Joint Diseases and Related Surgery

Jt Dis Relat Surg
2026;37(3):602-613

ORIGINAL ARTICLE

# Minimum 10-year outcomes of highly cross-linked polyethylene in total hip arthroplasty for hip dysplasia: Effect of cup inclination in a matched comparative study

Byung-Chan Choi, MD, PhD[1*], Kyung-Jae Lee, MD, PhD[1*], Byung-Woo Min, MD, PhD[2], Ho-Sung Suh, MD[1]

[1]Department of Orthopaedic Surgery, Keimyung University Dongsan Hospital, Keimyung University School of Medicine, Daegu, South Koria

[2]Department of Orthopaedic Surgery, W Hospital, Daegu, South Korea

Hip dysplasia is a major cause of secondary osteoarthritis (OA) of the hip. Advanced OA due to hip dysplasia often requires technically demanding total hip arthroplasty (THA).[1,2] During acetabular reconstruction, limited bone coverage, a high hip center, and malpositioning of acetabular cup are common challenges.[3,4] For stable cup fixation, 50% to 75% host bone coverage is usually recommended and it is usually measured using various image modalities.[4-7] Although restoring the anatomical hip center is ideal, a higher hip center is often acceptable if it ensures sufficient coverage.[8] Malpositioning of the acetabular cup frequently occurs during THA for hip dysplasia

Received: October 27, 2025
Accepted: January 27, 2026
Published online: May 15, 2026

**Correspondence**: Byung-woo Min, MD. Department of Orthopaedic Surgery, W Hospital, Daegu, South Korea.

E-mail: min0366@gmail.com

** These authors contributed equally to this work.*

**Citation:** Choi BC, Lee KJ, Min BW, Suh HS. Minimum 10-year outcomes of highly cross-linked polyethylene in total hip arthroplasty for hip dysplasia: Effect of cup inclination in a matched comparative study. Jt Dis Relat Surg 2026;37(3):602-613. doi: 10.52312/jdrs.2026.2702.

© 2026 Joint Diseases and Related Surgery. This is an open access article published under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (CC BY-NC 4.0), which permits non-commercial use, distribution, reproduction, and adaptation in any medium, provided the original work is properly cited. http://creativecommons.org/licenses/by-nc/4.0/

## ABSTRACT

**Objectives:** This study aims to compare the long-term outcome of highly cross-linked polyethylene (HXLPE) in hip dysplasia with osteonecrosis of the femoral head (ONFH) and evaluate the effect of cup inclination on HXLPE wear after total hip arthroplasty (THA) during a minimum 10-year follow-up.

**Patients and methods:** Between January 2000 and December 2012, a total of 124 patients who underwent primary THA for hip dysplasia or ONFH with a minimum 10-year follow-up were retrospectively analyzed. A total of 62 patients were successfully matched between the two groups (ONFH group, n = 62 and hip dysplasia group, n = 62). Primary outcomes included acetabular cup inclination, anteversion, and wear rates of HXLPE. Based on cup inclination, both groups were divided into three subgroups, classified as (1) ≤ 45°, (2) < 45° to < 50°, and (3) ≥ 55°. Secondary outcomes included the clinical score and radiographic findings of osteolysis, implant loosening, stress shielding, and heterotopic ossification. Kaplan-Meier curve and Cox regression test were used to compare the implant survivorship in the full cohort prior to exclusion and matching (178 hip dysplasia and 397 ONFH patients).

**Results:** There was no significant difference in survival rate without revision of prosthesis at 10-year between two groups (hip dysplasia: 94.7%, 95% confidence interval [CI]: 91.1% to 98.4% *vs*. ONFH: 95.7% (95% CI: 93.3% to 98.2%) ($p$ = 0.4) Cup inclination was significantly steeper in the hip dysplasia group (47.6°, 95% CI: 46.0° to 49.3°) than in the ONFH group (43.9°, 95% CI: 42.3° to 45.5°) ($p$ = 0.002). Steep cup inclination (> 55°) was significantly more frequent in the hip dysplasia group (11.3%, 7/62) than in the ONFH group (6.5%, 4/62; $p$ = 0.006). However, wear rates of HXLPE were not significantly different between groups, and no correlation was found between cup inclination and HXLPE wear rate. No progressive osteolysis or prosthetic loosening was observed during follow-up.

**Conclusion:** Although patients with hip dysplasia demonstrated a steeper mean cup inclination and a higher incidence of steep cup positioning compared to those with ONFH, implant survivorship remained comparable between groups in the overall cohort. In the matched cohort analysis, HXLPE wear rates and clinical outcomes were also comparable between the groups. These findings suggest that, despite technical challenges in acetabular positioning, the use of HXLPE in THA for hip dysplasia provides satisfactory long-term performance and may alleviate concerns regarding cup inclination-related wear.

***Keywords:*** Cup inclination, highly cross-linked polyethylene, hip dysplasia, total hip arthroplasty.

due to shallow acetabulum and medial osteophyte.[9,10] Efforts to achieve sufficient host bone coverage can induce a steep cup inclination. Both finite element-based and clinical studies have demonstrated that steep cup inclination, particularly angles exceeding 55°, is associated not only with hip joint dislocation but also with accelerated polyethylene liner wear and subsequent periprosthetic osteolysis following THA for hip dysplasia.[11-15]

Highly cross-linked polyethylene (HXLPE) has replaced conventional polyethylene owing to its improved wear resistance. Favorable mid- to long-term results of HXLPE have been reported for various clinical setting.[16,17] However, in dysplastic hips, small cup size, steep inclination, and high hip center may still affect wear, and the long-term durability of HXLPE.[8,18]

In conventional polyethylene, a cup inclination of no more than 55° has been recommended. However, studies demonstrating the effect of cup inclination on HXLPE wear still remain scarce. In the present study, we hypothesized that long-term outcome of HXLPE in hip dysplasia was comparable to osteonecrosis of the femoral head (ONFH) and cup inclination had minor impact to wear of HXLPE, although cup inclination would be steeper and steep positioning more frequent in hip dysplasia. We, therefore, aimed to compare the long-term outcome of HXLPE in hip dysplasia with ONFH and evaluate the effect of cup inclination on HXLPE wear after THA during a minimum 10-year follow-up.

