CLINICAL ARTICLE

Fourth-Generation Ceramic-on-Ceramic THA in Patients with Ankylosing Spondylitis: A Minimum 10-Year Follow-Up

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Abstract

Objective: To report the long-term outcomes of total hip arthroplasty (THA) with fourth-generation ceramic-on-ceramic (CoC) bearing in patients with ankylosing spondylitis (AS).

Methods: We retrospectively identified 180 primary THAs performed in 110 patients with AS, including 100 (90.9%) men and 10 women (9.1%), from 2009 to 2011.The mean age of the patients at surgery was 33 years (range, 16 to 65 years). Cementless prostheses with fourth-generation CoC bearings were used in all patients. Survivorship of the implants and postoperative complications were calculated. Functional improvement was assessed by the hip flexion-extension range of motion (ROM) and Harris hip score (HHS). A special noise assessment questionnaire was performed at the last follow-up. The cumulative incidence of noise was calculated by the Kaplan–Meier method with 95% confidence intervals (CIs). Clinical characteristics and functional outcomes were compared in the hips with noise to those without noise.

Results: The mean follow-up was 11 years (range, 10 to 12 years), and survivorship of the implants was 99.4% at the most recent follow-up. The complications included dislocation (one hip, 0.6%), periprosthetic joint infection (one hip, 0.6%), mild to moderate pain (five hips, 2.8%), heterotopic ossification (12 hips, 6.7%), and noise (52 hips, 28.9%). The flexion-extension ROM improved significantly with a median from 10° (range, 0 ~ 130°) to 100° (30 ~ 130°) after THA ($p < 0.001$), and the HHS increased significantly from 41 ± 20 to 90 ± 8 ($p < 0.001$). The cumulative incidence of noise at 0.5, 5, and 10 years was 6.1% (95% CI, 2.6 ~ 9.6), 16.7% (95% CI, 11.2 ~ 22.1), and 28.9% (95% CI, 22.2 ~ 35.5), respectively, and that of squeaking at 0.5, 5, and 10 years was 4.4% (95% CI, 1.4 ~ 7.4), 13.3% (95% CI, 8.4 ~ 18.3), and 23.9% (95% CI, 17.6 ~ 30.1), respectively. None of the patients with noise generation in the hip reported it affecting daily activities or causing dissatisfaction. No differences in age, sex, BMI, disease duration, bilateral THA, the frequency of bony ankylosis, the proportion of using a 36-mm-diameter femoral head, pre/postoperative flexion-extension ROM, or pre/postoperative HHS were found between hips with noise and those without noise ($p > 0.05$).

Conclusion: THAs with fourth-generation CoC bearings exhibit excellent long-term survival and clinical outcomes in patients with AS, with a very low dislocation rate. The incidence of noise associated with CoC bearings in THA performed in patients increases over time, but it does not affect postoperative hip function or daily activities.

Key words: ankylosing spondylitis; ceramic-on-ceramic bearing; complications; survivorship; total hip arthroplasty

Introduction

Ankylosing spondylitis (AS) is an autoimmune disease that initially affects the sacroiliac joints, with subsequent progression to the spine and probably some other peripheral joints. The prevalence of AS varies between continents, with a mean per 10,000 (from 36 eligible studies)

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of 23.8 in Europe, 16.7 in Asia, 31.9 in North America, 10.2 in Latin America, and 7.4 in Africa[1]. Typical symptoms of AS are spinal stiffness and loss of spinal mobility, with ankylosis visible on conventional radiographs after some months to many years. Generally, peripheral arthritis mainly affects the lower limbs, but not exclusively. The hip is the peripheral joint that is commonly involved, resulting in severe functional disabilities and deformities due to gradually progressive stiffness or ankylosis[2]. The previously reported prevalence of clinical hip involvement varies from 19% to 36% in patients with AS, the relatively wide range of which could be explained by the different definitions that are used to describe the investigated population and by different definitions of hip involvement[3].

