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The Wear Rate and Survivorship in Total Hip Arthroplasty Using a Third-generation Ceramic Head on a Conventional Polyethylene Liner: A Minimum of 15-year Follow-up

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Purpose: The purpose of this study was to evaluate the wear and survival rates of third-generation ceramic heads on a conventional ultra-high molecular weight polyethylene liner.

Materials and Methods: A total of 160 hips (147 patients with a mean age of 55.9 years) who underwent total hip arthroplasty using the third-generation ceramic head on a conventional polyethylene liner from March 1998 to August 2003 were reviewed retrospectively. Evaluation of the wear rate for 56 hips (49 patients) followed-up for at least 15 years was performed using the PolyWare program version 8 (Draftware Developers, USA). The Kaplan–Meier survivorship was also evaluated.

Results: Linear wear and volumetric wear rates were 0.11±0.47 mm/year and 32.75±24.50 mm^3/year, respectively. Nine revisions were performed during the follow-up period because of cup or stem loosening. The Kaplan–Meier survival rate, using cup revision or total revision total hip arthroplasty (THA) as the endpoint of analysis, was 93.7% at 15 years and 73.6% at 20 years.

Conclusion: Because all revisions were performed between 15 and 20 years in our study, surgeons should pay greater attention to patients who underwent THA with ceramic-on-polyethylene bearing from 15 years postoperatively. Contemporary alumina ceramic on highly cross-linked polyethylene could certainly be a good alternative bearing couple providing better longevity.

Key Words: Total hip arthroplasty, Polyethylene, Ceramic, Survivorship

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Hip Pelvis 34(2): 115-121, 2022

INTRODUCTION

Total hip arthroplasty (THA) has been one of the most successful surgical procedures for treatment of end-stage hip joint diseases such as severe osteoarthritis, osteonecrosis, and congenital hip anomalies during the last several decades[1]. With increased life expectancy, the importance of prosthesis survival is increasing. World-wide concerns regarding a rapidly expanding burden for revision THA are emerging as a result of osteolysis and loosening due to the bearing surface[2]. Therefore, the bearing surface is a significant factor in determining the longevity of THA[3,4].

There are several available options for selection of the bearing surface in THA. Although the optimal bearing surfaces for THA is still under debate, polyethylene liners have been mainly used regardless of the artificial head[5,6]. With the evolution of materials and manufacturing technologies, the wear resistance and reliability of the bearing surfaces of artificial hip joints are greater than ever.

Although metal-on-polyethylene (MoP) bearing has been used for several decades, the main concern was the wear particle-related periprosthetic osteolysis, resulting in THA failure. Alumina ceramic with newer polyethylene has been introduced in an effort to decrease the amount of polyethylene wear debris. Recent long-term studies have reported satisfactory results in functional and radiologic outcomes for use of alumina ceramic with newer polyethylene[7]. Therefore, a ceramic-on-polyethylene (CoP) bearing surface is thought to be an excellent bearing couple. Hence, CoP has become a popular bearing surface used in THA and accounts for more than half of all THA cases in the United States[5].

Contrary to the USA, ceramic-on-ceramic (CoC) bearings have been used in approximately 80% of THAs for the last two decades in Korea because Korea's national health insurance system allows use of ceramic bearings at a relatively low cost compared to other countries[8]. Although CoC bearing is a mainstay of THA in Korea, there are concerns with regard to complications related to CoC bearing such as ceramic fracture and squeak. With an increasing interest in CoP bearing internationally if former CoP shows satisfactory results, it can be expected that the long-term results will be better when ceramic is used on a cross-linked polyethylene liner, which is highly resistant to wear.

Ceramic-on-conventional polyethylene bearings have been used in our institution for a long time and promising clinical results have been obtained. Therefore, the purpose of this study was to evaluate the wear rate and survivorship of CoPs bearing for a minimum of 15 years.

