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Significantly Lower Wear of Ceramic-on-Ceramic Bearings Than Metal-on-Highly Cross-Linked Polyethylene Bearings: A 10- to 14-Year Follow-Up Study

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ABSTRACT

Background: This study aimed to retrospectively compare clinical and radiographic results between consecutive total hip arthroplasties (THAs) using ceramic on ceramic (CoC) and metal-on-highly cross-linked polyethylene (MoP), with >10 years of follow-up.
Methods: Sixty-seven patients (52 women and 15 men) underwent CoC THA, whereas 81 (67 women and 14 men) underwent MoP THA. The average patient age at the time of surgery was 54.0 years in the CoC group and 54.2 years in the MoP group.
Results: The mean postoperative Harris Hip Scores were 88.9 and 86.4 in the CoC and MoP groups, respectively ($P = .063$), and the mean annual liner rates of wear were 0.0043 and 0.0163 mm/year, respectively ($P < .001$). Osteolysis was observed on the femoral side of 1 joint (1.5%) in the CoC group and in 1 (1.2%) acetabular and femoral (1.2%) joint each in the MoP group. Three joints (3.7%) in the MoP group showed aseptic cup loosening, one of which (1.2%) required revision THA because of progression of the loosening. Revision THA was also required in 1 joint (1.5%) in the CoC group because of ceramic fracture. The Kaplan–Meier survival rate at 10 years with implant loosening or revision THA as the end point was 98.5% for CoC and 96.3% for MoP ($P = .416$).
Conclusion: The wear rate of CoC implants was significantly lower than that of MoP implants. Kaplan–Meier survival at 10 years with implant loosening and revision THA as end points did not differ significantly between these implants.

Total hip arthroplasty (THA) has become a common treatment for osteoarthritis of the hip [1,2]. However, despite improved implant designs and surgical techniques, bearing surface wear and the resultant wear-induced osteolysis continue to be major limitations to long-term prosthesis survival [1–6].

Metal-on-polyethylene bearing surfaces were once considered the gold standard for THA and have shown good long-term results in elderly patients [5,7]. However, in recent decades, the debris generated from polyethylene liner wear with time was found to be associated with the occurrence of osteolysis, which subsequently leads to implant loosening and failure. The osteolysis rate of metal-on-polyethylene bearings has been reported to be as high as 26%, and the aseptic loosening rate was found to be 3% after 10 years of follow-up in a previous study [1]. To avoid problems caused by wear debris, different bearing surfaces have been developed, such as metal-on-highly cross-linked polyethylene (MoP), which shows lower linear and volumetric wear than conventional polyethylene [3,4,8]. Similarly, hard bearing surfaces such as ceramic on ceramic (CoC) have also been developed to address the problem of osteolysis [6].

The aim of the present study was to compare the clinical and radiographic results, especially the wear rate, of consecutive CoC bearings to those of MoP bearings obtained in a 10-year follow-up period.

Materials and Methods

Patient Selection

Between April 2000 and December 2004, we performed consecutive CoC THAs at 1 institution and MoP THAs at another to

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minimize the risk of selection bias. A total of 187 patients (193 THAs) who completed a minimum follow-up period of 10 years were eligible for the study. The exclusion criteria included death from causes unrelated to surgery (5 patients; 5 joints), patient inaccessibility (8 patients moved abroad; 8 joints), Crowe group III/IV hips (3 patients; 3 joints), and revision THA (29 patients; 29 joints).

Informed consent was obtained from all patients, and the study was approved by the ethics committee of our hospital. Demographic data are given in Table 1. All operations were performed by a single senior surgeon or a junior surgeon who was supervised by the senior surgeon. The posterolateral approach was used for surgery, with the patients in the lateral decubitus position. The socket was fixed in the acetabulum using an acetabular alignment guide.[7]

Acetabular and Femoral Components

Three titanium alloy acetabular components were used in this study: Trident PSL, TriAD, and Securfit AD, with a hydroxyapatite arc deposited titanium surface (Stryker Orthopaedics, Mahwah, NJ). Although the ceramic material in all 3 implants was the same, the ceramic liners of Trident PSL and TriAD were recessed within a metal-backed titanium sleeve, whereas those of Securfit AD were not.

