Wear performance of cobalt chromium, ceramic, and oxidized zirconium on highly crosslinked polyethylene at mid-term follow-up

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ABSTRACT

Patients with THA using a ceramic head and using an OxZr head were each matched to patients with a CoCr head. Mean implantation time was 5 years. There was no difference in steady state wear rate between the ceramic (0.066 ± 0.050 mm/year) and CoCr match groups (0.052 ± 0.041 mm/year), or between the OxZr (0.022 ± 0.029 mm/year) and CoCr match groups (0.048 ± 0.071 mm/year). Follow-up into the second decade will be necessary before any changes in THA wear rate from using ceramic or OxZr bearings may be appreciated clinically with available imaging techniques.

1. Introduction

Total hip arthroplasty (THA) is a successful treatment option for patients with advanced hip arthritis. Engineering advances have enabled outstanding long-term survivorship, with polyethylene wear and associated osteolysis being greatly reduced with the advent of highly crosslinked polyethylene.¹ Now attention is turning to the other half of the bearing couple, with the goal of THA lasting for multiple decades.

Cobalt chromium (CoCr) femoral heads have long been the most frequent choice by surgeons for THA. In most cases it is less expensive than premium bearing options, offers modularity with low risk of implant fracture, and has good wear resistance when paired with highly crosslinked polyethylene. However, recent concerns surrounding trunnionosis at the head-stem junction have been raised.² The incidence of trunnionosis appears to be reduced or eliminated with the use of ceramic or oxidized zirconium (OxZr) heads.^{3,4}

Ceramic femoral heads have shown less friction, enhanced lubrication, and good resistance to abrasion, resulting in reduced conventional polyethylene wear rates compared to CoCr.^{5,6} However, ceramic femoral head fracture risk remains a concern.⁷ OxZr was developed with the goals of reducing wear relative to CoCr heads and reducing the risk of fracture compared to ceramic heads. While wear simulator studies have demonstrated improved wear resistance with both ceramic and OxZr over CoCr, clinically, implant survivorship and patient outcomes have been no different.^{8,9}

It is important to critically evaluate new technology as it is introduced into orthopaedics, especially when new technology is offered at a cost premium.¹⁰ There are many examples where new technology has been introduced, and has gone on to perform no better or even worse than existing products.¹¹ Therefore, the objective of this study is to examine, using radiostereometric analysis (RSA), the polyethylene wear rates of ceramic, OxZr, and CoCr on highly crosslinked polyethylene at mid-term follow-up. It was hypothesized that the two premium bearing materials would demonstrate lower wear than the CoCr bearing.

2. Materials and methods

We performed a retrospective review of our institutional arthroplasty database from 2004 to 2011. We identified all patients who underwent a primary total hip arthroplasty using highly cross-linked polyethylene. Patients that met the inclusion criteria were primary THA performed for osteoarthritis using a CoCr, OxZr, or ceramic femoral head on highly crosslinked polyethylene. Patients were excluded if they had undergone subsequent revision procedures or were outside 3–8 years post-operation. Patients were also excluded if they had cemented femoral implants. Our institutional research ethics boards approved the study. Patients were contacted by phone, and informed consent was obtained during their clinic visit.

The study cohort was narrowed into 4 groups: ceramic heads with a

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Table 1
Patient implant details and demographics.