Ideally, treatment strategies should include early identification of hip involvement and prevention of hip impairment. Two Chinese studies reported the results of early detection for hip involvement in AS based on magnetic resonance imaging (MRI). One study found that the proportion of AS patients with hip inflammatory changes detected by MRI was much higher than that detected by radiographic changes or clinical symptoms[4], and the other suggested that AS patients with symptoms or risk factors for hip involvement should undergo hip MRI to identify lesions in the early stage[5]. In the prevention of hip damage, only a few studies have observed a clinical improvement in hip symptoms and function or stabilized radiographic progression of hip arthritis after treatment with tumor necrosis factor (TNF) inhibitors[6–8]. However, there is a paucity of data with a high level of evidence on the effectiveness of therapeutic strategies with TNF inhibitors for hip involvement in AS. Hip replacement is still required when hip pain becomes severe or when restricted movements adversely affect function.

Total hip arthroplasty (THA) has shown satisfactory results in relieving pain, correcting deformities, and improving hip function and quality of life in the treatment of end-stage arthritis in AS[9–16]. Disease onset at an early age has been considered a high risk of developing hip disease in AS and consequently represents a greater need for THA[2]. Commonly, these patients are relatively young, and their issues tend to involve functional, postural, and locomotive problems rather than pain[10]. Moreover, patients with AS have varying degrees of hip deformity, such as flexion contracture, stiffness in various positions of internal or external rotation, and complete bony ankylosis, which pose great challenges to surgical treatment and postoperative clinical care. Given this increased difficulty of primary THA due to the complex deformity in hips, several studies reported the results of bilateral synchronous THA and highlighted the surgical techniques for the treatment of severe hip ankylosis in patients with AS[12,16]. Preoperative planning should take into account the hip-spine interplay, in which the overall spinal sagittal balance changes with decreased lumbar lordosis and increased thoracic kyphosis due to progressive spinal ankylosis, leading to increased posterior pelvic tilt and acetabular anteversion[17]. Therefore, for successful surgical management, the primary preoperative preparation should fully account for the technical difficulties of performing THA in this special population. However, more importantly, to obtain good long-term clinical outcomes, the design of prostheses is the top priority.

Although a wide variety of attempts have been made to prolong the lifespan of prostheses, implant longevity remains a central issue in long-term follow-up, and revision surgery may still be required due to the young age of patients with AS at the time of undergoing primary THA[18]. The main reported causes for revision THA include polyethylene wear, osteolysis, and aseptic loosening[18–21], of which the first two are both results of failure on bearing surfaces. Reliable fixation has been achieved at the bone-prosthesis interface with the application of biologically fixed prostheses, but wear on the joint surface still limits the lifespan of the artificial hip. Thus, ceramic-on-ceramic (CoC) bearings have become an option available to surgeons due to their decreased wear and lower rates of osteolytic lesions when compared with those of metal-on-conventional polyethylene[22]. In recent years, studies have shown that modern cementless THA with CoC bearings exhibits successful mid- to long-term survivorship and functional outcomes in young patients[19,21,23–25]. However, no study to date has reported the long-term clinical outcomes of such implants in patients with AS, who also typically undergo THA at a young age and with considerable complexities in hip deformity. We hypothesized that THAs with fourth-generation CoC bearings could exhibit satisfactory results in this particular population. The aims of this study were as follows: (i)to evaluate the long-term clinical outcomes and common complications in patients with AS with advanced hip involvement who underwent modern cementless THA with fourth-generation CoC bearings; and (ii) to conduct a specific assessment of noise generation in the hips treated by THA with such bearings.

Materials and Methods

Patients

After obtaining approval from our institutional review board (Approval No. of Ethics Committee: S2021-066-01), we retrospectively reviewed all 130 patients with AS who underwent primary THA at our institution from January 2009 to October 2011. AS diagnosis was based on the 1984 modified New York criteria[26]. The inclusion criteria were as follows: (i) patients with an identified diagnosis of AS with advanced hip involvement; and (ii) patients who had definite indications of THA due to refractory pain or disability and radiographic evidence of structural damage in the hips, independent of age[27]. The exclusion criteria were as follows: (i) lost to follow-up (16 patients); (ii) simultaneous involvement in both hips and knees because the postoperative hip function may be affected by the involved knee (two patients); (iii) bedridden patients due to cerebral hemorrhage (one patient); and (iv) died of cancer (one patient). Following these exclusions, the remaining 110 patients (180 hips) were

enrolled in this retrospective study. The overall follow-up rate was 84.6%.

