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Gender Differences in Wear Rates for 28 versus 32 millimeter Ceramic Femoral Heads on Modern Highly Cross-linked Polyethylene at Midterm Follow-up in Young Patients Undergoing Total Hip Arthroplasty

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Abstract

Background—We report on the midterm linear and volumetric wear of highly cross-linked polyethylene (HXLPE) and survivorship of two prospective young THA cohorts that differed by the size of ceramic femoral head used: 28 vs. 32 millimeters.

Methods—We prospectively analyzed 220 consecutive primary THAs in patients >50 years who received a cementless THA with a ceramic femoral head on HXLPE liner (C-HXLPE). There were 101 patients (46%) with 28mm heads and 119 patients (54%) who received 32mm heads at a mean follow-up of 5.5 years (range 60–109 months). Wear was calculated using Martell Software.

Results—The 28mm C-HXLPE cohort demonstrated average linear and volumetric wear of 0.020 mm/year (SD 0.074, 95% CI [0.003, 0.037]) and 18.775 mm³/yr (SD 21.743, 95% CI [13.773, 23.778]) compared to 0.032 mm/yr (SD 0.087, 95% CI [0.013, 0.050]) and 29.847 mm³/yr (SD 35.441, 95% CI [22.294, 37.401]) in the 32mm C-HXLPE group. Subgroup analysis by gender and head size discovered significantly greater wear in females with 32mm compared to 28mm heads in both linear (0.01, 95% CI [−0.014, 0.033] vs. 0.048, 95% CI [0.022, 0.074] mm/y, $p=0.004$) and volumetric wear (14.11, 95% CI [8.957, 19.271] vs. 29.71, 95% CI [17.584, 41.840] mm³/yr, $p=0.009$). We found a 96% (95% CI [92.30%, 97.94%]) survivorship by Kaplan-Meier analysis at minimum 5-years with no failures due to osteolysis.

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Conclusions—Ceramic-on-HXLPE demonstrates extremely low wear properties in young patients at midterm follow-up. We identified a gender-dependent difference in wear based on head size, with 32mm heads being associated with increased wear in females.

Keywords

Highly cross-linked polyethylene; Wear; Gender differences; Martell Method; Total Hip Arthroplasty Outcomes

Introduction

Highly cross-linked polyethylene (HXLPE) bearing surfaces have gained widespread acceptance in total hip arthroplasty (THA) since their introduction fifteen years ago due to its excellent wear properties [7, 10, 33]. Subsequently, the use of HXLPE has increased dramatically, with ceramic femoral heads on HXLPE liners (C-HXLPE) accounting for the second most common bearing combination in use today [30]. With improved wear characteristics, modern implants are revised less frequently and midterm results demonstrate excellent survivorship, even the younger patient populations [25, 29, 37, 40].

As younger patients increasingly seek THA as a reconstructive option, more emphasis has been placed on surgical technique (i.e. insuring proper component positioning) and conscientious selection of bearing components with the primary goal to prolong implant survivorship [12, 21, 36]. Some authors have championed ceramic-on-polyethylene as the preferred bearing combination for young THA patients because of its optimization of surface toughness and wettability of the femoral head, which leads to an overall decreased wear profile in combination with modern HXLPE [11, 20, 27]. As for the optimum head size, it is well documented that larger heads are associated with increased rates of linear and volumetric polyethylene wear [1, 28]. No previous studies, however, have directly examined the role of gender and ceramic head size on HXLPE wear rates when controlling for activity levels. Thus, uncertainty remains regarding the best head size to select when utilizing a ceramic-on-HXLPE couple in total hip arthroplasty for young males or females. The purpose of our study was to report on the midterm linear and volumetric wear results, patient-reported outcomes, and clinical survivorship of two consecutive prospectively followed young (age < 50 years) primary THA cohorts that differed by the size of alumina ceramic femoral head (28 vs. 32 millimeters, mm).

Methods

After receiving approval from our institutional review committee, we queried our prospective internal joint registry for all patients 50 years of age or less (young patients) who underwent primary THA performed by one senior author between February 2004 and December 2008. We limited our inclusion to patients with the bearing combination of a 28 or 32-millimeter alumina ceramic femoral heads on HXLPE acetabular liners (28mm-HXLPE and 32mm-HXLPE). From a surgical perspective, the two consecutive, prospectively selected groups differed by stem type and the ceramic femoral head size utilized at the time of THA: 28mm heads from February 2004–October 2006 and 32mm heads from November 2006–December 2008. All patients received a combination of