MATERIALS AND METHODS

This study was a retrospective review of the outcomes of consecutive patients who underwent THA using CoP bearing performed by a single surgeon at Yeungnam University Medical Center from March 1998 to August 2003. After approval of the study protocol by the institutional review board, an assessment of the patient records and serial radiographs were performed. The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board of Yeungnam University Hospital (approval No. 2019-07-015). Patient consent was waived due to the retrospective nature of the study. The medical charts of all patients were reviewed, and the following items were retrieved: age, sex, laterality, body mass index, preoperative Koval grade and the cause of arthroplasty. A total of 147 patients (160 hips) with a mean age of 55.9 years (range, 23-79 years) were reviewed during the study period (Table 1).

A total of 69 patients (75 hips) were lost to follow-up and 29 patients (29 hips) died due to medical comorbidities before a minimum of 15 years. The remaining 49 patients (56 hips) available for radiographic evaluation were enrolled in this study. Among them, 39 patients were male and 10 patients were female. The mean follow-up period was 210 months (range, 180-261 months) (Fig. 1).

Table 1. Patients Demographics

Variable	Value
Age (yr)	55.9 (23-79)
Sex	
Male	126 (78.8)
Female	34 (21.3)
Laterality	
Right	74 (46.3)
Left	86 (53.8)
Body mass index (kg/m^2)	22.1 (14.8-27.8)
Preoperative Koval grade	
1	82 (51.3)
2	52 (32.5)
3	26 (16.3)
The cause of arthroplasty	
Osteonecrosis	143 (89.4)
Osteoarthritis	13 (8.1)
Femoral neck fracture	4 (2.5)

Values are presented as mean (range) or number (%) of hips. The sum of the percentages does not equal 100% because of rounding.