Surgical Techniques and Postoperative Care

All procedures were performed by four experienced senior surgeons at a single institution. General anesthesia and the posterolateral approach were used, and a cementless hip prosthesis with a BIOLOX® Delta CoC bearing (CeramTec, Germany) was implanted in the patients. Cementless acetabular components (Betacup, LINK, Germany) were implanted by using the press-fit technique with no adjunctive screws. Cementless femoral components (Ribbed or LCU, LINK, Germany) were implanted by the press-fit technique after reaming the femoral medullary cavity. Oral indomethacin was used for the prevention of heterotopic ossification (HO). The patients were allowed to have controlled, early weight-bearing with the support of an assistive device on day 2 after the operation. According to the postoperative situation and outpatient review, full weight-bearing was permitted gradually after a minimum of 6~8 weeks.

Survivorship and Complications

Implant survivorship was defined as free from any revision surgery. The postoperative complications related to undergoing THA (dislocation, periprosthetic joint infection [PJI], pain, and HO) and the use of ceramic components (fracture and noise) were recorded. Aseptic loosening and HO were evaluated by comparing the anteroposterior pelvis and lateral hip radiographs taken after THA and the most recent follow-up. The acetabular component was assessed based on the demarcation of the zones described by DeLee and Charnley[28], and the femoral side was assessed by the zones described by Gruen *et al.*[29]. HO was determined by the Brooker classifications[30].

Functional Assessments

Functional outcomes were assessed by the hip flexion-extension range of motion (ROM) and Harris hip score (HHS)[31]. Assessments of the functional outcomes were performed by an independent clinical researcher who did not take part in the treatment. If patients were unable to return to the institution for an in-person follow-up, they were asked to complete the survey by telephone and send in radiographs.

Noise Assessment

A specific questionnaire of noise assessment, including the type, time of the first occurrence, frequency, intensity, activities that triggered the production of noise, and whether it affected daily life or not, was performed at the last follow-up[32]. The time intervals from surgery to noise generation were recorded with the time of patient-reported noise as an endpoint, and its cumulative incidence over time was calculated. Clinical characteristics and functional outcomes in the hips with noise were compared with those without noise.

Statistical Analysis

Continuous variables are expressed as the means±standard deviations (SDs) or medians (minimum to maximum) depending on whether the data conformed to a normal distribution. Student's t test or the nonparametric Mann–Whitney U test was used to compare the continuous variables. Chi-squared or Fisher's exact tests were used to compare the categorical and dichotomous variables. The cumulative incidence of noise was assessed by the Kaplan–Meier method with 95% confidence intervals (CIs). All statistical analyses were performed with R version 4.04 (R Core Team, R Foundation for Statistical Computing, Vienna, Austria) and IBM SPSS Statistics for Windows, version 25.0 (IBM, Armonk, NY, USA). $p < 0.05$ was considered statistically significant.

Results

General Results

There were 100 (90.9%) men and 10 (9.1%) women in this study. The age at surgery was 33 ± 9 years (range, 16 to 65 years), and the disease duration was 11 ± 6 years (range, 0.5 to 40 years). The body mass index (BMI) was 22.1 ± 4.4 kg/m^2 (range, 14.2 to 36.4 kg/m^2). There were 78 (43.3%) hips with complete ankylosis. Bilateral THA was performed in 70 (63.6%) patients, and unilateral THA was performed in 40 (36.4%) patients. Ninety-two (51.1%) and 88 (48.9%) THAs were performed on the left and right sides, respectively. Femoral heads with diameters of 36 mm and 28 mm were used in 177 (98.3%) and three (1.7%) hips, respectively. (Table 1).

Functional Improvement and Radiographic Evaluation

The mean follow-up was 11 years (range, 10 to 12 years). At the most recent follow-up, the flexion-extension ROM improved significantly, with a median from 10° (range, 0 ~ 130°) to 100° (range, 30 ~ 130°) after THA ($Z = -13.965$, $p < 0.001$). Similarly, the HHS increased significantly

TABLE 1 Demographics and basic data

	Values	Range
Patients (n)	110	
Age at surgery (years)	33 ± 9	16 to 65
Male (n, %)	100 (90.9%)	
BMI (kg/m^2)	22.1 ± 4.4	14.2 to 36.4
Disease duration (years)	10	1 to 30
Patients undergoing bilateral THA (n, %)	70 (63.6%)	
Hips (n)	180	
THA on the right side (n, %)	92 (51.1%)	
Complete ankylosis (n, %)	78 (43.3%)	
36-mm-diameter femoral head (n, %)	177 (98.3%)	

Abbreviations: AS, ankylosing spondylitis; BMI, body mass index; THA, total hip arthroplasty.