Three titanium alloy femoral components with the same metal constituents as the acetabular components were also used: Securfit, Super Securfit, and C-stem (Stryker Orthopaedics; Table 2). In all cases, the highly cross-linked polyethylene liner used was Crossfire Polyethylene Insert (Stryker Orthopaedics), whereas the ceramic liner and head were BIOLOX forte (CeramTec, Plochingen, Germany). The diameter of the cobalt chrome head was 26 mm for 81 joints (100%). The diameter of the ceramic head was 28 mm for 36 joints (53.7%) and 32 mm for 31 joints (46.3%; Table 3).

Data Collection

The patients' clinical data including the Harris Hip Score were prospectively recorded by a senior surgeon 1 month before THA, 6 months and 1 year after THA, and then annually and at the final follow-up after THA. These data were then retrospectively investigated from the patients' medical records.

Radiographs of the hips in the standard anteroposterior (AP) view and Lauenstein view with the patient in the supine position were recorded 3 months postoperatively and then annually. AP radiographs with both hips in neutral rotation and 0° abduction and Lauenstein-view (frog position) radiographs with the hips in 45° abduction were collected for each patient [9,10].

Table 1
Patient Demographics.

Parameters	CoC Group (n = 67)	MoP Group (n = 81)	*P* Values
Age (range), y	54.0 (28-70)	54.2 (24-79)	.788
Gender (female/male)	52/15	67/14	.534
BMI (range), kg/m^2	23.9 (17.7-32)	22.5 (16.8-31.8)	.639
Follow-up (range), y	11.0 (10-13)	11.3 (10-14)	.185
Diagnosis, n (%)			.571
Osteoarthritis	56 (83.6)	64 (79.0)	
Avascular necrosis	11 (16.4)	16 (19.8)	
Post-traumatic osteoarthritis	0	1 (1.2)	

CoC, ceramic on ceramic; MoP, metal-on-highly cross-linked polyethylene; BMI, body mass index.

Table 2
Characteristics of Implants.

	CoC Group (n = 67)	MoP Group (n = 81)
Cementless cup		
Trident PSL	30 (44.8%)	64 (79.0%)
TriAD HA	10 (14.9%)	17 (21.0%)
Securfit AD	27 (40.3%)	0
Cementless stem		
Securfit	31 (46.3%)	50 (61.7%)
Super Securfit	36 (53.7%)	6 (7.3%)
Cemented stem		
C-stem	NA	25 (30.9%)

CoC, ceramic on ceramic; MoP, metal-on-highly cross-linked polyethylene; NA, not available.

Radiographic evaluations with images magnified to 400% were independently performed by 2 surgeons using the Neochart computer system (Fujitsu Co, Tokyo, Japan).

Definite loosening of the femoral component was defined as progressive axial subsidence of >3 mm or a varus or valgus shift [9]. Definite loosening of the acetabular component was diagnosed if the position of the component changed (over 2 mm vertically and/or medially or laterally) or if a continuous radiolucent line wider than 2 mm was seen on both AP- and Lauenstein-view radiographs [10]. Osteolysis was defined as areas of endosteal, intracortical, or cancellous destruction of the bone that were not linear, exceeded 2 mm in width, and were progressive [11]. Acetabular inclination was measured using the transischial line as reference, and anteversion was investigated using the method of Lewinnek et al [12-14].

Using the methods of Dorr et al [15], 2 surgeons examined femoral head penetration into the liners from digitized AP- and Lauenstein-view radiographs by using the computer-digitizer facilities of the Roman V1.70 software (Institute of Orthopaedics, Oswestry, UK) [3,16,17]. The size of the implanted femoral head (26, 28, or 32 mm) was used as an internal reference (Fig. 1).

Femoral head penetration was investigated at annual intervals to calculate the wear, true wear, and creep rates. Wear rate was calculated by dividing total femoral head penetration by the time of the last follow-up in years. Linear regression was conducted for the mean femoral head penetration over time, and the creep and true wear rates were ascertained as the y-intercept and the slope of linear regression, respectively [16].

Intraclass correlation coefficients were calculated and used to determine interobserver reliability regarding the measurement of femoral head penetration.

Statistical Analysis

Statistical analyses included Fisher exact test, Student *t* test, and Kaplan–Meier survival analysis. All analyses were performed using SPSS, version 21 (IBM Corp, Armonk, NY). A *P* value <.05 was considered statistically significant.

Table 3
Femoral Head Diameter.

