracture, also around a well-fixed stem, was treated with open reduction and internal fixation using cable and wire, and it completely healed without additional procedures. There were two other fractures that occurred due to slipdown. A fracture occurred around the greater trochanter without displacement 19.2 years postoperatively and was treated conservatively, achieving bony union after 3 months without additional procedures. The other fracture occurred 24.6 years postoperatively around a well-fixed stem. Although open reduction with internal fixation was initially planned, conservative treatment was chosen due to severe hemothorax. The patient was administered daily teriparatide, resulting in fracture healing after 2 months.

A periprosthetic joint infection occurred in a well-functioning hip at 21.2 years postoperatively. The patient was treated with

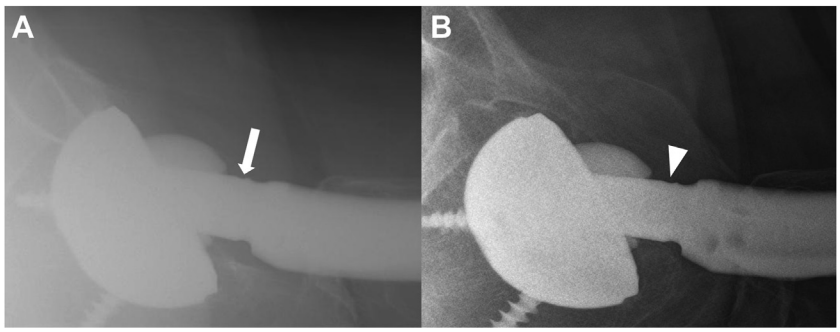

Figure 3. (A) A simple radiograph with a trans-lateral view of total hip arthroplasty at 7.5 years postoperatively showing stem notching of the anterior aspect of the neck (arrow). (B) After 10 years, the notching did not progress further (arrowhead).

debridement while retaining the implant. Following the debridement, intravenous antibiotics were administered for 6 weeks, followed by an additional 6 weeks of oral antibiotic suppression. The patient remained symptom-free during the follow-up period.

Ceramic-Related Noise

Of the 67 hips, 17 (25%) were associated with ceramic-related noise (10 hips with intermittent clicking sound, five hips with squeaking, and two hips with grinding). None of these hips were associated with pain or any modification of daily activities. Most of the noises occurred when the patient was rising from a squatting position. No significant associations were found between hip noise and patient-related or prosthesis-related factors, including age, sex, weight, height, BMI, position of the implant, or neck length of the femoral component. In hips with noise and without noise, there was no significant difference in cup abduction (40.1 versus 40.7°, $P = 0.238$) or anteversion (18.6 versus 18.4°, $P = 0.495$). A patient reported an audible clicking noise during squatting. This noise was reproduced in outpatient clinic evaluation (Supplementary Audio).

Stem Notching

Notching, also referred to as fretting in previous studies was detected in seven hips, with six of these cases observed at the 10-year follow-up. The notches were located on the anterior portion of the stem neck in all cases. The mean interval from the index surgery to the appearance of notching was 8.3 years (range, 4.7 to 15.2). The depth of notching was closely monitored in serial radiographs, and no further progression or deepening of the notches was evident at the latest follow-up (Figure 3).

Ceramic Component Fractures

In total, three ceramic head fractures and one liner fracture occurred in this series [11,12]. A patient sustained a fracture of the alumina femoral head with a 28-mm short neck and a peripheral chip fracture on the posterosuperior portion of the alumina acetabular insert following a major motor vehicle accident that occurred 4.2 years postoperatively. Intraoperative examination showed damage to the inferior portion of the summit of the Morse taper of the well-fixed stem. After extensive debridement and synovectomy to remove as much ceramic debris as possible, a new cobalt-chromium femoral head and a polyethylene insert were implanted, while the stem and cup were left in place [11].

Another fracture occurred without trauma 11.3 years after the initial surgery. The patient reported a crunching sensation when rising from the toilet, and radiographs taken 2 days later confirmed the fracture. The fractured alumina femoral component had a 28-mm short neck. We replaced the bearing surface with a cobalt-chromium femoral head and polyethylene insert, leaving the well-fixed stem and cup in place [12]. During follow-up, the patient experienced discomfort, and radiologic examination confirmed severe metallosis and dislocation 5.8 years after the revision surgery. Thorough debridement was performed, and the bearing was changed to a 4th-generation ceramic-on-polyethylene (CoP) bearing. The patient remained symptom-free until the latest follow-up [25].