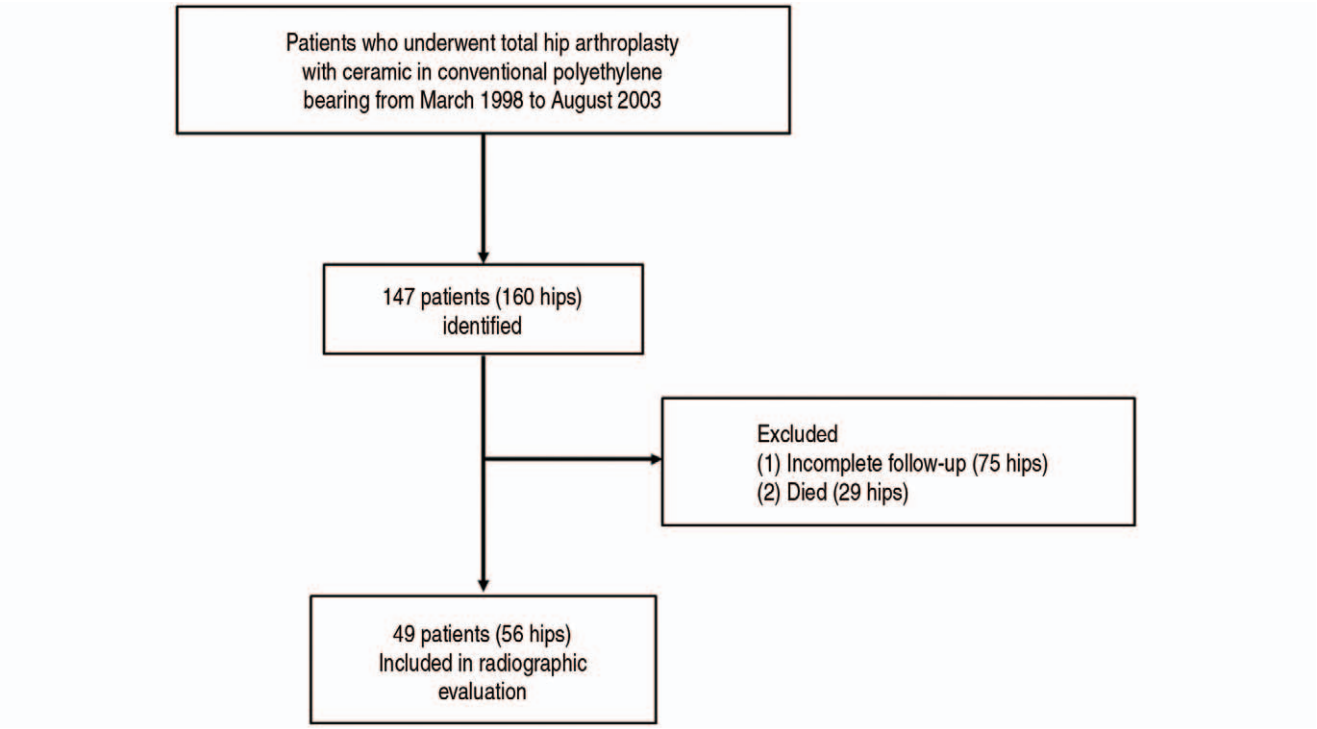

Fig. 1. The flow chart for the study.

All patients underwent THA using a cementless femoral stem (CLS® Spotorno [Zimmer, Warsaw, IN, USA]; formerly Sulzer Orthopaedics, Winterthur, Switzerland) and a cementless acetabular component (Wager standard cup® [Zimmer]; formerly Protek, Bern, Switzerland). All femoral heads were 28 mm in diameter Biolox Forte alumina (CeramTec, Plochingen, Germany) that articulated with ultra-high molecular weight polyethylene (UHMWPE) liner. Patients were followed-up at 1, 3, 6, and 12 months postoperatively after THA. Subsequently, the patients were asked to visit every year.

1. Surgical Technique

A posterolateral approach was used in performance of all surgical procedures with the patient in the lateral decubitus position. All acetabular components were inserted using a press-fit technique underreaming the acetabulum by 1-2 mm. The socket was fixed in the acetabulum using an acetabular alignment guide, with a target acetabular position of 20˚ of ante-version and 45˚ of inclination. An adjunctive acetabular screw was used when needed in order to secure the initial mechanical stability of the acetabular component. All cementless stems were inserted using standard press-fit techniques to ensure longitudinal and rotational stability. After implant insertion, repair of the capsule and short external rotator was performed using the appropriate tension to prevent dislocation.

2. Radiographic Evaluation

All radiographic evaluations included anteroposterior (AP) and axial views of the pelvis and were performed by two independent orthopedic surgeons who did not participate in the surgery. The evidence of osteolysis, according to the DeLee and Charnley zone in the acetabulum and Gruen zone in the femur, was determined using sequential radio-graphic views[9,10]. It also allowed comparative assessment of component position versus immediate postoperative views to determine the presence of component migration and rotation of more than 3 mm and 8˚ [11]. Penetration of the femoral head into polyethylene liners was calculated as two- and three-dimensional penetrations on AP radiographs using PolyWare version 8 software (Draftware Developers, Vevay, IN, USA) by two orthopedic surgeons (C.H.P. and B.J.S.). The wear rates were measured twice by two surgeons at intervals of one week. Wear rates were regarded as the average of two values. The wear rate was calculated using the 5-point mark on the edges of the femoral head and acetabular cup; immediate postoperative and final follow-