Diameter	Ceramic Head, n (%)	Cobalt Chrome Head, n (%)
26 mm	NA	81 (100)
28 mm	36 (53.7)	0
32 mm	31 (46.3)	0

NA, not available.

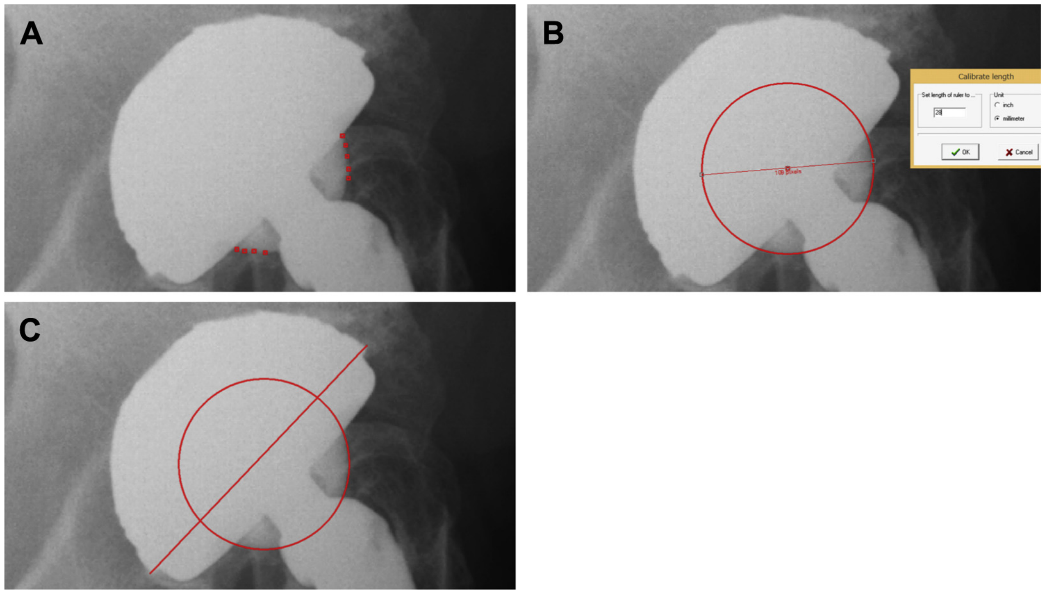

Fig. 1. (A) More than 8 points were chosen on the edge of the femoral head, which were averaged to generate the center of the femoral head. (B) The implanted size of the femoral head (26, 28, and 32 mm) was used as an internal reference. (C) Using the methods of Dorr et al, femoral head penetration into the liners was measured from digitized AP- and Lauenstein-view radiographs. AP, anteroposterior.

Results

Clinical Results

In the patient population included in the present study, 67 (52 women and 15 men) underwent CoC THA, whereas 81 (67 women and 14 men) underwent MoP THA. No significant differences were noted in the patients' age at surgery, gender, or body mass index; follow-up time; or diagnosis between the CoC and MoP groups. The mean postoperative Harris Hip Score was 88.9 and 86.4 in the CoC and MoP groups, respectively ($P = .063$; Table 4).

Dislocation occurred in 3 joints (4.5%) in the CoC group and 1 joint (1.2%) in the MoP group. All 4 dislocations were successfully treated conservatively by using single closed reduction, and no recurrence was noted.

Heterotopic bone formation was observed in 4 joints (6.0%) in the CoC group and 4 (4.9%) in the MoP group. All these joints were classified as Brooker class 1, showed no symptoms, and were treated conservatively [17]. One joint (1.5%) in the CoC group showed ceramic liner fracture, which may have occurred because of slight malseating of the liner during its insertion into the metal acetabular cup [18].

One joint in the MoP group (1.2%) required revision THA because of aseptic loosening of the cup. One joint (1.5%) in the CoC group showed audible squeaking. No cases of deep infection, deep vein thrombosis, or pulmonary embolism were found in either group.

Radiographic Results

Neither the anteversion nor inclination of the acetabular component position differed between the CoC and MoP groups ($P = .714$ and $P = .458$, respectively; Table 5).

Osteolysis was observed at the proximal part of the femoral component in 1 case (1.5%) in the CoC group and in the acetabular and femoral components in 1 case (1.2%) each in the MoP group (CoC vs MoP: acetabular and femoral joints, $P = .566$ and $P = .681$). All 3 cases were of focal osteolysis (Table 5).