cementless acetabular shell augmented with screw fixation (Trilogy®, Zimmer, Warsaw, IN) and an alumina femoral head (*Trilogy® AB Ceramic Femoral Head*, Zimmer, Warsaw, IN). This specific head type used BioloX® forte alumina, which is a third-generation ceramic material formulated through a hot isostatically pressed technique to reduce grain size while maintaining density in the ceramic material. All HXLPE acetabular liners (Longevity®, Zimmer, Warsaw, IN) were fabricated by a proprietary process that included high-dose electron-beam irradiation (9 milliRads) and sterilization in Ethylene Oxide Gas. Every patient had associated cementless femoral component fixation, either with an ML Taper (Zimmer) or a Beaded or Fiber metal MidCoat stem design (VerSys®, Zimmer). We included only those patients with minimum five-year follow-up. Patients were excluded if they had undergone previous THA or received any combination of components other than listed above. We did not discriminate based on preoperative diagnosis. The primary end-point for the purpose of the study was defined as all-cause revision, with secondary end-points including reoperation or death.

Two hundred sixty-four primary THAs (24 bilateral) were performed in 240 young subjects during the aforementioned time period of interest. 83.3% of hips (220/264) met the minimum 5-year clinical follow-up requirement, resulting in the exclusion of 44 hips due to loss to follow-up. Of the 44 subjects excluded, eighteen were in the 28mm head group and the remaining twenty-six were part of the 32mm head size cohort. Nineteen patients considered lost to follow-up had post-operative data less than 1 year from index THA. There was no significant difference in regards to length of follow-up achieved between the two head size groups ($p=0.54$). The subgroup overall achieved a mean twenty-five month follow-up ($SD = 11.7$ months). Of the 220 hips remaining, fourteen were excluded from wear analysis for meeting an earlier end-point: 5 enrollees expired and 9 hips were revised. These subjects' outcomes were included for survivorship calculations, however. The groups were not randomized to one head size versus another; instead, on December 1, 2006 there was a definitive switch in which the treating surgeon began using 32mm ceramic heads and stopped utilizing 28mm heads for his young total hip patients. One hundred and one hips (46%) that received a 28mm ceramic head achieved an average follow-up of 6.1 years (range 60–109 months) while the 32mm head group consisted of 119 hips (54%) that obtained a mean follow-up of 5.3 years (range 60–93 months).

Patient-reported outcome measures of interest included the Short Form-12 (SF-12) mental and physical survey [41], the modified Harris hip score (mHHS) [16], the Western Ontario and McMaster Universities (WOMAC) Index [5], and the UCLA activity scale [2]. The HHS and WOMAC have been validated as a reliable measures of overall function after hip replacement [6, 18]. All patient metrics and questionnaires were recorded during pre-operative or interval clinical visits, with standard surveillance appointments recommended at six-weeks, one, two and five years after THA.

Patient demographic characteristics were similar across groups without any significant differences noted (Table 1). No significant preoperative differences were found in primary diagnosis, race, age or BMI between the two study cohorts. When considering the gender distribution, there were an increased proportion of females in the 28mm versus the 32mm-HXLPE cohort (54.5%, 55/101 vs. 45.5%, 54/119), but this did not reach statistical

significance ($\chi^2_{(1)} = .18$). Importantly, the two groups did not significantly differ in post-operative UCLA scores, indicating similar activity levels between subjects irrespective of head size (Table 2). For the purpose of wear analysis, activity levels were dichotomized as low (UCLA score 1–6) and high activities (UCLA score 7–10) [31, 42].

The Martell computerized, semi-automated, edge-detection method was used to determine the two-dimensional vector wear by one author trained in the use and function of the program (Martell Hip Analysis Suite, HAS, version 8.0.4.3; University of Chicago, Chicago IL). Calculation of linear wear was performed using this validated algorithm that accounted for bedding-in period by utilizing the one-year anteroposterior (AP) pelvis radiograph as a control when comparing subsequent films [32] to exclude for potential changes in the femoral head position from non-wear related head penetration or liner settling. The linear wear rate was calculated by dividing cumulative wear for all patients in each cohort by the cumulative radiographic time interval between the one-year and final radiographs. Volumetric wear was calculated within the HAS based on custom derived equations and numerical integration. The input variables determining volumetric wear include the femoral head size, the magnitude of linear wear vector, and the vector's direction with respect to the cup face (beta angle) [19]. Cup anteversion was confirmed on cross-table lateral radiographs for all participants. Acetabular component inclination was defined as the angle formed between one line along the inferior border of the ischial tuberosities and a second connecting the inferomedial and superolateral points of the ellipse formed by the cup as visualized on supine AP radiograph.

