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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Research article

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Abstract

Background: Recently, the use of ceramic-on-polyethylene (CoP) bearing surfaces has increased in the United States with the development of material properties. However, it remains controversial which bearing couples are effective. The purpose of this study was to evaluate the wear and survival rates of third-generation ceramic heads on a conventional polyethylene liner.

Methods: We retrospectively reviewed 160 hips (147 patients with a mean age of 56 years) who underwent total hip arthroplasty using the third-generation ceramic head on a conventional polyethylene liner from March 1998 to August 2003. The wear rate was evaluated using the PolyWare program Version 8 (Draftware Developers Inc., IN, USA) in 32 hips followed-up for at least 15 years. In addition, we evaluated the Kaplan-Meier survivorship.

Results: Linear wear and volumetric wear rates were 0.102±0.57 mm/year and 30.2±27.5 mm^3/year, respectively. Fourteen reoperations due to all causes and 10 revisions were performed during the follow-up period. The 15-year survival rate was 84.1% for any surgery as the endpoint and 87.6% for the revision surgery as the endpoint. Most of the causes of revision were cup loosening, and no ceramic head fracture occurred.

Conclusions: The CoP bearing surface maintains the advantages of the soft polyethylene surface and has good resistance to wear. Therefore, alumina ceramic on newer polyethylene could certainly be a good alternative bearing couple without any concern for ceramic fractures, especially in younger patients.

Level of evidence: Level III, retrospective cohort design

Introduction

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

There are several available options for choosing the bearing surface in THA. However, there are debates regarding the optimal bearing surfaces for THA.[5, 6] Polyethylene liners have been mostly used and are still used regardless of the artificial head.

With the evolution of materials and manufacturing technologies, the bearing surfaces of artificial hip joints have higher wear resistance and reliability than ever. Recent long-term studies have reported that alumina ceramic with newer polyethylene shows no significant difference in osteolysis or patient satisfaction.[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]

Korea has a national health insurance system able to use ceramic bearing at a relatively low cost than in other countries. Ceramic-on-ceramic (CoC) bearings have been used for the last two decades, approximately 80% of cases.[8] However, CoP bearings have been used for a long time and have shown promising clinical results in our institution. Therefore, the purpose of this study was to evaluate the wear rate and survivorship of CoPs bearing for a minimum of 15 years. If the current study 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. Furthermore, it will influence the choice of the bearing surface, considering the patient’s lifespan.

Materials And Methods

We reviewed the medical records of patients who underwent THA using CoP bearings after obtaining approval from the institutional review board. Between March 1998 and August 2003, 147 patients (160 hips) with a mean age of 56 years (range, 23–79 years) were operated on by a single surgeon using CoP bearings. All patients underwent THA with a cementless femoral stem (CLS® Spotorno, Zimmer, Warsaw, IN, USA; formerly Sulzer Orthopaedics, Switzerland) and a cementless acetabular component (Protek, Sulzer Orthopaedics, 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.

At the final follow-up, 29 patients (29 hips) died due to medical comorbidities. A total of 84 patients (92 hips) were lost to follow-up before a minimum of 15 years. The remaining 34 patients (39 hips) available for radiographic evaluation were enrolled in this study. Among them, 26 were male and 8 female. Patients were followed-up at 1, 3, 6, and 12 months postoperatively. Subsequently, we asked the patients to visit every year. The mean follow-up period was 199 months (range, 180–240 months).

Surgical Technique

All surgical procedures used a posterolateral approach with the patient in the lateral decubitus position. All acetabular components were inserted using a press-fit technique under the acetabulum’s reaming by 1–2 mm. The socket was fixed in the acetabulum using an acetabular alignment guide, with a target acetabular position of 20° of anteversion and 45° of inclination. To secure the initial mechanical stability of the acetabular component, we used an adjunctive acetabular screw when needed. All cementless stems were inserted using standard press-fit techniques to ensure longitudinal and rotational stability. After implant insertion, the capsule and short external rotator were repaired with the appropriate tension to prevent dislocation.

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 radiographic 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 Inc., Vevay, IN, USA) by two orthopedic surgeons (CHP, BJS). At intervals of one week, two surgeons measured the wear rates twice. We regarded wear rates 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, comparing immediate postoperative and final follow-up radiographs in this program (Fig. 1). This program also allowed us to know volumetric wear. The mean annual penetration rates were calculated. This program divided the result by the number of years and automatically determined the annual wear rate.