Table 2 Functional outcomes of the patients

	Preoperative	Postoperative	t or Z	*p* Value
Flexion-extension ROM(°)	10 (0 to 130)	100 (30 to 130)	−13.965†	<0.001*
Harris hip score	41 ± 20 (4 ~ 78)	90 ± 8 (28 ~ 89)	−26.579‡	<0.001*

Note: The continuous variables are presented as the median (minimum to maximum) or mean ± standard deviation (range).; Abbriations: AS, ankylosing spondylitis; THA, total hip arthroplasty; ROM, range of motion.; * $p < 0.05$ represents statistical significance.; † Represent the Z value.; ‡ Represent the t value.

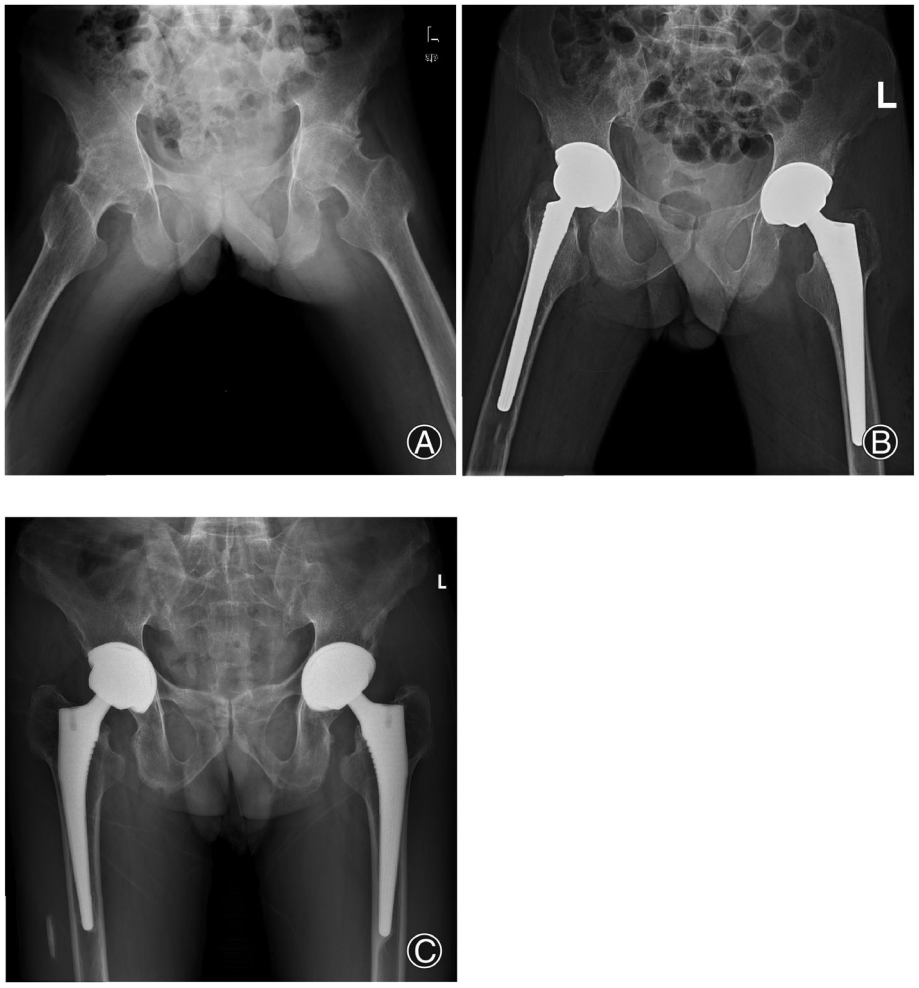

FIGURE 1 Preoperative (A), postoperative (B), and postoperative 10 years (C) radiographs of a 31-year-old male AS patient, who had bilateral hip ankylosis at a position of 30° flexion, 25° abduction, and 15° external rotation before THA (A). The right hip still had a certain degree of external rotation the next day after THA (B), and the external rotation had been completely corrected at 10-year follow-up (C).

from 41 ± 20 (range, 4 ~ 78) to 90 ± 8 (range, 28 ~ 89) (t = −26.579, $p < 0.001$) (Table 2). During the follow-up, none of the hips showed osteolysis, component loosening, or fracture of ceramic components. The radiographic outcomes of a typical patient with AS with hip ankylosis who underwent bilateral THA are shown in Figure 1.