## PATIENTS AND METHODS

This single-center, retrospective study was conducted at Keimyung University Dongsan Hospital, Keimyung University School of Medicine, Department of Orthopaedic Surgery between January 2000 and December 2012. A total of 246 hip dysplasia and 650 ONFH patients who underwent primary THA were reviewed. All patients were evaluated for clinical and radiographic outcomes at scheduled follow-up visit. Patients with ONFH were selected as the control group to represent a non-dysplastic primary THA population. Anatomical differences between the groups were expected to result in differences in acetabular cup inclination. To minimize potential confounding from demographic variables, we designed a matched comparative study. First, patients who underwent ceramic-on-ceramic bearing THA or cemented/hybrid-type THA were excluded, leaving 178 patients with hip dysplasia and 397 patients with ONFH. Implant survivorship was analyzed. Next, patients with had less than 10-year follow-up or those who underwent revision operation were excluded. We, then, attempted to match hip dysplasia and ONFH patients who underwent cementless THA with HXLPE for ONFH, with a minimum follow-up of 10 years during the same period. The matching criteria included identical sex, differences in age < 3 years, and body mass index (BMI) < 2 kg/m$^2$. A total of 62 patients were successfully matched between the two groups (ONFH group, n = 62 and hip dysplasia group, n = 62). At the time of matching, the outcomes of all patients were still unknown (Figure 1). A written informed consent was obtained from each patient. The study protocol was approved by the Keimyung University Dongsan Hospital Institutional Review Board (Date: 19.10.2024, IRB No: 2024-10-012). The study was conducted in accordance with the principles of the Declaration of Helsinki.

### Surgical procedure and prosthesis

The modified Hardinge approach was used and the procedures were performed by two surgeons. Acetabular cup was positioned in the true acetabulum with sufficient medialization. In cases of high dislocation, extensive soft tissue release, and anatomical landmarks such as bony prominence of the acetabular roof, obturator foramen were used to identify the true acetabulum. If needed, we confirmed location of the true acetabulum with portable radiograph before start reaming. None of the patients underwent additional procedures such as acetabular structural bone grafting to increase cup contact. Acetabular cup was inserted using cementless press-fit fixation. In patients with high dislocation, femoral shortening osteotomy was considered during preoperative planning based on leg length assessment and was performed at the trochanteric or subtrochanteric level. Three different cementless cup systems from one manufacturer (Trilogy, Converge cup from Zimmer; Warsaw; IN and inter-Op cup from Sulzer Orthopaedics, Austin, TX, USA) were used in this study due to the evolving inventory at our center. Longevity® and Durasul® liner (Zimmer Biomet Inc., IN, USA) were used in all patients of this study.

### Outcome assessment

Revision was defined as any surgical procedure involving the exchange or removal of any component of the implant. Cause of revision was

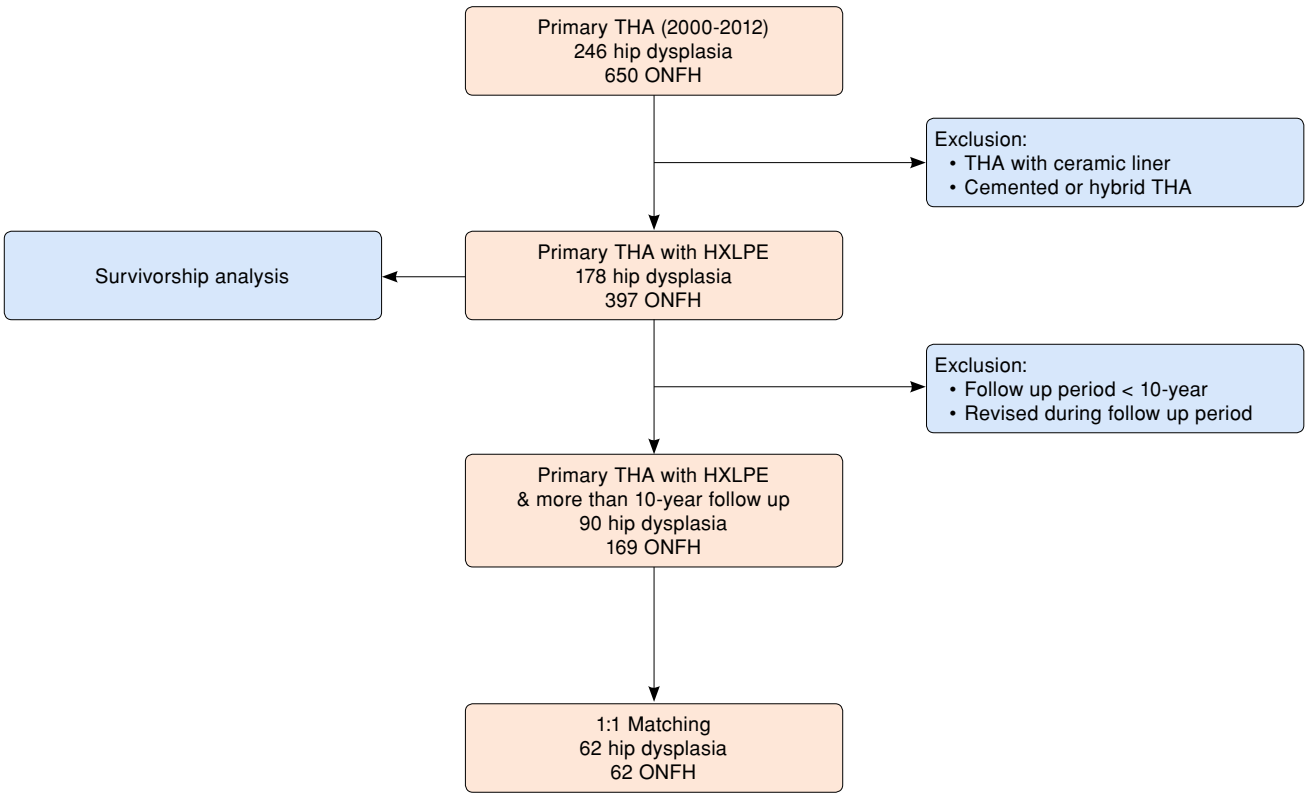



**FIGURE 1.** The study flowchart.
THA, total hip arthroplasty; ONFH, osteonecrosis of the femoral head; HXLPE, highly cross-linked polyethylene.

investigated and categorized with wear-related (osteolysis, aseptic loosening) or others.

The primary radiological outcomes included the inclination and anteversion of the cup, and wear rate of the HXLPE. Cup inclination was measured as the angle formed between a line tangential to the face of the acetabular cup and a line drawn along the inferior border of the ischial tuberosities, using anteroposterior (AP) pelvic simple radiograph taken in supine position. Anteversion of cup and polyethylene wear were determined using a computer-assisted method with PolyWare software (Draftware Developers, Vevay, IN, USA) (Figure 2). To reduce the effects of embedding and creep, an initial radiograph was recorded 2-6 months after surgery. Two orthopedic surgeons measured all radiological parameters twice to determine the intra- and inter-observer reliability. Based on cup inclination, both groups were divided into three subgroups, classified as (1) ≤ 45°, (2) < 45° to < 55°, and (3) ≥ 55°. Subgroup analysis was performed to investigate the correlation between cup inclination and wear rate of the HXLPE liners.