Although no joints in the CoC group showed aseptic cup loosening, 3 joints (3.7%) in the MoP group showed loosening ($P = .258$). One of these joints (1.2%) required revision THA because the loosening progressed.

Femoral head penetration could not be measured for 4 joints in the CoC group because the margin of the femoral head could not be identified clearly in these joints. Thus, this parameter was

Table 4
Clinical and Radiographic Findings.

	CoC Group (n = 67)	MoP Group (n = 81)	*P* Values
HHS			
Preoperative	56.1 ± 8.8	55.4 ± 10.6	.344
Latest	88.9 ± 7.2	86.4 ± 7.2	.063
Revision THA	1 (1.5%)	1 (1.2%)	.702
Deep joint infection	0	0	1
Dislocation	3 (4.5%)	1 (1.2%)	.242
DVT, PE	0	0	1
Heterotopic bone	4 (6.0%)	4 (4.9%)	.531
Ceramic fracture			
Liner	1 (1.5%)	NA	
Head	0	NA	<.0001
Squeaking	1 (1.5%)	NA	<.0001

CoC, ceramic on ceramic; MoP, metal-on-highly cross-linked polyethylene; HHS, Harris Hip Score; THA, total hip arthroplasty; DVT, deep vein thrombosis; PE, pulmonary embolism; NA, not available.

Table 5
Clinical and Radiographic Findings.

	CoC Group (n = 67)	MoP Group (n = 81)	*P* Values
Acetabular component position			
Anteversion (°)	13.4 ± 5.4	18.1 ± 5.4	.714
Inclination (°)	44.7 ± 5.3	47.3 ± 6.8	.458
Osteolysis			
Acetabular	0	1 (1.2%)	.566
Femoral	1 (1.5%)	1 (1.2%)	.681
Aseptic loosening			
Cup	0	3 (3.7%)	.258
Stem	0	0	1
Wear (mm/y)			
AP view	0.0043 ± 0.0018	0.0162 ± 0.0052	<.0001
Lauenstein view	0.0048 ± 0.0036	0.0158 ± 0.0053	<.0001

CoC, ceramic on ceramic; MoP, metal-on-highly cross-linked polyethylene; AP, anteroposterior.

Table 6
Comparison of the Wear Rate According to the 3 Different Head Sizes (Cobalt−Chrome Head [26 mm], Ceramic Head [28 mm], and Ceramic Head [32 mm]).

	AP View	
	Ceramic Wear Rate (mm/y)	Ceramic Wear Rate (mm/y)
26-mm Size head (n = 78)	NA	0.0163 ± 0.0053
28-mm Size head (n = 34)	0.0044 ± 0.0016[a]	NA
32-mm Size head (n = 29)	0.0041 ± 0.0020[a,b]	NA
	Lauenstein View	
	Ceramic Wear Rate (mm/y)	Ceramic Wear Rate (mm/y)
26-mm Size head (n = 78)	NA	0.0158 ± 0.0054
28-mm Size head (n = 34)	0.0044 ± 0.0014[a]	NA
32-mm Size head (n = 29)	0.0053 ± 0.0047[a,b]	NA

AP, anteroposterior; NA, not available.
[a] There were statistically significant differences between the ceramic wear rate and the polyethylene wear rate.
[b] There were no significant differences between the wear rate of the 28-mm ceramic head and that of the 32-mm ceramic head.

measured for 63 joints in this group. The intraclass correlation coefficient was 0.737 (95% confidence interval [CI]: 0.16-0.982, $P = .0043$) for CoC and 0.876 (95% CI: 0.490-0.977, $P = .002$) for MoP.

The wear rate in the CoC group was found to be 0.0043 ± 0.0018 mm on AP view radiographs and 0.0048 ± 0.0032 mm on Lauenstein-view radiographs. The wear rate in the MoP group was found to be 0.0163 ± 0.0053 mm on AP-view radiographs and 0.0158 ± 0.0054 mm on Lauenstein-view radiographs. Thus, the wear rate was significantly lower for CoC than MoP irrespective of the radiographic view (AP and Lauenstein, $P < .0001$ and $P < .0001$, respectively; Table 5).