Survivorship and Complications

Implant survivorship was 99.4% at a minimum follow-up of 10 years. The main postoperative complications included dislocation (one hip, 0.6%; posterior dislocation of the right hip 3 days after the operation,which was treated successfully by closed reduction), PJI (one hip, 0.6%; existing sinus tract communicating with the joint), mild to moderate pain (five hips, 2.8%; occurred during weight-bearing or squatting), HO (12 hips, 6.7%), and noise (52 hips, 28.9%; with squeaking in 43 and clicking in nine patients) in the hips. Five patients (4.5%) were still dependent on crutches to walk after the operation, and two of them were due to the forward movement of the center of gravity caused by kyphosis.

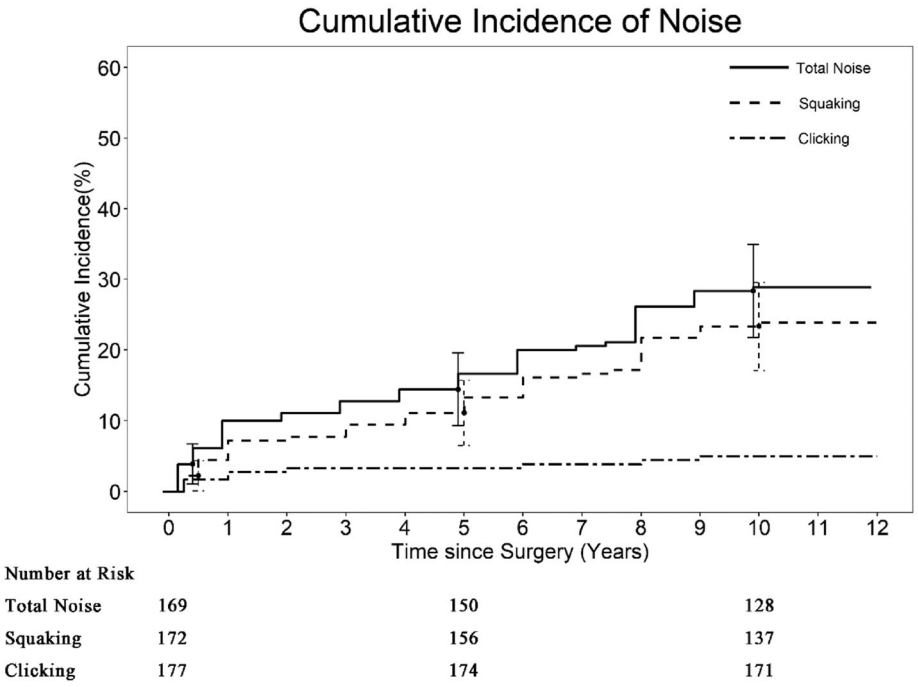

FIGURE 2 The cumulative incidence of noise over time.

TABLE 3 Comparison between hips with noise and those without noise

Parameters	Noise hip (n = 52)	No noise hip (n = 128)	t, Z, or χ^2	*p* value
Baseline characteristics				
Age (years)	33 ± 7 (20 ~ 49)	32 ± 10 (16 ~ 65)	−0.300†	0.765
Male (n, %)	51 (98.1%)	114 (89.1%)	3.934‡	0.070
BMI (kg/m^2)	22.6 ± 4.1 (15.1 ~ 29.1)	22.0 ± 4.6 (14.2 ~ 36.4)	−0.902†	0.368
Disease duration (years)	10 ± 7 (2 ~ 25)	11 ± 6 (1 ~ 30)	1.206†	0.403
Bilateral THA (n, %)	42 (80.7%)	98 (76.6%)	0.379‡	0.538
Bony ankylosis (n, %)	23 (44.2%)	55 (43.0%)	0.024‡	0.877
36-mm diameter femoral head (n, %)	50 (96.2%)	127 (99.2%)	2.119‡	0.201
Preoperative hip function				
Flexion-extension ROM(°)	5 (0 to 130)	10 (0 to 130)	−0.349§	0.727
HHS	38 ± 22 (4 ~ 78)	42 ± 20 (4 ~ 71)	0.951†	0.344
Postoperative hip function				
Flexion-extension ROM(°)	100 (80 to 130)	100 (30 to 130)	−0.827§	0.408
HHS	90 ± 5 (76 ~ 97)	90 ± 10 (28 ~ 98)	0.334†	0.739

Note: The continuous variables are presented as the mean ± standard deviation (range) or median (minimum to maximum).; Abbreviations: HHS, Harris hip score; ROM, range of motion; THA, total hip arthroplasty.; † Represent t value.; ‡ Represent χ^2 value.; § Represent Z value.