Harris Hip Score (HHS), hip joint dislocation, radiographic signs of osteolysis, implant loosening, stress shielding, and heterotopic ossification were evaluated as secondary outcomes. Patients were followed up regularly, and HHS was assessed at each visit. Osteolysis was defined as radiographic findings of any focal area of bone resorption > 2 mm wide that was not visible on an immediate postoperative radiograph.[19] An acetabular component was considered radiographically loose when migration of the cup had occurred or radiolucency > 2 mm was observed around the prosthesis. Rotational changes > 8° or linear changes > 3 mm on serial radiographs was considered an indication of cup migration.[20] Femoral component stability and osseointegration were assessed according to the method described by Zicat et al.[19] Stress shielding and heterotopic ossification were classified according to Engh's and Brooker's classifications.[21,22] Radiographic outcomes, including osteolysis and implant loosening, were described using the DeLee and Charnley zones for the acetabular component and the Gruen zones for the femoral component.[23,24]

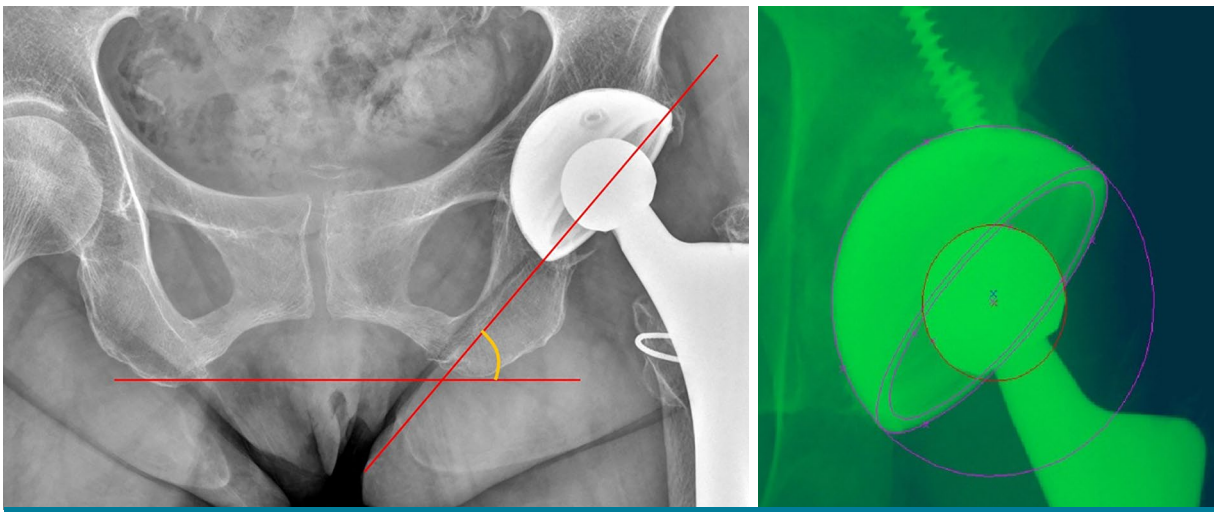


**FIGURE 2.** Cup inclination, anteversion measurement.

### Statistical analysis

Study power analysis and sample size calculation were performed. A power analysis with $\alpha$=0.05 and a sample size of 62 in each group was performed. The power of our study was estimated to be 89.1% for cup inclination, which was statistically significant.

Statistical analysis was performed using the IBM SPSS version 26.0 software (IBM Corp., Armonk, NY, USA). Continuous data were presented in mean ± standard deviation (SD) or median (min-max), while categorical data were presented in number and frequency. The Kaplan-Meier curve and Cox regression test were used to compare the implant survivorship in the full cohort prior to exclusion and matching (178 hip dysplasia and 397 ONFH patients) to maximize statistical power. The Student t-test was used to compare continuous variables. Change in HHS was compared by dependent samples t-test. The chi-square test was used to compare categorical variables and the incidence of specific radiographic signs. Correlation between cup inclination and wear rate was assessed using the Pearson correlation analysis. The intra-and inter-observer reliabilities of the four radiological measures were evaluated using intraclass correlation coefficients (ICCs). A $p$ value of $< 0.05$ was considered statistically significant with 95% confidence interval (CI).

## RESULTS

A total of 124 patients including 62 patients in each group were recruited. Of the patients, 42 were male and 82 were female with a mean age of 52.4 ± 8.9 (range, 27 to 70) years. No significant differences were observed between the two groups in terms of sex, age, BMI, or follow-up period. Forty-nine, nine, and four patients had hip dysplasia of Crowe type I or II, III, and IV, respectively. In the ONFH group, 37 patients had Ficat Stage III, 16 had Ficat Stage IV, and nine had post-traumatic avascular necrosis of the femoral head (Table I).

Elevated or hooded liner was used in 25 (40.3%) patients in the hip dysplasia group and 34 (54.8%) in the ONFH group. Metal or ceramic head was used in the all patients. No significant differences were observed in the mean cup size, liner thickness, or head size (Table I).

The overall survival rate without revision of prosthesis at 10 year was 94.7% (95% CI: 91.1% to 98.4%) in 178 hip dysplasia patients and 95.7% (95% CI: 93.3% to 98.2%) in 397 ONFH patients. There was no significant difference in survivorship between hip dysplasia and ONFH ($p = 0.4$) (Figure 3). There was no case of wear-related revision in hip dysplasia and one case of aseptic loosening in ONFH. Two cases in hip dysplasia underwent revision THA following recurrent dislocation and one case in ONFH. Causes of revision THA are detailed in Table II.

The mean cup inclination was 47.6° ± 6.6° in hip dysplasia group and 43.9° ± 6.3° in ONFH group. It was significantly steeper in the hip dysplasia group compared to the ONFH group ($p = 0.002$). Cup anteversion was not significantly different between the two groups ($p = 0.150$). Differences of the mean volumetric and linear wear rate between the two