Details	Ceramic (n = 20)	CoCr Match (n = 20)	p Value
Acetabular cup	Pinnacle (20)	Pinnacle (20)	1.000
Polyethylene liner	AltrX (17), Marathon (3)	AltrX (16), Marathon (4)	0.576
Femoral head diameter	28 mm (4), 32 mm (15), 36 mm (1)	32 mm (15), 36 mm (5)	< 0.001
Femoral stem	Summit (20)	Summit (20)	1.000
Age at surgery (years)	57.1 ± 6.1	57.2 ± 6.4	0.980
Sex	16 F, 4 M	16 F, 4 M	1.000
BMI (kg/m ²)	30.4 ± 6.4	31.0 ± 6.8	0.790
Implantation time (years)	5.1 ± 0.9	5.6 ± 0.8	0.076
Details	OxZr (n = 18)	CoCr Match (n = 18)	p Value
Acetabular cup	R3 (16), Reflection (2)	R3 (17), Reflection (1)	0.453
Polyethylene liner	R3 XLPE (16), Reflection XLPE (2)	R3 XLPE (17), Reflection XLPE (1)	0.453
Femoral head diameter	28 mm (1), 32 mm (10), 36 mm (7)	32 mm (15), 36 mm (3)	0.055
Femoral stem	Synergy (17), Anthology (1)	Synergy (13), SMF (4), CPCs (1)	0.035
Age at surgery (years)	59.9 ± 5.6	60.1 ± 6.0	0.910
Sex	8 F, 10 M	8 F, 10 M	1.000
BMI (kg/m ²)	31.0 ± 5.6	35.2 ± 8.5	0.057
Implantation time (years)	5.2 ± 0.9	5.4 ± 0.8	0.606

matched group of CoCr heads (n = 20 per group), and OxZr heads with a matched group of CoCr heads (n = 18 per group). Matching was based on age, gender, and body mass index (BMI). The ceramic and matched CoCr group used Depuy (Warsaw, IN) implants (Table 1), including both Marathon and AltrX highly crosslinked polyethylene. Marathon polyethylene was introduced in 1998 and is made from extruded rod GUR 1050 polyethylene, gamma irradiated to 50 kGy, followed by melting and annealing, with gas plasma sterilization. AltrX polyethylene was introduced in 2007 and is made from extruded rod GUR 1020 polyethylene, gamma irradiated to 75 kGy, followed by melting and annealing, with gas plasma sterilization. The OxZr and matched CoCr group used Smith & Nephew (Memphis, TN) implants with XLPE highly crosslinked polyethylene. XLPE was introduced in 2001 and is made from extruded rod GUR 1050 polyethylene, gamma irradiated to 100 kGy, remelted, and sterilized with ethylene oxide. Patient demographics for all groups are listed in Table 1.

Patients underwent a standard supine radiostereometric analysis (RSA) exam of the hip. In conventional RSA, prospective exams are acquired over multiple time points, defining the initial bedding in period due to creep and subsequent steady state wear rate.¹² RSA wear analysis can also be performed in a retrospective manner using the center index method.¹³ With this method, the relative location in three-dimensional space of the femoral head to the acetabular cup is measured in the present-day exam. The immediate post-operation position of the head to the cup is assumed to be a central point defined by the circumference of the acetabular cup. The relative difference between these two positions is calculated as wear. Although this technique has been demonstrated to be accurate, it includes both creep (from the bedding-in period) as well as wear, thereby overestimating the true wear rate.

Therefore, to account for the bedding-in period, we utilized the Martell method to measure the relative position of the head versus the cup from anterior-posterior and lateral radiographs of each patient acquired at 1 or 2 years post-operation.¹⁴ The three-dimensional distance between the head and cup at 1 or 2 years was subtracted from the distance between the head and cup at the latest follow up, yielding the

true head penetration due to wear. This value was divided by the implantation time less 1 or 2 years (as appropriate), to provide the steady state wear rate. In some cases 1 or 2 year radiographs were unavailable, so 6-week radiographs were used instead, and the total implantation time was used to determine the wear rate. In these instances, both creep and wear are part of the wear rate. The 6-week radiographs were required for 3 ceramic and 1 matched CoCr case, and for 2 cases in the OxZr and 1 matched CoCr case.

With low wear rates using highly crosslinked polyethylene and the uncertainty of the wear measurements, negative wear rates can occur, and can be addressed in multiple ways.¹⁵ These values can be left in the calculation of the average wear rates, but tend to artificially decrease the average as they cancel out positive wear. Alternatively, these values can be excluded, but tend to artificially increase the average wear rate as only high wearing values will be included. Finally, negative values can be treated as equivalent to no wear and given a value of 0, which is likely most representative of the true case. All three methods of calculation were performed and included for completeness.