With regard to the sizes of the femoral heads, wear rate did not differ significantly between the 28-mm and 32-mm femoral heads in the CoC group (Table 6). However, these rates were significantly lower than those of the MoP group ($P < .0001$ and $P < .0001$, respectively; Table 6). The creep rate for CoC was 0.0029 mm/y on AP-view radiographs and 0.0013 mm/y on Lauenstein-view radiographs. On the other hand, the creep rate for MoP was 0.0458 mm on AP-view radiographs and 0.0352 mm on Lauenstein-view radiographs (Fig. 2). The true wear rate for CoC was 0.0043 mm/y on AP-view radiographs and 0.0046 mm/y on Lauenstein-view radiographs, whereas that for MoP was 0.0089 mm/y on AP-view radiographs and 0.0114 mm/y on Lauenstein-view radiographs.

Kaplan−Meier survival at 10 years with implant loosening or revision THA as the end point was 98.5% (95% CI: 89.97-99.8) for CoC and 96.3% (95% CI: 89.0-98.8) for MoP ($P = .416$; Fig. 3).

Discussion

THA is one of the most useful surgical treatments for end-stage osteoarthritis of the hip [2]. In most cases, it reliably ensures pain relief, joint stability, and bearing durability to enable patients to perform most life activities. However, durability is threatened when wear debris leads to osteolysis, which can result in implant loosening and ultimately implant failure [19,20]. Therefore, modern materials with improved wear characteristics, such as ceramics and highly cross-linked polyethylene, have gained popularity for use in THA [19-21]. Previous studies have shown that clinical and radiographic results at 4 or 5 years of follow-up do not differ significantly between CoC and MoP [3,5], but few studies have compared long-term outcomes between CoC THA and MoP THA [19]. In the present study, we found that the clinical results, complication rates, and survival rates at the 10-year follow-up did not differ significantly between the CoC and MoP groups.

The main problems related to CoC are ceramic fracture and squeaking. The previously reported incidence of ceramic fracture after CoC THA varied between 0.26% and 13.4% [21,22], whereas that of squeaking ranged from 0% to 10.7% [21]. In the present study, ceramic fracture and audible squeaking were observed in 1 joint each, and revision THA was required in the case of ceramic fracture but not in that of audible squeaking. The patient with audible squeaking experienced no pain and did not want to undergo surgical treatment.

Previous studies found a mean liner wear rate of 0.01-0.037 mm/y for MoP as observed on AP-view radiographs [23-25]. In contrast, the mean liner wear rate for CoC was 0.00183-0.0067 mm/year on AP-view radiographs [3,26]. In our study, the mean wear rate on the AP-view radiographs was 0.0043 ± 0.0018 mm/y for CoC and 0.0163 ± 0.0053 mm/y for MoP. Thus, our results were fairly consistent with those of previous reports, in that the wear rate for CoC was around a quarter of that for MoP. Additionally, large head sizes have been associated with a higher rate of wear in hip simulator studies [24]. In this study, the ceramic heads (28 and 32 mm) were bigger than the cobalt−chrome head (26 mm), but the wear rate of CoC was significantly lower than that of MoP.

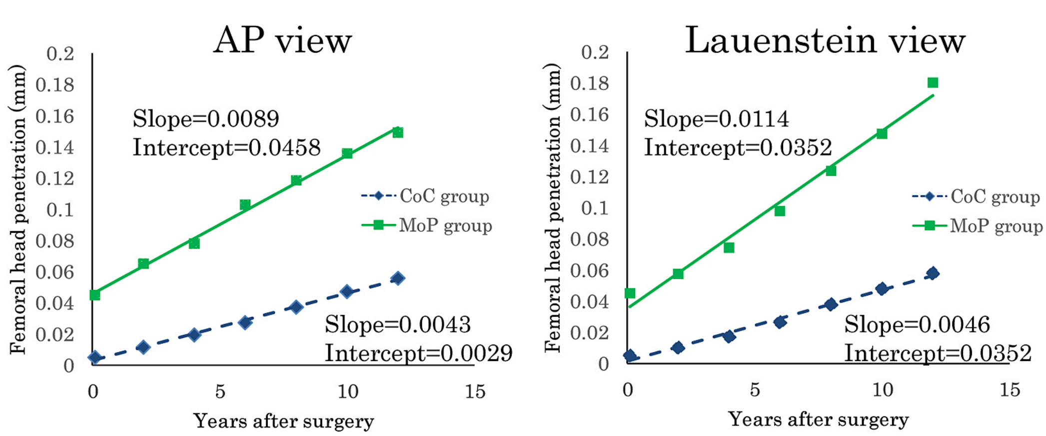

Fig. 2. Linear regression for mean femoral head penetration over time in the CoC THA and MoP THA groups. The slope and intercept are considered to represent true wear and creep, respectively. CoC, ceramic on ceramic; THA, total hip arthroplast; MoP, metal-on-highly cross-linked polyethylene.