**TABLE I**
Demographic and clinical data of patients

| | All cases (n = 124) | | | | Hip dysplasia (n = 62) | | | | ONFH (n = 62) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | n | Mean ± SD | Median | Range | n | Mean ± SD | Median | Range | n | Mean ± SD | Median | Range | *p* |
| Age (year) | | 52.4 ± 8.9 | | | | 52.4 ± 9.1 | | | | 52.3 ± 8.8 | | | 0.984 |
| Sex | | | | | | | | | | | | | 1.000 |
| Male | 42 | | | | 21 | | | | 21 | | | | |
| Female | 82 | | | | 41 | | | | 41 | | | | |
| Body mass index (kg/m$^2$) | | 23.3 ± 2.4 | | | | 23.3 ± 2.5 | | | | 23.3 ± 2.4 | | | 0.929 |
| Follow-up (year) | | 13.3 ± 2.8 | | | | 13.1 ± 2.8 | | | | 13.5 ± 2.8 | | | 0.403 |
| Crowe type | | | | | | | | | | | | | |
| I | | | | | 36 | | | | | | | | |
| II | | | | | 13 | | | | | | | | |
| III | | | | | 9 | | | | | | | | |
| IV | | | | | 4 | | | | | | | | |
| Ficat stage | | | | | | | | | | | | | |
| III | | | | | | | | | 37 | | | | |
| IV | | | | | | | | | 16 | | | | |
| PT AVN | | | | | | | | | 9 | | | | |
| Cup | | | | | | | | | | | | | 0.121 |
| Converge | 34 | | | | 12 | | | | 22 | | | | |
| Interoperability | 25 | | | | 13 | | | | 12 | | | | |
| Trilogy | 65 | | | | 37 | | | | 28 | | | | |
| Mean cup size (mm) | | | 58.2 | 51-67 | | | 58.7 | 51-60 | | | 57.7 | 53-67 | 0.110 |
| Liner | | | | | | | | | | | | | 0.293 |
| Durasul standard | 23 | | | | 15 | | | | 8 | | | | |
| Durasul hooded | 18 | | | | 7 | | | | 11 | | | | |
| Longevity standard | 42 | | | | 22 | | | | 20 | | | | |
| Longevity elevated | 41 | | | | 18 | | | | 23 | | | | |
| Mean liner thickness (mm) | | | 9.21 | 6.8-14.9 | | | 9.47 | 6.8-14.9 | | | 8.86 | 6.8-11.9 | 0.142 |
| Head size (mm) | | | | | | | | | | | | | 0.099 |
| 28 | 74 | | | | 32 | | | | 42 | | | | |
| 36 | 50 | | | | 30 | | | | 20 | | | | |

ONFH; osteonecrosis of the femoral head; SD, standard deviation; PT AVN, post-traumatic avascular necrosis.

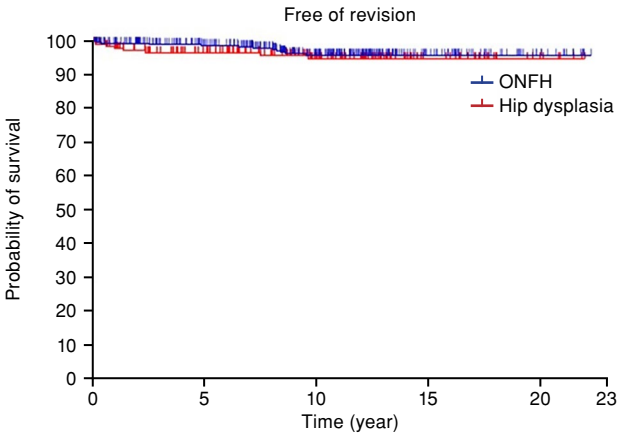



**FIGURE 3.** Kaplan-Meier survivorship
ONFH, osteonecrosis of the femoral head.

groups were also not significant (volumetric wear rate $p = 0.177$; linear wear rate: $p = 0.702$) (Table III).

The incidence of cup inclination less than 45° was 35.5% in the hip dysplasia group, and 62.9% in the ONFH group. The number of cases with cup inclination more than 55° was seven (11.3%) in the hip dysplasia group and four (6.5%) in the ONFH group and the incidence of cup inclination more than 55° was significantly greater in the hip dysplasia group ($p = 0.006$) (Figure 4). The volumetric and linear wear rates among the three subgroups were not significantly different (Table IV). In addition, no significant correlation was observed between cup inclination and volumetric or linear wear rates of HXLPE (Figure 5).

Preoperative HHS of both groups showed improvement at the final follow-up. Both the preoperative and final HHS were not significantly different between the two groups (Table V).

**TABLE II**
Cause of revision

| | Hip dysplasia (n = 178) | ONFH (n = 397) |
|---|---|---|
| Cause of revision | n | n |
| Wear-related | | |
| Osteolysis | 0 | 0 |
| Aseptic loosening | 0 | 1 |
| Others | | |
| PJI | 3 | 8 |
| Periprosthetic fracture | 4 | 3 |
| Recurrent dislocation | 2 | 1 |

ONFH, osteonecrosis of the femoral head; PJI, periprosthetic joint infection.

The incidence of hip joint dislocation was reported in one case in the hip dysplasia group and two in the ONFH group. The patient in the hip dysplasia group experienced two episodes of dislocation following a slip down at three years postoperatively. One patient in the ONFH group experienced three episodes of anterior dislocation beginning six months after surgery following a slip down. Another patient experienced a single episode of posterior dislocation at three months postoperatively during hip flexion. All patients were conservatively treated with closed reduction and positional education. No significant differences were found between the two groups ($p = 0.559$) (Table V).

No cases of progressive osteolysis or prosthetic loosening were observed. In the hip dysplasia group, stress shielding occurred in six cases and in eight cases in the ONFH group. Heterotopic ossification was observed in 12 cases in the hip dysplasia group and 10 cases in the ONFH group. No limitation of motion or pain, which can be

**TABLE III**
Primary outcomes

| | Hip dysplasia (n = 62) | | | ONFH (n = 62) | | | |
|---|---|---|---|---|---|---|---|
| | n | % | Mean ± SD | n | % | Mean ± SD | *p* |
| Cup inclination (°) | | | 47.6 ± 6.6 | | | 43.9 ± 6.3 | 0.002* |
| Cup anteversion (°) | | | 15.9 ± 9.2 | | | 13.8 ± 6.2 | 0.150 |
| Volumetric wear rate ($mm^3$/year) | | | 15.392 ± 17.673 | | | 10.859 ± 10.759 | 0.177 |
| Linear wear rate (mm/year) | | | 0.026 ± 0.021 | | | 0.023 ± 0.018 | 0.702 |
| Distribution of cup inclination | | | | | | | 0.006* |
| Cup inclination ≤ 45° | 22 | 35.5 | | 39 | 62.9 | | |
| 45° < Cup inclination < 55° | 33 | 53.2 | | 19 | 30.6 | | |
| Cup inclination ≥ 55° | 7 | 11.3 | | 4 | 6.5 | | |

ONFH, osteonecrosis of the femoral head; SD, standard deviation; *, statistically significant.

**TABLE IV**
Subgroup analysis

| | Volumetric wear rate ($mm^3$/year) | | | Linear wear rate (mm/year) | | |
|---|---|---|---|---|---|---|
| | Hip dysplasia group (n= 7 / 33 / 22) | ONFH group (n= 4 / 19 / 39) | | Hip dysplasia group (n= 7 / 33 / 22) | ONFH group (n= 4 / 19 / 39) | |
| | Mean ± SD | Mean ± SD | *p* | Mean ± SD | Mean ± SD | *p* |
| Cup inclination ≤ 45° | 19.743 ± 17.625 | 12.240 ± 9.847 | 0.444 | 0.0302 ± 0.022 | 0.0205 ± 0.016 | 0.250 |
| 45° < Cup inclination < 55° | 13.680 ± 18.605 | 9.415 ± 12.487 | 0.121 | 0.0229 ± 0.020 | 0.0275 ± 0.020 | 0.304 |
| Cup inclination ≥ 55° | 9.931 ± 3.112 | 4.247 ± 2.639 | 0.109 | 0.0251 ± 0.010 | 0.0226 ± 0.011 | 0.927 |
| *p*-value | 0.4529 | 0.1061 | | 0.7114 | 0.2058 | |

ONFH, osteonecrosis of the femoral head; SD, standard deviation.

considered clinical symptoms of heterotopic ossification, was observed in these cases (Table V).