Noise Assessment

The cumulative incidence of noise at 0.5, 5, and 10 years postoperatively was 6.1% (95% CI, 2.6 ~ 9.6), 16.7% (95% CI, 11.2 ~ 22.1), and 28.9% (95% CI, 22.2 ~ 35.5), respectively. The cumulative incidence of squeaking at 0.5, 5, and 10 years postoperatively was 4.4% (95% CI, 1.4 ~ 7.4), 13.3% (95% CI, 8.4 ~ 18.3), and 23.9% (95% CI, 17.6 ~ 30.1), respectively (Figure 2). None of the patients with noise generation in the hip reported it affecting their daily activities or causing dissatisfaction. Of all the hips with noise, there were 43 (82.7%) with squeaking and nine (17.3%) with clicking. No differences in age, sex, BMI, disease duration, bilateral THA, frequency of bony ankylosis, proportion of hips using a 36-mm-diameter femoral head, pre/postoperative flexion-extension ROM, or pre/postoperative HHS were found between hips with noise and those without noise ($p > 0.05$) (Table 3).

Discussion

To the best of our knowledge, this is the first study reporting long-term outcomes in patients with AS with advanced hip involvement who underwent modern

cementless THA with fourth-generation CoC bearings. Implant survivorship was 99.4% at a minimum follow-up of 10 years, with a very low dislocation rate (0.6%). Significant functional improvement was observed in patients after THA. The incidence of noise and squeaking increased over time, with cumulative incidences of 28.9% and 23.9% at 10 years, respectively.

Survivorship and Functional Improvement

Previous studies have shown satisfactory results of cementless THA in patients with AS[10–15]. Bhan *et al.* reported 92 hips undergoing cementless THA in 54 patients with AS with an average of 8.5 years of follow-up and revealed 98.8% and 85.8% survival at 5 and 8.5 years, respectively[10]. Although encouraging outcomes have been achieved at the bone-implant interface, the longevity of THA is still limited by wear of the articulating surfaces. In particular, conventional polyethylene wear and osteolysis, usually the results of bearing surface failure, have been shown to be common causes for THA revision[18,33]. The CoC bearing has an extremely hard composition, which allows higher resistance to wear and scratching, and itshydrophilic properties could minimize frictional forces[34]. As aforementioned, cementless THAs with CoC bearings have shown successful mid- to long-term survivorship and functional outcomes in young patients[19,21,23–25]. Similarly, cementless implants with Delta CoC bearings exhibit satisfactory functional outcomes in patients with AS. Implant survivorship was 99.4% at a minimum follow-up of 10 years, with only one hip being scheduled for revision surgery due to PJI. Meanwhile, the median flexion-extension ROM increased from 10° to 100°, and the mean HHS showed the same improvement from 41 before to 90 after surgery. The results are comparable to those reported in previous studies[9–15]. Therefore, given the greatly increased complexity of end-stage arthritis in patients with AS compared with patients with other common hip diseases, our result indicates that modern cementless THA with fourth-generation CoC bearings can be used as a preferred treatment option.