The other patient fell from a pullup bar 23.4 years postoperatively and reported immediate pain. The fracture was confirmed in the emergency department. The fractured alumina femoral head had a 28-mm medium neck. In this patient, we replaced the bearing surface with a 4th-generation ceramic-on-ceramic bearing instead of a metal-on-polyethylene bearing, due to previously reported catastrophic complications of metallosis in patients treated with metal-on-polyethylene bearings following ceramic component fractures [25,26].

CT Evaluation

The CT scans were performed on 20 (29.9%) of the 67 hips to detect possible complications such as osteolysis, undetected stem notching, and occult ceramic component fractures. No complications were identified in the CT scans of this cohort.

Reoperation and Survival Analyses

Overall, there were six reoperations during the follow-up period (Table 3). These included three implant revisions for fracture of the alumina femoral head, one reoperation for treating a periprosthetic fracture, one for treating a dislocation, and one for treating periprosthetic joint infection.

Kaplan-Meier survivorship analysis based on 67 hips at risk, with any implant revision for any reason as the end point, revealed a cumulative survival rate of 96.3% (95% confidence interval: 92.2 to 100) at 25 years. With a reoperation for any reason as the end point, the 25-year survival rate was 92.8% (95% confidence interval: 87.1 to 98.5) (Figure 4).

Discussion

This study demonstrates exceptional long-term outcomes for cementless, third-generation alumina CoC THA, with an excellent survival rate. Owing to their superior biomechanical properties, ceramic bearings have exhibited lower incidences of osteolysis compared to conventional polyethylene bearings, thus gaining

Table 3
Complications and Revisions After Third-Generation Ceramic-on-Ceramic Total Hip Arthroplasty.

Complications	Number (Number of Reoperations)
Dislocation	2 (1)
Periprosthetic femoral fracture	4 (1)
Periprosthetic joint infection	1 (1)
Ceramic head fracture	3 (3)
Ceramic liner fracture	0 (0)
Noise	17 (0)
Acetabular osteolysis	0 (0)

popularity, particularly among younger and more active patients [6]. However, ceramic-related complications have become more apparent with longer follow-up periods [7,27,28]. Some of these complications necessitate revision surgery, underscoring the importance of accurately understanding the incidence, natural progression, and appropriate management of ceramic-related issues. To our knowledge, this study provides the longest follow-up of third-generation CoC articulations to date, detailing the prevalence of hip noise, the progression of stem neck notching, and the survivorship of cementless THA with alumina ceramic bearings over a minimum of 25 years.

Ceramic Component Fracture

Ceramic component fracture remains an unresolved issue with this particular bearing type, often necessitating immediate revision surgeries upon occurrence [25,29,30]. Previous long-term follow-up studies have rarely reported ceramic component fractures. Kim et al. and Solarino et al. reported no ceramic component fractures in cohorts of 1,131 hips with a minimum follow-up of 10 years and 172 hips with a minimum follow-up of 5 years, respectively [9,10]. Xu et al. reported one case of ceramic head fracture and one case of ceramic liner fracture among 100 hips with a minimum follow-up of 20 years [7]. The low incidence of ceramic component fractures likely explains the rarity and variation in reported fractures. In a study using registry data, Howard et al. found revisions for fractures linked to 38 of 31,982 (0.119%) Biolox Forte heads and 35 of 31,258 (0.112%) Biolox Forte liners [31]. In this study, the incidence of fracture was even lower in bearings using Biolox Delta, a zirconia-toughened alumina ceramic. This generation of ceramic demonstrated high resistance to fracture, maintaining a burst strength of 52 kN even after hydrothermal aging and repetitive loading [32]. The durability of zirconia-toughened alumina ceramics is attributed to their transformation toughening mechanism, which increases fracture toughness under stress.

In our study, three fractures occurred in 67 hips at 4.2, 11.3, and 23.4 years postoperatively, indicating no specific time preference for ceramic component fractures. Similarly, our unpublished data suggest that ceramic component fractures can occur at any point during the follow-up period and without traumatic events. A possible reason for the fractures that occurred in a longer-term follow-up could be repetitive stress on the short bore length of the 28-mm alumina head, as highlighted by Koo et al. [29] Therefore, appropriate education during follow-up is essential for patients who had CoC THA.