The average of the measurements recorded by the two investigators. All ICCs of intra- and inter-observer reliabilities were found to be satisfactory (> 0.8; range, 0.85 to 0.96).

## DISCUSSION

In the present study, we compared the long-term outcome of HXLPE in hip dysplasia with ONFH and evaluated the effect of cup inclination on HXLPE wear after THA. Our study results showed that implant survivorship following THA

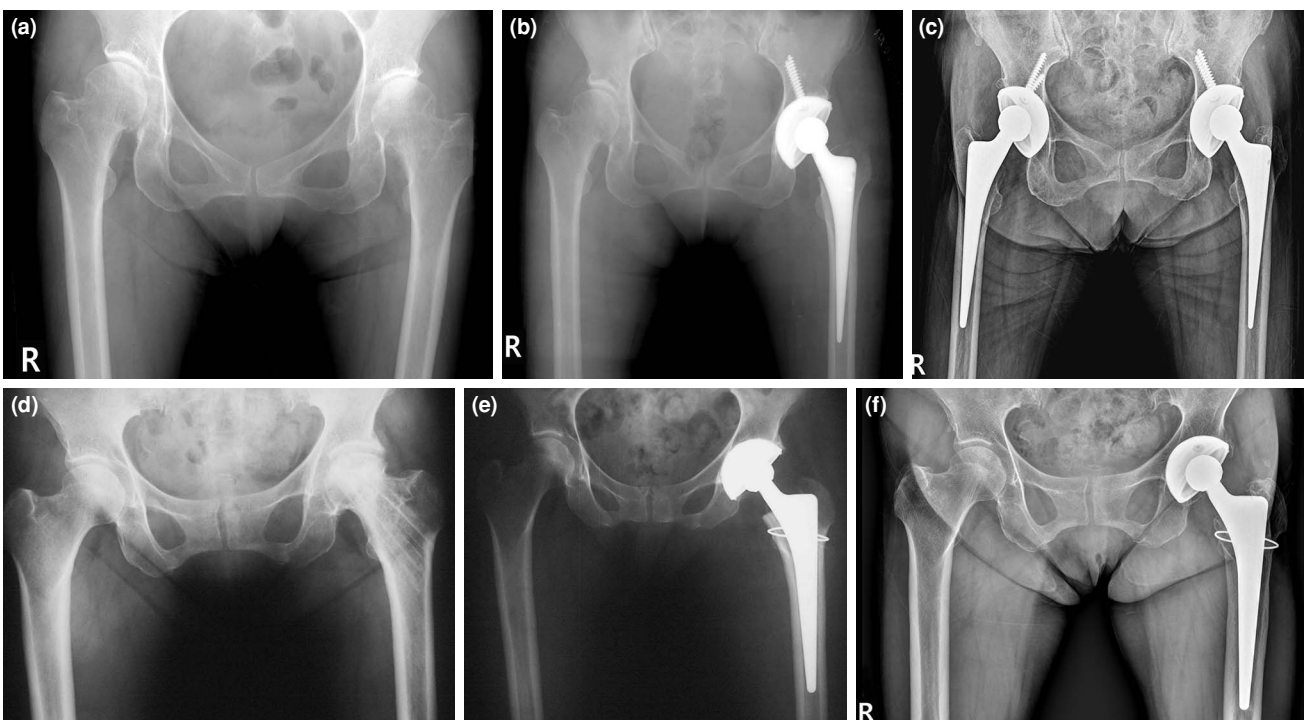



**FIGURE 4.** Sixty-three-year-old woman in hip dysplasia group was matched with 61-year-old woman in ONFH (osteonecrosis) group. **(a)** A radiograph showed left hip OA due to hip dysplasia. **(b)** Left THA (total hip arthroplasty) was performed; cup inclination of acetabular cup was 63.1°. **(c)** A radiograph showed stable fixation of acetabular cup, linear wear rate was 0.0200 mm/year, and volumetric wear rate was 11.0 $mm^3$/year at 17.2 years follow up period. **(d)** A radiograph showed left post-traumatic avascular necrosis. **(e)** Left THA was performed; cup inclination of acetabular cup was 44.5°. **(f)** A radiograph showed stable fixation of acetabular cup, linear wear rate was 0.086 mm/year, and volumetric wear rate was 32.6 $mm^3$/year at 11.1 years follow up period.
ONFH, osteonecrosis of the femoral head; OA, osteoarthritis; THA, total hip arthroplasty.