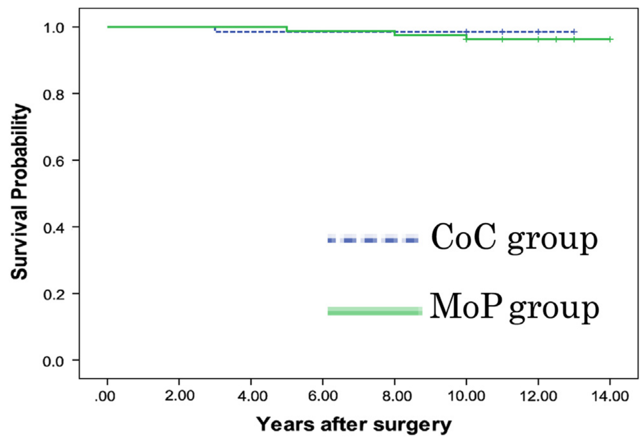

Fig. 3. Kaplan–Meier survival with end points of implant loosening and revision THA. No significant differences are seen between the CoC and MoP groups.

The true wear rate for MoP was previously found to be 0.006 mm/y [16]. However, to our knowledge, the true wear rate for CoC has not been reported thus far. The true wear rate of CoC in the present study was around half that of MoP. Because the creep represented bedding in, the true wear rate differed less than the wear rate [5]. Ceramics not only have a low wear rate but are also bioinert [25,27]. Longer term studies are needed to determine how the true wear rate, wear rate, and bioactivity of these materials affect implant longevity. Delta CoC is now available, and better clinical results will be expected for young and active patients.

This study has some limitations. First, it was retrospective in nature and had a relatively small number of patients. Although MoP and CoC THA were performed at different institutions, this study was not a randomized controlled trial. Additionally, we used both cementless and cemented stems, 2 different ceramic liners with or without a metal-backed titanium sleeve and femoral heads of 3 different sizes. These differences may have affected the clinical and radiographic results. Therefore, we need to repeat our investigation using a single uniform implant. Third, we measured femoral head penetration using the technique of Dorr et al and the computer–digitizer facilities of the Roman V1.70 software. The validity of this method for measuring femoral head penetration after CoC THA has been reported in the past [3,26]. However, it is typically used to examine femoral head penetration after MoP THA, and it is not easy to use it for CoC [15]. Thus, we were unable to measure femoral head penetration in 4 cases in the CoC group.

Conclusions

The wear rate of CoC implants was significantly lower than that of MoP implants, but Kaplan–Meier survival at 10 years with implant loosening and revision THA as end points did not differ significantly between these implant types. Longer term studies are needed to better understand the effects of wear rate and material bioactivity on implant longevity.