Patient-reported outcome measures were recorded pre-operatively and at the time of the follow-up imaging. Outcome scores collected included the Western Ontario and McMaster Osteoarthritis Index (WOMAC), Harris Hip Score (HHS), and the Short Form Health Index (SF-12).

Descriptive statistics (means and standard deviations) were calculated for patient demographics, wear rates, and outcomes scores. The D'Agostino and Pearson normality test was applied to assess the distribution of the data. Subsequently, either a *t*-test or a Mann-Whitney *U* test was used to compare the groups, depending on whether the data was normally distributed or not, respectively. For ratios of specific implant variables between groups, a chi square test was used to calculate the difference in distribution. All statistics were completed using Prism 7 (GraphPad Software Inc., La Jolla, CA).

3. Results

The magnitude of steady state wear rates varied by method of calculation (Table 2). There was no significant difference in wear rates between ceramic heads and the matching CoCr heads, or between OxZr heads and the matching CoCr heads, regardless of calculation method. Using the negatives set to 0 calculation method, there was no significant difference in wear rates between the CoCr ceramic match and OxZr match groups (mean difference = 0.004 mm/year, *p* = 0.316). However, using the negatives set to 0 calculation method, the OxZr group had a significantly lower wear rate than the ceramic group (mean difference = 0.044 mm/year, *p* = 0.002).

The ceramic-matched CoCr head group demonstrated a significantly greater improvement in the SF12 mental component score (Table 3) compared to the ceramic group (*p* = 0.032, mean difference = 9.1). However, the ceramic group demonstrated a significantly greater improvement in the SF12 physical component score compared to the matched CoCr group (*p* = 0.002, mean difference = 12.8). There were no differences in the OxZr and matched CoCr groups for either SF12 score. There was no difference in any groups for WOMAC or Harris Hip

Table 2
Wear rates by group.

Measurement (mm/year)	Ceramic	CoCr Match	p Value
All Values	0.066 ± 0.050	0.047 ± 0.049	0.478
Negatives Excluded	0.066 ± 0.050	0.069 ± 0.032	0.458
Negatives Set to 0	0.066 ± 0.050	0.052 ± 0.041	0.477
Measurement (mm/year)	OxZr	CoCr Match	p Value
All Values	−0.007 ± 0.062	0.011 ± 0.108	0.743
Negatives Excluded	0.050 ± 0.069	0.109 ± 0.069	0.050
Negatives Set to 0	0.022 ± 0.029	0.048 ± 0.071	0.516

Table 3
Change in outcome scores (pre-operative to latest post-operative).

Outcome Score	Ceramic	CoCr Match	p Value
HHS	44.5 ± 18.5	41.7 ± 16.6	0.978
WOMAC	44.8 ± 26.1	40.0 ± 23.3	0.573
SF12 MCS	−1.3 ± 12.4	7.8 ± 11.7	0.032
SF12 PCS	22.2 ± 9.5	9.4 ± 12.8	0.002

Outcome Score	OxZr	CoCr Match	p Value
HHS	41.2 ± 7.4	48.7 ± 21.4	0.126
WOMAC	48.4 ± 20.5	42.7 ± 26.1	0.986
SF12 MCS	3.4 ± 7.5	4.0 ± 11.2	0.958
SF12 PCS	16.9 ± 12.8	13.9 ± 12.3	0.501

Score.

4. Discussion

We believe that this is the first study to specifically examine together ceramic, OxZr, and CoCr on highly crosslinked polyethylene implants from Depuy (AltraX and Marathon) and Smith & Nephew (R3 and Reflection). We found no improvement in wear resistance with the use of ceramic or OxZr femoral heads over CoCr heads at an average follow-up of 5 years. There was also no difference in clinical outcomes scores between the OxZr and matched CoCr groups. However, the ceramic group fared better than the matched CoCr group for the SF12 physical component score, with the opposite occurring for the SF12 mental component score. This is likely a function of the relatively small number of patients per group.