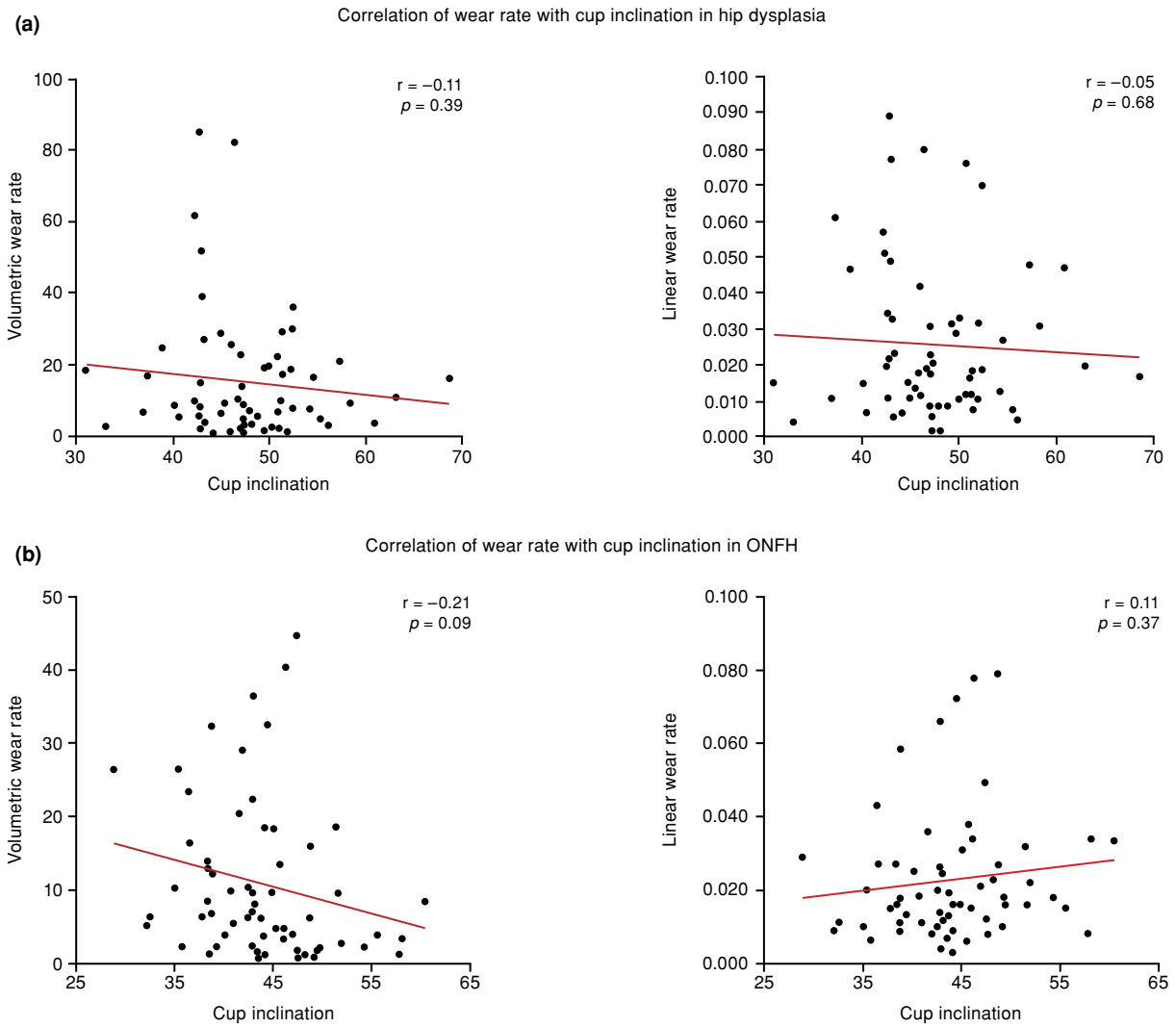



**FIGURE 5.** Scatter plot of wear rate and cup inclination. Neither linear nor volumetric wear rate with cup inclination did not show significant correlation in both groups. **(a)** Correlation of wear rate with cup inclination in hip dysplasia group. **(b)** Correlation of wear rate with cup inclination in ONFH group.
ONFH, osteonecrosis of the femoral head.

in patients with hip dysplasia was satisfactory compared to ONFH. Between the matched cohort, the mean cup inclination was significantly steeper and the cup inclination more than 55° occurred more frequently in the hip dysplasia compared to ONFH. Despite the tendency of steep cup inclination, the wear rate of the HXLPE liner in hip dysplasia was comparable to that in ONFH at a minimum of 10-year follow-up. Several other long-term radiological and clinical outcomes were also comparable. These findings suggest that increased cup inclination in hip dysplasia may not adversely affect HXLPE wear or long-term clinical outcomes following THA.

Implant survivorship of THA in hip dysplasia has usually been reported as promising in previous studies. Caylak et al.[25] reported favorable survivorship of ceramic-on-ceramic bearing THA in patients with hip dysplasia. Excellent survivorship of HXLPE was also observed in a study with minimum 13-year follow-up.[8] These findings are consistent with our results. However, a limited number of studies have reported excessive wear and osteolysis in THA for hip dysplasia.[13,18] In those studies, the underlying causes of wear-related complications were not clearly elucidated. Although no wear-related complications were observed in our cohort,

**TABLE V**
Secondary outcome

| | Hip dysplasia (n = 62) | | | ONFH (n = 62) | | | |
|---|---|---|---|---|---|---|---|
| | n | Median | Range | n | Median | Range | *p* |
| Preoperative HHS | | 52.2 | 37-87 | | 54.2 | 31-72 | 0.203 |
| Last follow up HHS | | 91.3 | 79-97 | | 92.1 | 84-97 | 0.263 |
| Dislocation | | | | | | | 0.559 |
| Solitary | 0 | | | 1 | | | |
| Recurrent | 1 | | | 1 | | | |
| Osteolysis | 0 | | | 0 | | | |
| Implant loosening | 0 | | | 0 | | | |
| Stress shielding (°) | | | | | | | |
| 1st | 3 | | | 3 | | | |
| 2nd | 1 | | | 4 | | | |
| 3rd | 2 | | | 1 | | | |
| 4th | 0 | | | 0 | | | |
| Heterotopic ossification | | | | | | | |
| Grade 1 | 7 | | | 2 | | | |
| Grade 2 | 4 | | | 6 | | | |
| Grade 3 | 1 | | | 2 | | | |
| Grade 4 | 0 | | | 0 | | | |

ONFH; osteonecrosis of the femoral head; HHS; Harris Hip Score.

this issue remains controversial, and further investigations are warranted.

Hip dysplasia predisposes patients to a higher risk of acetabular cup malpositioning. Steep cup inclination is considered as a potential risk of THA for hip dysplasia. This inevitably happens to improve the host bone coverage, which is another difficulty when performing THA for hip dysplasia. Several authors have reported frequent incidences of steep cup inclinations in THA for hip dysplasia. To illustrate, the average cup inclination in hip dysplasia was > 45° in Tsukamoto et al.'s study,[18] and Georgiades et al.[14] reported a cup inclination of > 45° in 45.5% of cases. In our study, the mean cup inclination of hip dysplasia was 47° and the incidence of cup inclination > 45° was 64.5% and that of > 55° was 11%. These results are consistent with those of previous studies.

In the literature, several finite element analyses have investigated the correlation between the cup inclination and wear rate. Patil et al.[12] demonstrated that the wear rate of a polyethylene liner significantly increased when the cup inclination was 55° compared to 45°. D'Lima et al.[26] reported that optimizing the acetabular cup position was critical for minimizing impingement and contact stress. Otherwise, the finite element analysis suggested an inverse relationship. This might result from the decreased head coverage, thereby decreasing the contact surface where wear occurs.[27] The assessment of the factor that is associated with wear in finite element analysis might be unreasonable because the wear of HXLPE is affected not only by cup inclination, but also by dynamic stability and impingement during joint motion. Del Schutte et al.[28] reported an average of 1.20 mm wear rate with no correlation between the wear rate of conventional polyethylene and cup inclination. Although this result agrees with that of ours, the mean wear rate is higher compared to our results. Several factors may contribute to the lower wear rate in our cohort. We believe that the use of HXLPE is the most important factor in reducing wear. Previous studies have demonstrated that accelerated wear is associated with the use of conventional polyethylene, and finite element analyses in those studies were conducted using conventional ultra-high-molecular-weight polyethylene.