Complications and Prevention

Previously reported dislocation rates after primary THA in patients with AS range from 2% to 4% at 10 and 9 years of follow-up, respectively[10,15]. A relatively early study revealed that AS increases the risk of prosthetic hip dislocation after THA with a 1.7 relative risk of dislocation at 2 years after primary THA when compared with a matched cohort without spondyloarthropathy[35]. However, a recent study reported a low rate of dislocation with a cumulative incidence of 1.9% at 5 years and 2.9% at 20 years[17]. The dislocation rate in this study was only 0.6% at 10 years. Posterior dislocation occurred at the right hip 3 days after the operation in one patient undergoing bilateral THA and was treated successfully by closed reduction. There are several possible explanations for the lower dislocation rate. First, the overall center of gravity adjustment ability is decreased due to the loss of spinopelvic coordinated motion, which makes the hip ROM relatively limited compared with that in patients without AS and results in difficulty achieving the extreme locomotion required by dislocation. Second, we suggest that a spinal corrective operation should be performed prior to THA in patients with AS to obtain better sagittal balance, unless the hip flexion contracture deformity is too severe to perform spinal osteotomy[36]. When the degree of spine deformity does not require a corrective operation, the implantation of the acetabular component should consider modestly increasing the anteversion angle to prevent anterior impingement and posterior dislocation. This is because the ability of pelvic retroversion is lost from the standing to sitting position due to the spine-pelvis fusion fixation, which forces the hips to increase their ROM in response to the position change[37]. Last, a large femoral head with a diameter of 36 mm was used in almost all implants (98.3%). It has been shown that CoC bearings decrease the cumulative long-term risk of dislocation compared with that for CoP bearings[38], especially when implanted with a large-diameter (≥32 mm) femoral head[39,40]. HO was seen in 12 (6.7%) of all postoperative hips. The incidence of HO in patients with AS undergoing THA varied widely in different series[10,14,41,42]. Commonly, prophylaxis of HO has mainly been performed with the administration of nonsteroidal anti-inflammatory drugs (NSAIDs) and radiation therapy. However, we did not use radiation therapy for prophylaxis routinely because its necessity is still controversial[13,43]. Two patients complained of mild soreness in their hips during weight-bearing, with one on both sides and the other on the left side, and one patient complained of moderate pain in the bilateral hips while squatting. Symptoms improved after oral administration of NSAIDs.

Noise Assessment

Noise is one of the main complications related to the use of ceramic bearings. Two early meta-analyses showed a squeaking incidence of 2.4% and 4.2% after THA[44,45]. Lim *et al.* reviewed 667 patients (749 hips) undergoing primary THA with fourth-generation ceramic bearings and reported audible noise in 48 hips (6.4%) at a mean follow-up of 6.5 years[46]. Similar reports with a shorter follow-up can also be found in the literature[47,48]. Goldhofer *et al.* reported a study of 195 patients (206 hips) who underwent THAs with a large-diameter CoC bearing and observed an increase in the squeaking rate from 7.3% after 2 years to 17.4% after 5 years[49]. Similarly, we confirmed that the incidence of noise increases over time in patients with AS patients undergoing CoC THAs. The cumulative incidence of noise at 0.5, 5, and 10 years postoperatively was 6.1%, 16.7%, and 28.9%, respectively, with squeaking in 43 (82.7%) and clicking in nine (17.3%) cases. Possible explanations for squeaking include the formation of stripe wear, lubrication conditions, and contact stress; a mismatch between the shell and the liner; and different stem designs. An explanation for clicking was micro separation due to femoral neck impingement on an elevated metal rim[22]. Notably, compared with previously

reported results, the incidence of squeaking was relatively high after THA in this study. We suggest that the reason may be that the contact stress is applied to the bearing interface of the only movable joint during hip locomotion due to the loss of spine-pelvis coordination in patients with AS, which may result in increased frictional forces at a specific zone and subsequent noise. More importantly, the postoperative flexion-extension ROM and HHS showed no differences between hips with noise and those without noise, and no patient reported being affected or daily activities being limited by the noises. The results indicate that although the accompanying noises were relatively high and increased over time with a minimum follow-up of 10 years in AS patients undergoing THA with CoC bearings, the postoperative hip function and daily activities were not affected.

Limitations

The current study has several limitations. First, this is a single-center follow-up study, with no control groups to compare with other bearing surfaces. Second, spine involvement was not assessed, and severe spinal deformities may influence the functional outcomes in those patients. Third, this study may have recall bias due to the retrospective survey method. Last, loss to follow-up remains a concern in long-term follow-up studies. Thus, some uncollected complications or revision THAs may exist in those who were lost to follow-up.

Conclusions

In conclusion, THA with fourth-generation CoC bearings exhibits excellent survival and clinical outcomes at long-term follow-up in patients with AS, with a very low dislocation rate. Noise generation remains common in fourth-generation CoC bearings, and the incidence of noise related to the use of ceramic bearings increases over time. However, noise generation does not affect postoperative hip function or daily activities in patients.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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