Garvin et al. at 9–14 years post-operation found no difference ($p = 0.58$) in wear rates between ceramic (0.011 mm/year), OxZr (0.022 mm/year), or CoCr (0.024 mm/year) on highly crosslinked polyethylene (Zimmer Longevity) using the Martell method.¹⁶ Sato et al. at 6 years average follow-up found no difference ($p = 0.45$) between zirconia (0.0008 mm/year), alumina (−0.0007 mm/year), or CoCr (−0.009 mm/year) on highly crosslinked polyethylene (JMM Aeonian) measured with PolyWare.¹⁷ Selvarajah et al. examined 36 mm ceramic heads against highly crosslinked polyethylene (Stryker X3) at 5 years follow-up and found a steady state wear rate of 0.110 mm/year using PolyWare.¹⁸

For OxZr, our findings are consistent with the randomized controlled trial of Jonsson et al., who at 5 years follow-up found no difference ($p = 0.6$) in wear rates between OxZr (0.01 mm/year) and CoCr (0.02 mm/year) against highly crosslinked polyethylene (Smith & Nephew Reflection) using RSA.¹⁹ They also reported no difference in HHS between groups. Our findings are also consistent with the trial of Jassim et al. at 5 years follow-up, with no difference ($p = 0.153$) in wear rates between OxZr (0.023 mm/year) and CoCr (0.028 mm/year) against highly crosslinked polyethylene (Smith & Nephew Reflection) using the Martell method.²⁰ They also saw no difference between groups with the SF36 and WOMAC. However, Zaoui et al. at 4 years follow-up did find a significant reduction ($p < 0.001$) in wear rate with OxZr (0.02 mm/year) over CoCr (0.05 mm/year) against highly crosslinked polyethylene in all-poly cups (Smith & Nephew Reflection) using the Martell method.²¹

Wear may not be the most important long-term issue in modern highly crosslinked polyethylene bearings for total hip arthroplasty. Corrosion at the head-neck junction of the femoral components may be a clinical problem limiting the longevity of these implants.²² The use of alternative femoral head materials, such as ceramic and OxZr, has been associated with reduced corrosion and fretting when compared to CoCr heads.^{3,4} Therefore, such materials may have two benefits over CoCr: reduced wear and reduced taper corrosion.

This study has a number of limitations. It is retrospective rather than prospective in nature and has a mid-term follow-up while longer

term data is available for some other types of highly crosslinked polyethylene. While the centre index method and Martell method are both validated wear analysis techniques, prospectively acquired RSA data is the gold standard for wear measurement.^{12–14} The major limitation of the centre index method is that it includes the creep/bedding in period, inflating wear values, which is why we utilized the Martell method to subtract the head-cup location in clinical radiographs acquired at 1 or 2 years. However, there were a number of patients where only 6-week radiographs were available, particularly in the ceramic group, which may have slightly inflated the wear rates we report here. There was also an unequal distribution of femoral head size across all groups, and there is a debate in the literature whether head size affects wear rates.^{23–25} However, a strength of the study is the matching between groups for patient age, sex, BMI, implantation time, and polyethylene material. The final, major limitation is the sample size, which was limited by the number of patients per group available for matching, which meant the study is likely underpowered to detect a significant difference between groups.

In conclusion, we saw no difference in steady state wear rates with ceramic or OxZr compared to matched CoCr groups, and virtually no difference in clinical outcome scores. At an average follow-up of 5 years, it may be too early for the premium femoral head bearing materials to make a significant difference, especially given the strong wear resistance of highly crosslinked polyethylene.²⁶ The 10-year revision rates reported in the Australian Registry are similar for all three bearing materials on crosslinked polyethylene, at 3.2% for ceramicized metal, 4.4% for ceramic, and 4.3% for metal.²⁷ Ongoing follow-up into the second decade and beyond will be necessary before any changes in wear rate may be appreciated with current imaging techniques.

Disclosures

The authors have no disclosures.

Each author certifies that his institution approved or waived approval for the use of human subjects for this investigation and that all investigations were conducted in conformity with ethical principles of research.

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