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. No range of motion limitation was present immediately after surgery, and no abduction pillow was used in any patient.

Statistical Analysis

Continuous data are presented as means and standard deviations. The paired t-test and Kruskal-Wallis test were used to compare continuous variables, and Kaplan-Meier survivorship was also evaluated. Statistical analyses were conducted using IBM SPSS version 23.0 (IBM Co., Armonk, NY, USA).

Results

Revision and Survivorship

At the final follow-up, six acetabular components and two femoral components were revised due to cup or stem loosening and periprosthetic fractures. There was no isolated revision of polyethylene wear and ceramic head failure. In all cases involving acetabular or femoral component revision, the modular femoral head was exchanged.

The Kaplan-Meier survival rate at 15 years, using implant loosening or revision THA as the endpoint of analysis, was 84.1% at any surgery and 87.6% at the revision surgery. (Fig. 2)

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 shown in six hips in zones one and seven. Among them, five hips did not loosen except for one hip. Cortical porosity was found in five hips, but no stem subsidence was observed. Osteolysis was found in nine hips, among which five hips underwent revision surgery due to loosening. The mean linear and volumetric polyethylene wear rates were 0.102 mm/year (range, 0.001–0.271 mm/year) and 30.16 mm^3/year (range, 2–95 mm^3/year), respectively.

Discussions

Over the last five decades, hard-on-soft bearings have been used in THA, especially cobalt-chrome femoral heads articulating with UHMWPE liners. 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, leading to 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 metalheads.[13, 14]

Highly cross-linked polyethylene (HXLPE) was developed to address the problem of wear and osteolysis associated with UHMWPE bearing surfaces. Many studies have shown that HXLPE has significantly reduced and is associated with a greater implant survival rate regardless of the head used than conventional UHMWPE.[7, 15]

Hard-on-hard bearings for total hip arthroplasty have improved dramatically over the past several decades. With the introduction of new material options on the bearing surface, the use of hard-on-hard bearings will likely continue to increase, particularly in active, young patients. In particular, ceramic bearings are attractive because of the hardness and high resistance of scratches, and thus, they are tolerant to wear debris. However, the fracture and the squeaking sound, as well as the high-cost problem, make the choice debatable.[16–18]

The use of materials with low production of wear debris has become an attractive alternative in active young patients. Ceramic bearings have far-reduced volumetric wear debris compared to other types of bearings.[19] Many studies have reported that CoC-bearing surfaces decrease rates of wear, osteolysis, and aseptic loosening, which accounts for more than half of the revisions. However, the high cost, squeaking, component impingement, micro-separation, and prosthesis fracture make the choice difficult.[17] A 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.

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.[20] Comparing CoP, the mean linear wear rate and volumetric wear were 0.2182 ± 13.7 mm/year and 136.2 ± 8.5 mm^3/year, respectively, higher than CoC bearing.[21, 22] To improve the wear of polyethylene liners, some efforts have been made to improve the wear rates through design changes, material substitution, or polymer modification. Changes included varying the molecular weight of the polyethylene or changing the additives, and modification of the polyethylene material itself. Hence, newer materials significantly reduce the wear rate. HXLPE created by radiating and re-heating the polyethylene implants has been shown to have lower wear rates than conventional polyethylene (0.26 mm/year vs. 0.05 mm/year).[23]

In our study, we found that the survival rates of CoP bearing at 15 years related to implant loosening and osteolysis did not differ significantly compared to previously known data with metal-on-polyethylene bearing.[24] Furthermore, there were no severe complications such as fractures and squeaking of the CoC bearing. Potential problems with polyethylene bearing surfaces such as wear and osteolysis could be decreased as new materials were developed.[6]

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.[25, 26] 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 acetabular liners.[27] On the other hand, there are negligible reports of ceramic head fractures with polyethylene liners.[28] Furthermore, there were no cases of squeaking in the CoP group in this study, whereas CoC bearings were reported to have a squeak incidence of up to 20% in previous studies.[29] Thus, CoP articulation is gradually spotlighted 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 was retrospective in nature, with a relatively small number of patients. The analysis was based on consecutive cases, with no randomization and no power analysis performed.