References

1. D'Antonio JA, Capello WN, Naughton M. Ceramic bearings for total hip arthroplasty have high survivorship at 10 years. Clin Orthop Relat Res 2012;470:373.
2. Shetty V, Shitole B, Shetty G, et al. Optimal bearing surfaces for total hip replacement in the young patient: a meta-analysis. Int Orthop 2011;35:1281.
3. Callary SA, Solomon LB, Holubowycz OT, et al. Wear of highly crosslinked polyethylene acetabular components. Acta Orthop 2015;86:156.
4. D'Antonio J, Capello W, Manley M, et al. New experience with alumina-on-alumina ceramic bearings for total hip arthroplasty. J Arthroplasty 2002;17:390.
5. Engh CA, Stepniewski AS, Ginn SD, et al. A randomized prospective evaluation of outcomes after total hip arthroplasty using cross-linked marathon and non-cross-linked Enduron polyethylene liners. J Arthroplasty 2006;21:17.
6. Nikolaou VS, Edwards MR, Bogoch E, et al. A prospective randomised controlled trial comparing three alternative bearing surfaces in primary total hip replacement. J Bone Joint Surg Br 2012;94:459.
7. Kanoh T, Hasegawa Y, Masui T, et al. Accurate acetabular component orientation after total hip arthroplasty using an acetabular alignment guide. J Arthroplasty 2010;25:81.
8. Takao M, Ohzono K, Nishii T, et al. Cementless modular total hip arthroplasty with subtrochanteric shortening osteotomy for hips with developmental dysplasia. J Bone Joint Surg Am 2011;93:548.
9. Kim YH, Kim JS, Oh SH, et al. Comparison of porous-coated titanium femoral stems with and without hydroxyapatite coating. J Bone Joint Surg Am 2003;85:1982.
10. Sutherland CJ, Wilde AH, Borden LS, et al. A ten-year follow-up of one hundred consecutive Müller curved-stem total hip-replacement arthroplasties. J Bone Joint Surg Am 1982;64:970.
11. Lee JH, Lee BW, Lee BJ, et al. Midterm results of primary total hip arthroplasty using highly cross-linked polyethylene minimum 7-year follow-up study. J Arthroplast 2011;26:1014.
12. Mestriner MB, Verquietini CMA, Waisberg G, et al. Radiographic evaluation in epiphysiolysis: possible predictors of bilaterality? Acta Ortop Bras 2012;20:203.
13. Lewinnek GE, Lewis JL, Tarr R, et al. Dislocations after total hip-replacement arthroplasties. J Bone Joint Surg Am 1978;60:217.
14. Barrack RL, Lavernia C, Szuszczewicz ES, et al. Radiographic wear measurements in a cementless metal-backed modular cobalt-chromium acetabular component. J Arthroplasty 2001;16:820.
15. Dorr LD, Wan Z. Comparative results of a distal modular sleeve, circumferential coating, and stiffness relief using the Anatomic Porous Replacement II. J Arthroplasty 1996;11:419.
16. García-Rey E, García-Cimbrelo E, Cruz-Pardos A, et al. New polyethylenes in total hip replacement: a prospective, comparative clinical study of two types of liner. J Bone Joint Surg Br 2008;90:149.
17. Brooker AF, Bowerman JW, Robinson RA, et al. Ectopic ossification following total hip replacement. Incidence and a method of classification. J Bone Joint Surg Am 1973;55:1629.
18. Hu D, Yang X, Tan Y, et al. Ceramic-on-ceramic versus ceramic-on-polyethylene bearing surfaces in total hip arthroplasty. Orthopedics 2015;38:e331.
19. Wyles CC, Jimenez-Almonte JH, Murad MH, et al. There are no differences in short- to mid-term survivorship among total hip-bearing surface options: a network meta-analysis. Clin Orthop Relat Res 2014;473:2031.
20. Cai P, Hu Y, Xie J. Large-diameter delta ceramic-on-ceramic versus common-sized ceramic-on-polyethylene bearings in THA. Orthopedics 2012;35:e1307.
21. Gallo J, Goodman SB, Lostak J, et al. Advantages and disadvantages of ceramic on ceramic total hip arthroplasty: a review. Biomed Pap Med Fac Univ Palacky Olomouc Czech Repub 2012;156:204.
22. Willmann G. Ceramic femoral head retrieval data. Clin Orthop Relat Res 2000;379:22.
23. Bascarevic Z, Vukasinovic Z, Slavkovic N, et al. Alumina-on-alumina ceramic versus metal-on-highly cross-linked polyethylene bearings in total hip arthroplasty: a comparative study. Int Orthop 2010;34:1129.
24. Al-Hajjar M, Fisher J, Tipper JL, et al. Wear of 36-mm BIOLOX (R) delta ceramic-on-ceramic bearing in total hip replacements under edge loading conditions. Proc Inst Mech Eng Part H-Journal Eng Med 2013;227:535.
25. Archibeck MJ, Jacobs JJ, Black J. Alternate bearing surfaces in total joint arthroplasty: biologic considerations. Clin Orthop Relat Res 2000;379:12.
26. Epinette JA, Manley MT. No differences found in bearing related hip survivorship at 10-12 years follow-up between patients with ceramic on highly cross-linked polyethylene bearings compared to patients with ceramic on ceramic bearings. J Arthroplasty 2014;29:1369.
27. Hannouche D, Hamadouche M, Nizard R, et al. Ceramics in total hip replacement. Clin Orthop Relat Res 2005;430:62.