The choice of bearing after a ceramic component fracture remains a major concern. Residual ceramic particles could lead to the rapid onset of metallosis when metal-on-polyethylene bearings were used, necessitating additional revision surgeries [25,26]. In contrast, CoC bearings have demonstrated superior outcomes, with minimal wear, no metallosis, and longer implant survival [25]. Traina et al. also found that revision using CoC or CoP bearings after ceramic fractures significantly reduced the risk of failure, with CoC being the preferred option to avoid third-body wear from residual ceramic particles [33]. Based on these findings, selecting CoC or CoP bearings in cases of ceramic component fracture may help prevent complications and reduce the likelihood of further surgical intervention.

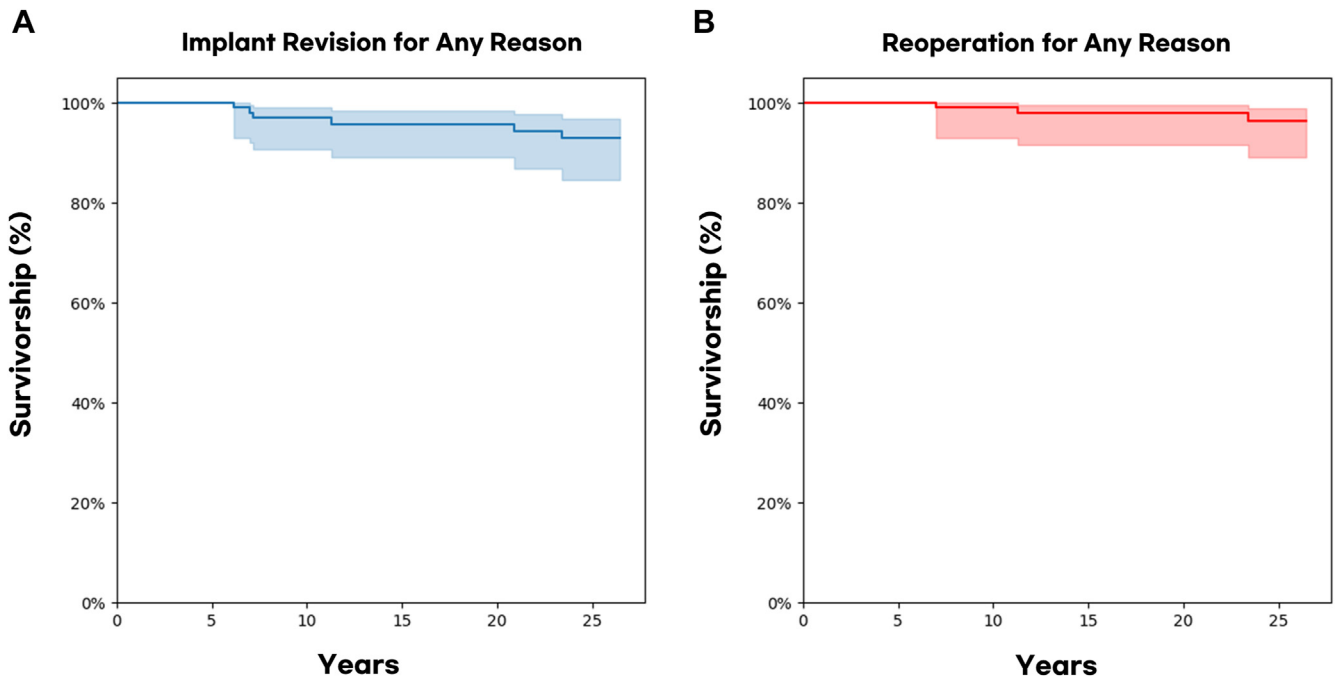

Figure 4. Kaplan–Meier curve (A) with implant revision for any reason as the end point and (B) with reoperation for any reason as the end point.