Hip joint dislocation and impingement potentially affect HXLPE wear. Although placing the acetabular cup in a high hip center is commonly used in THA for hip dysplasia, it is also a known

one of the risk factors of hip joint dislocation and impingement.[29] Small cup size may further contribute to dislocation, impingement, and implant failure.[13] Patients with high-grade hip dysplasia typically present with abnormal soft-tissue tension and forces, which experience rapid restoration during THA. As they adapt to these new biomechanical conditions, complications such as hip joint dislocation, impingement and accelerated wear can occur. Nevertheless, we believe that elevated liner can be useful option, and that HXLPE can provide sufficient wear resistance. Ultimately, restoring the normal hip anatomy offers the best long-term outcomes and surgeons should make every effort to achieve adequate cup positioning, including inclination, anteversion, sufficient medialization, and positioning in the true acetabulum. Although cup inclination was steep, the mean anteversion was within the normal range, and sufficient medialization was achieved in our study. The cup was fixed to the true acetabulum in all cases.

Wear and osteolysis are the representative problems of HXLPE and some studies have prevalent osteolysis and a high revision rate in hip dysplasia.[13,18] Alternative bearing surfaces are occasionally preferred for these reasons. Metal-on-metal bearing surfaces are known for their very low wear rates. However, delayed hypersensitivity reactions and the development of pseudotumors are inherent complications of this bearing type. Ceramic-on-ceramic bearing surfaces, an alternative, have shown successful outcomes in hip dysplasia.[25] Despite this tribological improvement, risks of ceramic-specific complications such as squeaking, ceramic fracture, and malpositioning of components, exist. Higuchi et al.[30] reported no difference between ceramic-on-ceramic bearings and metal-on-HXLPE bearings on mid-term follow-up. Therefore, comparison of several bearing surfaces is controversial. Nevertheless, no cases of osteolysis or implant loosening were reported.

Nonetheless, this study has certain limitations that should be acknowledged. Due to the retrospective design of the study and the relatively small number of patients included, selection bias could have occurred in the matching process, although we attempted to minimize bias by blinding outcomes before cohort matching. In addition, although prosthesis survivorship of unmatched patients was evaluated, there were a lot of cases which failed to match. The statistical power of some analyses is limited by the small differences in mean cup inclination and the small sample size, particularly in the group with cup inclination ≥ 55°. Although the incidence of cup inclination more than 55° was significantly greater in the hip dysplasia group, it was challenging to collect enough cases for this subgroup in our study. Care should be taken to avoid overinterpreting our findings, and a larger-scale study could more clearly demonstrate the correlation between cup inclination and wear rate. In addition, we did not precisely measure the postoperative hip center location, which may influence the wear rate. This was because all cups were positioned in the true acetabulum with sufficient medialization, and we considered cup inclination to be a more critical factor than hip center location. We primarily focused on demonstrating the relationship between cup inclination and the wear rate of HXLPE. We only performed computed tomography (CT) to evaluate osteolysis or loosening in patients (84%) who agreed to undergo CT, although CT is considered more sensitive to detect osteolysis or loosening than plain radiographs. We did not detect any problematic osteolytic lesions on CT scans of the study group.

On the other hand, to the best of our knowledge, this study is the first to compare the long-term wear rate and radiological and clinical outcomes of THA with HXLPE between hip dysplasia and ONFH in the literature. In addition, the studies on the association between cup inclination and the wear rate of HXLPE liners are limited. We subdivided each group based on cup inclination, analyzed the wear rate of the subgroups, and demonstrated that despite the steeper cup inclination tendency, the wear rate of HXLPE in hip dysplasia was comparable to that in ONFH.

In conclusion, although patients with hip dysplasia demonstrated a steeper mean cup inclination and a higher incidence of steep cup positioning compared to those with ONFH, implant survivorship remained comparable between groups in the overall cohort. In the matched cohort analysis, HXLPE wear rates and clinical outcomes were also comparable between the groups. Furthermore, no significant association was identified between cup inclination and HXLPE wear. These findings suggest that, despite technical challenges in acetabular positioning, the use of HXLPE in THA for hip dysplasia provides satisfactory long-term performance and may alleviate concerns regarding

cup inclination-related wear. Further multi-center, large-scale, prospective studies are warranted to confirm these findings and to better evaluate the long-term influence of acetabular cup positioning on HXLPE wear.

**Data Sharing Statement:** The data that support the findings of this study are available from the corresponding author upon reasonable request.

**Author Contributions:** B.W.M., K.J.L.: Conception and design of study; B.C.C., H.S.S.: Acquisition of data; B.C.C., K.J.L.: Analysis and/or interpretation of data; B.C.C., K.J.L., B.W.M.: Drafting the manuscript; K.J.L., B.W.M.: Revising the manuscript critically for important intellectual content.

**Conflict of Interest:** The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

**Funding:** The authors received no financial support for the research and/or authorship of this article.

**AI Disclosure:** The authors declare that artificial intelligence (AI) tools were not used, or were used solely for language editing, and had no role in data analysis, interpretation, or the formulation of conclusions. All scientific content, data interpretation, and conclusions are the sole responsibility of the authors. The authors further confirm that AI tools were not used to generate, fabricate, or 'hallucinate' references, and that all references have been carefully verified for accuracy.