Second, we did not evaluate the clinical outcome because many patients were lost to follow-up. However, there have been few studies on the wear rate of CoP bearings in the long-term period because CoP bearings are not a mainstay. Therefore, the long-term result of the wear rate of CoP bearings is sufficient in this study.

Conclusions

Bearing surfaces should not only be made of materials with high resistance, low wear rate, friction, and corrosion resistance but also be biocompatible. CoP, as a bearing couple, retains the advantages of the soft polyethylene surface and has good resistance to wear. Therefore, alumina ceramic on newer polyethylene could certainly be a good alternative bearing couple without concern for ceramic fracture, especially in younger patients.

List Abbreviations

THA: total hip arthroplasty

CoP: ceramic-on-polyethylene

CoC: Ceramic-on-ceramic

UHMWPE: Ultra High Molecular Weight Polyethylene

HXLPE: highly cross-linked polyethylene

Declarations

Ethics approval and consent to participate

The present study protocol was reviewed and approved by the Institutional Review Board of Yeungnam University Hospital (approval No. 2019-07-015). The need to obtain informed consent was waived because of the retrospective nature of the study.

Consent publication

Not applicable

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interest

The authors have no potential conflicts of interest to disclose.

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Author Contribution

Conceptualization: CH Park Methodology: CH Choi Formal analysis: BJ Shim, CH Park Original draft preparation: BJ Shim Review and editing: CH Choi, CH Park Approval of final manuscript: all authors.