Hip Pelvis 34(2): 115-121, 2022

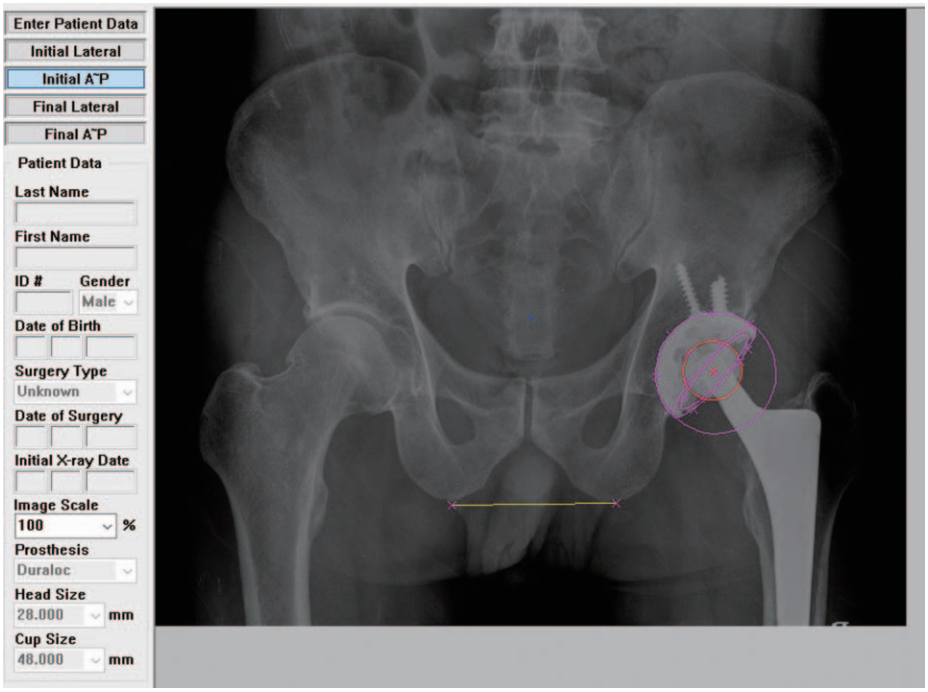

Fig. 2. For evaluation of wear rate, the PolyWare program compared the initial and final radiographs through detection of the ceramic head and cup edge automatically.

up radiographs were compared using this program (Fig. 2). This program also allowed us to determine volumetric wear. The mean annual penetration rates were calculated. Using this program the result was divided by the number of years and the annual wear rate was determined automatically.

3. Postoperative Rehabilitation Protocol

The same postoperative protocol was used in all cases. Patients were allowed to sit on the first postoperative day and stand with support, according to ability, after blood drainage removal. There was no limitation of range of motion immediately after surgery, and no abduction pillow was used for any patient.

4. Statistical Analysis

Continuous data are presented as means and standard deviations. The paired *t*-test and Kruskal–Wallis test were used for comparison of continuous variables, and Kaplan–Meier survivorship was also evaluated. Statistical analyses were performed using IBM SPSS Statistics (ver. 23.0; IBM, Armonk, NY, USA).

RESULTS

1. Radiographic Results

The mean abduction angle was 45.01° (range, 29.7-65.9°) and the mean anteversion was 13.36° (range, 3-37.5°). Radiolucent lines in the femur were observed in six hips in zones one and seven. Among them, five hips did not loosen except for one hip. Cortical porosity was observed in five hips, however no stem subsidence was observed. Osteolysis was observed in nine hips, among which five hips underwent revision surgery due to loosening. The mean linear and volumetric polyethylene wear rates were 0.11 ±0.47 mm/year (range, 0.001-0.271 mm/year) and 32.75 ±24.50 mm^3/year (range, 2-95 mm^3/year), respectively.

2. Revision and Survivorship

At the final follow-up, six acetabular components and three total components were revised due to cup or stem loosening. Except loosening, three hips were revised because of periprosthetic fracture and recurrent dislocation. There was no isolated revision of polyethylene wear and ceramic head failure. The modular femoral head was exchanged in all cases involving acetabular or femoral component revision.