Ceramic-Related Noise

Ceramic-related noise has been consistently documented over short- and mid-term follow-up periods, though the reported proportion of affected patients varies widely. Taniguchi et al. followed 62 patients for a median of 14 years, demonstrating that squeaking increased over time and was self-reported by 53% of patients who had third-generation alumina-on-alumina bearings, indicating lower than expected survivorship in this cohort [27]. Kim et al. reported that 6% (27 of 456) of patients noted noise during a median follow-up of 13 years, finding no differences between hips with and without noise regarding ceramic head size, neck length, BMI, and implant position [34]. Shang et al. observed that 28% of 4th-generation CoC hips experienced squeaking in 130 (110 patients) primary THAs with 4th-generation CoC bearings at a mean follow-up of 10.5 years, with a mean onset of 5.7 years [35]. Park et al. reported that the cumulative incidence of audible noise increased from 6.4% (48 of 749) to 8.2% (59 of 716) during a mean follow-up of 12 years [36]. Zhang et al. found that 31.6% (55 of 174 hips) reported noise at a mean follow-up of 28 months, with lower age and BMI being related to the noise [37]. In our study, the cumulative incidence increased from 13 of 88 hips with a minimum follow-up of 10 years to 17 (25%) of 67 hips. However, patients did not complain about the noise, and no revision surgeries were performed due to the noise.

Stem Neck Notching

Stem neck notching, resulting from impingement between the stem neck and ceramic liner, has been previously documented. Kim et al. followed 456 patients for a minimum of 10 years and reported an 11% incidence of stem neck notching. These notches appeared at a median of 3 years (range, 10 months to 8 years) postoperatively [34]. Another study detected notches in 23.4% of patients, first observed between 8 months and 13.2 years after surgery. This study revealed that low abduction and high anteversion of the cup were associated with the notches. No new notches were detected after 14 years postoperatively, although changes in the notches were rarely reported [38]. In our study, the incidence of notching was comparable to previous studies, with notches found in 7 (11.3%) of the 62 hips. Close observation of serial radiographs showed no further progression at the latest follow-up. Current literature indicates that notches are primarily detected within the first 10 years postoperatively and remain unchanged thereafter. Additionally, ceramic-related noise may be associated with notches but not with ceramic component fractures. A larger cohort study may be warranted to further investigate these findings.

Osteolysis

In our cohort, we did not find any osteolysis on either simple radiographs or CT evaluations. Although rare, peri-implant osteolysis in THA using CoC bearings has been reported in some studies. Kim et al. observed acetabular osteolysis in two cases during long-term follow-up, with one patient requiring a bone graft [39]. Recently, Ko et al. reported three cases of acetabular osteolysis and one case of femoral osteolysis among their patients who had more than 20 years of follow-up, though none of these patients exhibited symptoms and required additional surgeries [23]. These findings suggest that routine CT scans for all patients in this cohort may not be necessary. Instead, long-term CT evaluations should be selectively performed for patients presenting with relevant clinical symptoms.

Potential Limitations

This study has several inherent limitations. It is a single-center study with a small number of patients, all treated with the same implant by one experienced surgeon. Moreover, we experienced a 33% loss in follow-up after 25 years, which we believe is acceptable given the patients' advancing age and the large geographical area served by our hospital. However, the high proportion of follow-up losses may introduce selection bias, potentially skewing results toward individuals who had fewer complications or higher compliance. We were unable to achieve complete radiographic and clinical follow-up, primarily due to the patient's age and the distance from the hospital. Nonetheless, the analysis of clinical outcomes from the larger cohort with complete follow-up was still comparable. Additionally, our study was conducted in an East Asian country, so the proportion of diagnoses requiring THA and demographic data, including BMI, may differ from those in Western countries.

Conclusions

The third-generation ceramic-on-ceramic (CoC) bearings used for primary cementless THA showed excellent clinical results and implant survival rates at a minimum of 25 years postoperatively. Ceramic-on-ceramic bearing is a viable option for young, active patients. However, the risk of ceramic component fracture persists, which requires immediate revision surgery. While the incidence of ceramic-related noise has increased, it has not adversely affected implant survival or functional outcomes. Notably, stem notching, which predominantly occurred within the first 10 years postoperatively, showed no progression in subsequent follow-ups. Based on these findings, surgeons should provide appropriate education to both potential THA candidates and patients who already have THAs with CoC bearings.

CRediT authorship contribution statement

Hong Seok Kim: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Jeong Joon Yoo:** Writing – review & editing, Validation, Supervision, Conceptualization.

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