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Figures

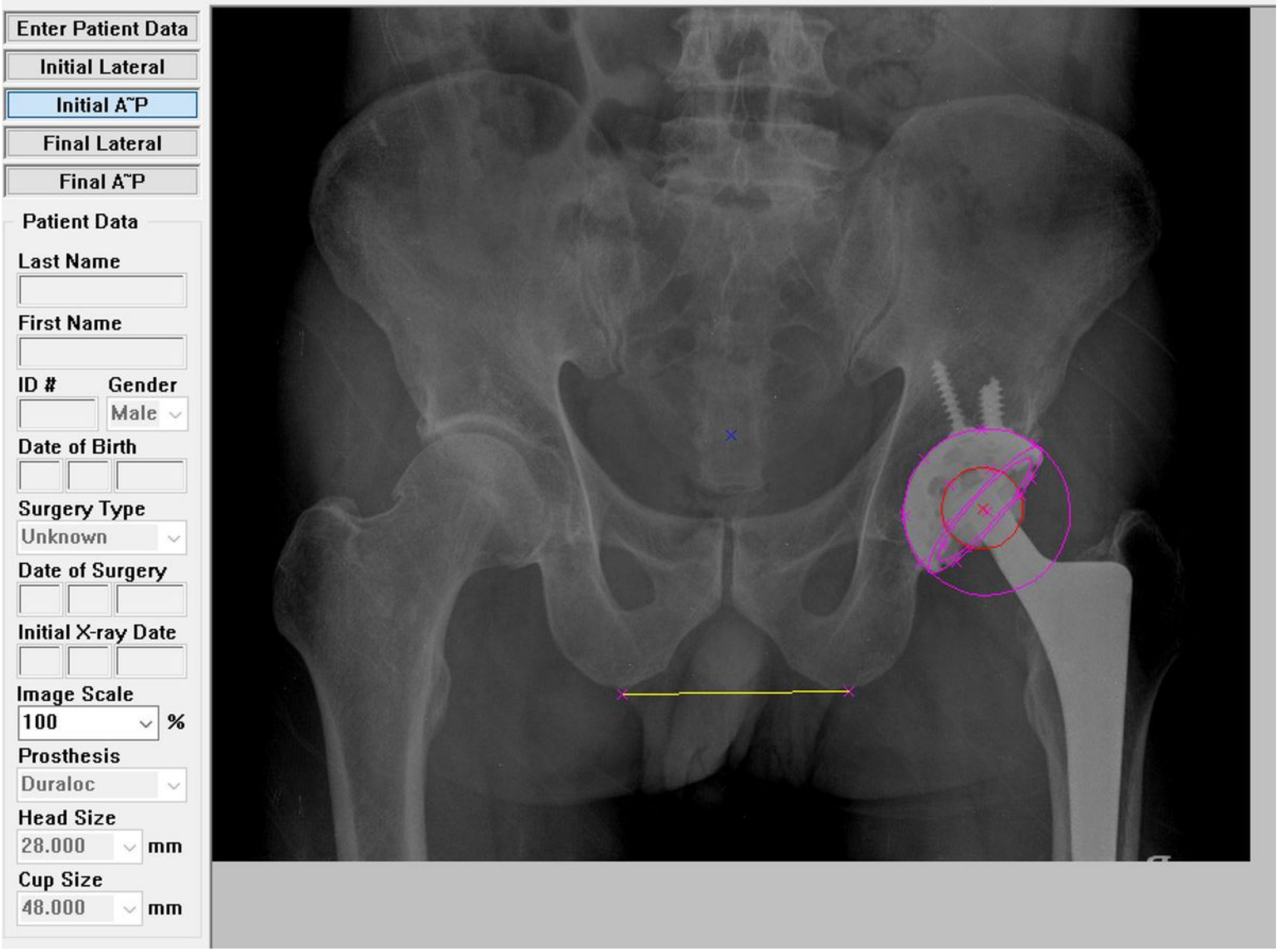

Figure 1

For evaluating wear rate, Polyware program compare the initial and final radiographs through detecting the ceramic head and cup edge automatically.

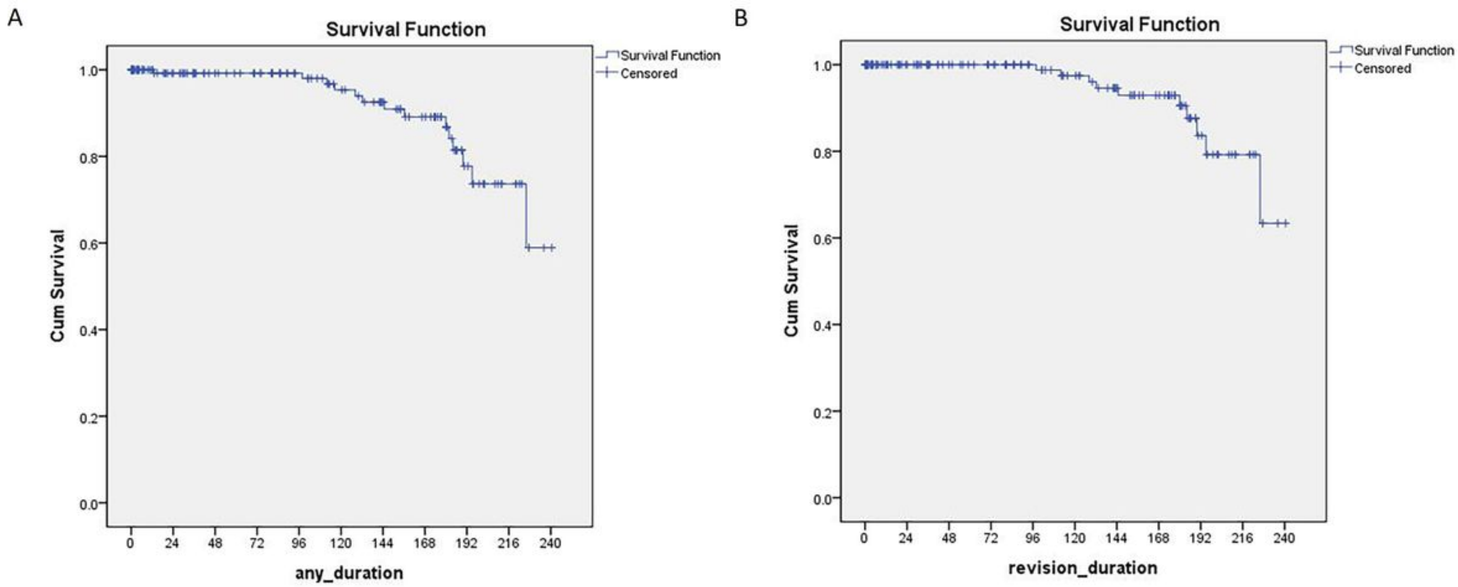

Figure 2

Kaplan-Meier survival curve with (a) implant loosening or revision THA and (b) any surgery as the endpoint of analysis