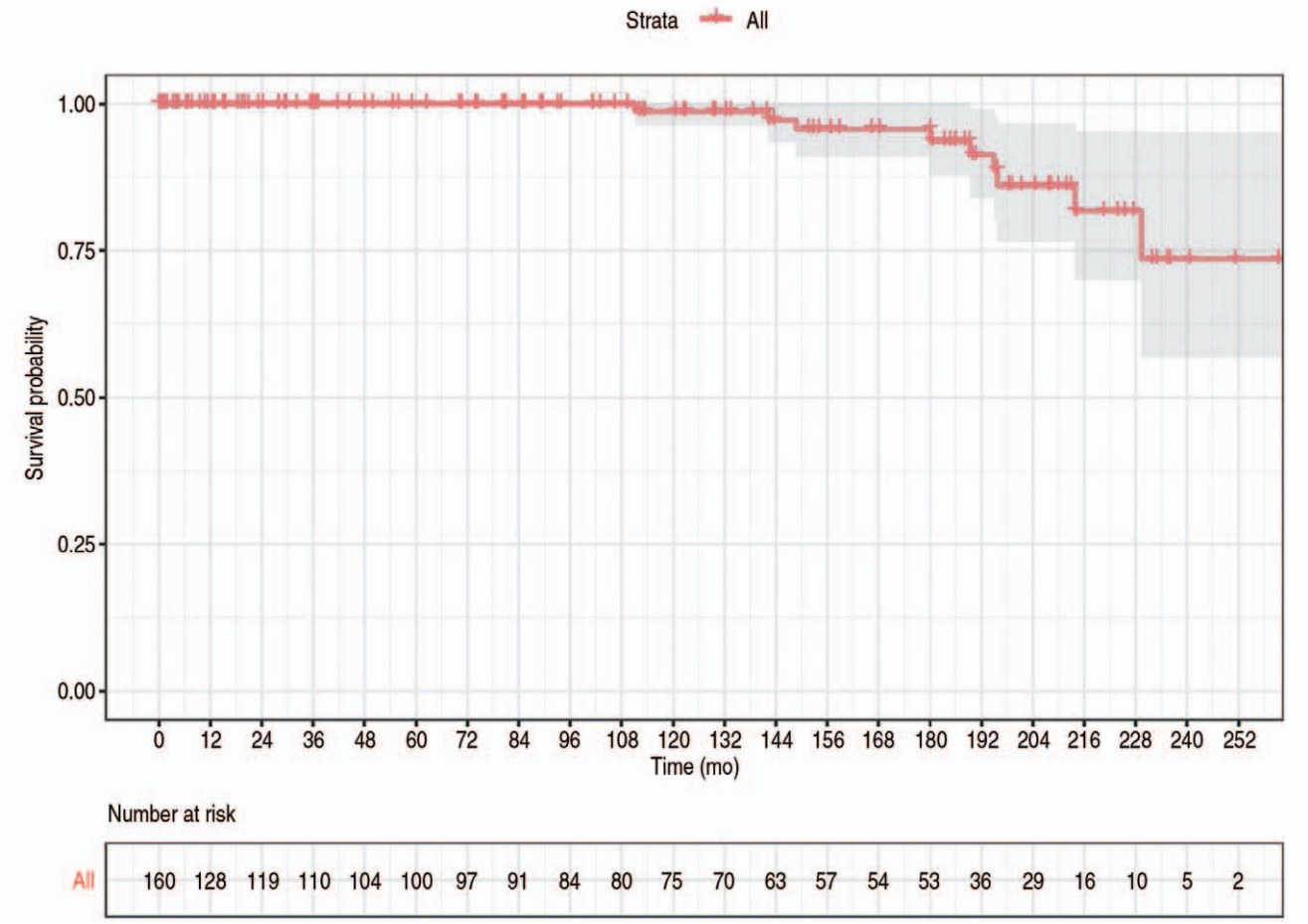

Fig. 3. Kaplan-Meier survival curve with revision total hip arthroplasty as the endpoint of analysis.

The Kaplan–Meier survival rate, using cup revision or total revision THA due to loosening as the endpoint of analysis, was 93.7% at 15 years and 73.6% at 20 years (Fig. 3).

DISCUSSION

Over the last five decades, hard-on-soft bearings, especially cobalt-chrome femoral heads articulating with UHMWPE liners, have been used in THA. Hard-on-soft bearings are widely used because of good long-term results[12]. In addition, the use of ceramic heads on polyethylene liners is gradually gaining wider acceptance[5]. However, the main drawback of hard-on-soft bearings is the wear particle-related periprosthetic osteolysis, resulting in THA failure. Periprosthetic osteolysis and aseptic loosening are severe problems in the durability of THA and are highly related to wear and the number of particulate debris. Wear and osteolysis occur mainly with standard polyethylene bearings associated with metal heads[13,14].

In our study the longevity of CoP bearing was satisfactory within 15 years postoperatively. Compared with the previous literature, the survival rates of CoP bearing at 15 years related to implant loosening and osteolysis did not differ compared to previously known data regarding MoP bearing[15]. However, all revision THA procedures were performed from 15 years postoperatively, and the survival rate was decreased after that. It is considered that periprosthetic osteolysis caused by wear particles for a long-term period induced prosthesis loosening. Although potential problems with polyethylene bearing surfaces such as wear and osteolysis could be decreased with development of new materials, surgeons should pay more attention to patients who underwent THA with CoP bearing after 15 years postoperatively[6].