## REFERENCES

1. Turan K, Kezer M, Çamurcu Y, Uysal Y, Kızılay YO, Ucpunar H, et al. Intraoperative neurophysiological monitoring in total hip arthroplasty for crowe types 3 and 4 hips. Clin Orthop Surg 2023;15:711-7. doi: 10.4055/cios22371.
2. Tolunay T, Baymurat AC, Çalta MŞ, Atalar H. Cakirgil method in the surgical treatment of older children with developmental dysplasia of the hip: Mid-term follow-up results of 17 hips and literature review. Jt Dis Relat Surg 2024;35:202-8. doi: 10.52312/jdrs.2023.1510.
3. Tateda K, Nagoya S, Suzuki D, Kosukegawa I, Yamashita T. Acetabular morphology in patients with developmental dysplasia of the hip with high dislocation. Hip Pelvis 2021;33:25-32. doi: 10.5371/hp.2021.33.1.25.
4. Rogers BA, Garbedian S, Kuchinad RA, Backstein D, Safir O, Gross AE. Total hip arthroplasty for adult hip dysplasia. J Bone Joint Surg Am 2012;94:1809-21. doi: 10.2106/JBJS.K.00779.
5. Ueno T, Kabata T, Kajino Y, Ohmori T, Yoshitani J, Tsuchiya H. Three-dimensional host bone coverage required in total hip arthroplasty for developmental dysplasia of the hip and its relationship with 2-dimensional coverage. J Arthroplasty 2019;34:93-101. doi: 10.1016/j.arth.2018.09.082.
6. Yon CJ, Lee KJ, Choi BC, Suh HS, Min BW. The validation of two-dimensional and three-dimensional radiographic measurements of host bone coverage in total hip arthroplasty for hip dysplasia: A comparison with intra-operative measurements. J Clin Med 2023;12:6227. doi: 10.3390/jcm12196227.
7. Wang L, Thoreson AR, Trousdale RT, Morrey BF, Dai K, An KN. Two-dimensional and three-dimensional cup coverage in total hip arthroplasty with developmental dysplasia of the hip. J Biomech 2013;46:1746-51. doi: 10.1016/j.jbiomech.2013.03.025.
8. Galea VP, Laaksonen I, Donahue GS, Fukui K, Kaneuji A, Malchau H, et al. Developmental dysplasia treated with cementless total hip arthroplasty utilizing high hip center reconstruction: A minimum 13-year follow-up study. J Arthroplasty 2018;33:2899-905. doi: 10.1016/j.arth.2018.04.037.
9. Della Valle AG, Padgett DE, Salvati EA. Preoperative planning for primary total hip arthroplasty. J Am Acad Orthop Surg 2005;13:455-62. doi: 10.5435/00124635-200511000-00005.
10. Inori F, Ohashi H, Yo H, Okajima Y, Matsui Y, Shintani K. Accuracy of cup height and medialization in THA for dysplastic hip osteoarthritis using an imageless navigation system. Orthopedics 2012;35:7-12. doi: 10.3928/01477447-20120919-50.
11. Park JW, Park JH, Kim HS, Lee YK, Han KY, Ha YC, et al. Optimization of acetabular cup abduction by adjusting pelvic pitch. Clin Orthop Surg 2024;16:16-22. doi: 10.4055/cios21219.
12. Patil S, Bergula A, Chen PC, Colwell CW Jr, D'Lima DD. Polyethylene wear and acetabular component orientation. J Bone Joint Surg Am 2003;85:56-63. doi: 10.2106/00004623-200300004-00007.
13. Murray PJ, Hwang KL, Imrie SN, Huddleston JI 3rd, Goodman SB. Polyethylene wear and osteolysis is associated with high revision rate of a small sized porous coated THA in patients with hip dysplasia. J Arthroplasty 2014;29:1373-7. doi: 10.1016/j.arth.2014.02.027.
14. Georgiades G, Babis GC, Kourlaba G, Hartofilakidis G. Effect of cementless acetabular component orientation, position, and containment in total hip arthroplasty for congenital hip disease. J Arthroplasty 2010;25:1143-50. doi: 10.1016/j.arth.2009.12.016.
15. Tian JL, Sun L, Hu RY, Han W, Tian XB. Correlation of cup inclination angle with liner wear for metal-on-polyethylene in hip primary arthroplasty. Orthop Surg 2017;9:186-90. doi: 10.1111/os.12337.
16. Min BW, Cho CH, Son ES, Lee KJ, Lee SW, Song KS. Highly cross-linked polyethylene in total hip arthroplasty in patients younger than 50 years with osteonecrosis of the femoral head: A minimum of 10 years of follow-up. J Arthroplasty 2020;35:805-10. doi: 10.1016/j.arth.2019.10.021.
17. Min BW, Bae KC, Cho CH, Son ES, Lee KJ, Lee SW. Highly cross-linked polyethylene in cementless total hip arthroplasty in patients with previous acetabular fractures: A minimum 5-year follow-up study. Indian J Orthop 2020;54:239-45. doi: 10.1007/s43465-020-00137-z.
18. Tsukamoto M, Ohnishi H, Mori T, Kawasaki M, Uchida S, Sakai A. Fifteen-year comparison of wear and osteolysis analysis for cross-linked or conventional polyethylene in cementless total hip arthroplasty for hip dysplasia-a retrospective cohort study. J Arthroplasty 2017;32:161-5.e1. doi: 10.1016/j.arth.2016.06.008.
19. Zicat B, Engh CA, Gokcen E. Patterns of osteolysis around total hip components inserted with and without cement. J Bone Joint Surg Am 1995;77:432-9. doi: 10.2106/00004623-199503000-00013.
20. Johnston RC, Fitzgerald RH Jr, Harris WH, Poss R, Müller ME, Sledge CB. Clinical and radiographic

evaluation of total hip replacement. A standard system of terminology for reporting results. J Bone Joint Surg Am 1990;72:161-8.

21. Brooker AF, Bowerman JW, Robinson RA, Riley LH Jr. Ectopic ossification following total hip replacement. Incidence and a method of classification. J Bone Joint Surg Am 1973;55:1629-32.
22. Engh CA, Massin P, Suthers KE. Roentgenographic assessment of the biologic fixation of porous-surfaced femoral components. Clin Orthop Relat Res. 1990;(257):107-28.
23. DeLee JG, Charnley J. Radiological demarcation of cemented sockets in total hip replacement. Clin Orthop Relat Res 1976;(121):20-32.
24. Gruen TA, McNeice GM, Amstutz HC. "Modes of failure" of cemented stem-type femoral components: A radiographic analysis of loosening. Clin Orthop Relat Res 1979;(141):17-27.
25. Caylak R, Ors C, Togrul E. Minimum 10-year results of cementless ceramic-on-ceramic total hip arthroplasty performed with transverse subtrochanteric osteotomy in crowe type IV hips. J Arthroplasty 2021;36:3519-26. doi: 10.1016/j.arth.2021.05.035.
26. D'Lima DD, Chen PC, Colwell CW Jr. Optimizing acetabular component position to minimize impingement and reduce contact stress. J Bone Joint Surg Am 2001;83:87-91. doi: 10.2106/00004623-200100022-00005.
27. Korduba LA, Essner A, Pivec R, Lancin P, Mont MA, Wang A, et al. Effect of acetabular cup abduction angle on wear of ultrahigh-molecular-weight polyethylene in hip simulator testing. Am J Orthop (Belle Mead NJ) 2014;43:466-71.
28. Del Schutte H Jr, Lipman AJ, Bannar SM, Livermore JT, Ilstrup D, Morrey BF. Effects of acetabular abduction on cup wear rates in total hip arthroplasty. J Arthroplasty 1998;13:621-6. doi: 10.1016/s0883-5403(98)80003-x.
29. Watts CD, Abdel MP, Hanssen AD, Pagnano MW. Anatomic hip center decreases aseptic loosening rates after total hip arthroplasty with cement in patients with crowe type-II dysplasia: A concise follow-up report at a mean of thirty-six years. J Bone Joint Surg Am 2016;98:910-5. doi: 10.2106/JBJS.15.00902.
30. Higuchi Y, Seki T, Hasegawa Y, Morita D, Komatsu D, Takegami Y, et al. Comparison of cementless total hip arthroplasty survivorship between metal-on-highly cross-linked polyethylene and ceramic on ceramic bearings: A case control study with a 5-9-year follow-up. Orthop Traumatol Surg Res 2018;104:663-9. doi: 10.1016/j.otsr.2018.04.016.