Highly cross-linked polyethylene (HXLPE) was developed in an effort to address the problem of wear and osteolysis associated with UHMWPE bearing surfaces. Findings from many studies have shown that HXLPE was significantly reduced and is associated with a greater implant survival rate regardless of the head

Hip Pelvis 34(2): 115-121, 2022

used compared with conventional UHMWPE[7,16].

Hard-on-hard bearings for THA have improved dramatically over the past several decades. Ceramic bearings are an attractive option, particularly in young, active patients because of the hardness and high resistance of scratches, and thus, they are tolerant to wear debris[17-19]. Ceramic bearings have far-reduced volumetric wear debris compared to other types of bearings[20]. Findings from previous studies have shown that the mean linear wear rate was 0.0043 mm/year in the CoC bearing, lower than that of the other bearings[21]. Whereas the mean linear wear rate and volumetric wear of CoP bearing were 0.22±13.70 mm/year and 136.2±8.5 mm^3/year, respectively, higher than CoC bearing in the meta-analysis[22,23]. Thus, a previous study showed that there is little loosening due to low wear rate of third generation CoC bearing and excellent results were obtained during the long term follow-up period[24]. However, the high cost, squeaking, component impingement, micro-separation, and prosthesis fracture make the choice difficult[18]. In particular, ceramic fracture can be a devastating complication that affects revision surgery employing the third body wears from ceramic debris. For these reasons, there has been concern regarding the increased use of CoC as an alternative to contemporary CoPs. Therefore, CoP could be a better option for elderly patients for whom the longevity of THA is relatively less important compared with young and active patients.

Some efforts have been made to improve the wear rates through design changes, material substitution, or polymer modification in order to decrease the wear of polyethylene liners. Changes included varying the molecular weight of the polyethylene or changing the additives, and modification of the polyethylene material itself. Hence, use of newer materials has resulted in a significant reduction of the wear rate. Wear rates were lower for HXLPE created by radiating and re-heating the polyethylene implants compared with conventional polyethylene (0.26 mm/year vs 0.05 mm/year)[25].

If there is no significant difference in the wear rate, ceramic fractures can also be an important factor influencing the determination of the bearing surface. Although THA with CoC bearings is expected to increase, ceramic brittleness remains a major concern for surgeons[26,27]. Regarding the improvement of ceramic materials, there are few ceramic head fractures in the fourth-generation ceramic, but ceramic liner fractures are still a concern due to malseating. Previous studies have reported that the fracture rate of ceramic components is between 0.004% and 0.05% for femoral heads and between 0.013% and 1.1% for ace-tabular liners[28]. On the other hand, reports of ceramic head fractures with polyethylene liners are negligible[29]. Furthermore, in this study no cases of squeaking were observed in the CoP group, whereas a squeak incidence of up to 20% was reported for CoC bearings in previous studies[30]. Thus, CoP articulation is gradually spotlighted in an effort to reduce several problems in ceramic components. However, the problem with the choice of bearing surface remains controversial, although our results are relatively consistent with those of other previous reports.

Several limitations of this study were noted. First, our study had a retrospective design, with a relatively small number of patients because the follow-up rate was comparably low for 15 years after THA. The analysis was based on consecutive cases, with no randomization and no power analysis performed. Nevertheless, we had the advantage of analyzing the wear rate of the polyethylene liner over 15 years in 56 hips.

Second, we did not address patient-reported outcomes in order to evaluate the function of THA. Although not only the radiographic results but also the clinical results are important, because of the retrospective nature of this study we were not able to collect the patient-reported outcome.

CONCLUSION

Contemporary alumina ceramic on HXLPE could certainly be a good alternative bearing couple with better longevity without concern for ceramic fracture, especially in elderly patients. However, surgeons should pay more attention to patients who underwent THA with CoP bearing after 15 years postoperatively.

CONFLICT OF INTEREST

The author declares that there is no potential conflict of interest relevant to this article.

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