Statistical analysis was performed using SAS software version 9.3 (SAS Inc., Cary, NC). Univariate analyses (χ^2 and independent t tests) were conducted to examine the association between femoral head size and various demographic variables. The femoral head size group differences regarding the change of patient-reported outcomes measured before and after THA were examined via a generalized mixed modeling approach adjusted for gender, age, preoperative diagnosis, BMI, and follow-up length. Five subjects whose information was included in the modeling equation were missing BMI data, and thus a listwise deletion approach was used. This is a statistical method commonly utilized if one assumes information missing is completely at random, thus rendering a large portion of sample useful and incorporates truthful standard errors into the model. A generalized linear model was also used to examine femoral head size group differences in terms of polyethylene linear and volumetric wear and cup inclination angle adjusted for gender, age, preoperative diagnosis, BMI, and follow-up length. Additionally, gender differences in wear and femoral head size differences within each gender (i.e., female and male, separately) were examined via the generalized linear model adjusted for age and BMI. Model assumptions were checked via residual plots and normality tests. Generalized estimating equation was used when the departure from normality was a concern. Revision free survival probability was estimated via Kaplan-Meier survival curve and survival difference by femoral head size was examined by log-rank test.

Results

Overall, we found an average true linear wear rate of 0.026 mm/year (SD 0.081) and a mean volumetric wear rate of 24.72 mm³/yr (SD 30.31) for the cohort as a whole. In looking at the two subgroups, we observed a rate of 0.02 mm/year (median 0.031, SD 0.074, 95% CI [0.003, 0.037]) in the 28mm ceramic-HXLPE group compared to 0.032 mm/yr (median 0.047, SD 0.087, 95% CI [0.013, 0.050]) in the 32mm C-HXLPE group. After adjusting for gender, BMI, age, pre-operative diagnosis, and follow-up time, there was no demonstrable difference between the groups (p=0.43). Volumetric wear rates for the two groups also did not significantly differ by head size: 18.78 mm³/yr (median 10.40, SD 21.74, 95% CI [13.773, 23.778]) versus 29.85 mm³/yr (median 17.79, SD 35.44, 95% CI [22.294, 37.401]) when comparing the 28mm-HXLPE to the 32mm-HXLPE ceramic cohorts (p=0.08). An analysis of linear and volumetric wear showed no statistically significant differences by either the Student's t-test or Mann-Whitney U when grouped by high versus low activity, defined by UCLA activity score >7 vs. ≤7, or when separated by activity within either the 28 or 32mm head cohort (Table 3).

When evaluating gender regardless of head size, we discovered no appreciable difference in linear or volumetric wear rates (Table 4). However, significant differences in wear were found in females who received 32mm compared to 28mm ceramic heads (Figure 1, Table 5). The average linear wear rate for females with 28mm-HXLPE bearing combination was found to be 0.01 mm/year (median 0.028, SD 0.073, 95% CI [-0.014, 0.033]) compared to 0.048 mm/year (median 0.053, SD 0.08, 95% CI [0.022, 0.074]) in those with 32mm-HXLPE components (p=0.004). Furthermore, volumetric wear results showed similar significant differences with a mean wear rate of 14.11 mm³/yr (median 8.42, SD 16.34, 95% CI [8.957, 19.271]) in females with 28mm ceramic heads versus 29.71 mm³/yr (median 17.88, SD 37.41, 95% CI [17.584, 41.840]) in those with 32mm femoral heads (p=0.009). No significant wear differences were detected in males based on varying head sizes (Table 5).

Significant improvements were noted in all patient-reported outcome measures regardless of femoral head size (p<0.001), except in the SF-12 mental subscale (Table 2). Improvements of all patient-reported outcome (PRO) measures after THA in patients with 28mm femoral head did not differ significantly from those of patients with 32mm femoral head (Table 2). The only significant PRO difference between the 44 subjects excluded from the study and those included was in regards to UCLA Activity score, which was statistically lower both pre and postoperatively in the excluded cohort (pre-op UCLA 3.3 vs. 4.6, p<0.001; post-op UCLA 4.9 vs. 6.4, p=0.001) (Table 6). Radiographic analysis demonstrated no evidence of periprosthetic osteolysis in any of the surviving subjects. The mean anteversion angle of all acetabular components was 21.4° for the 28mm cohort and 19.8° for the 32mm cohort, with no significant differences noted between the groups (p=0.69). Similarly, the average cup inclination angle did not exhibit significant differences (28mm heads =45.6°, 32mm heads =46.4°, p=0.76). No differences were detected in cup version or inclination angles between the different head size subgroups within each gender (version: female p=0.54, male p=0.40; inclination: female p=0.57, male p=0.36).

At midterm follow-up, there was a 96% (95% CI [92.30%, 97.94%]) overall revision-free survivorship for all ceramic-on-HXLPE THAs in patients 50 years or less (Figure 2). When considering survivorship based on head-size, no significant difference was detected between 28 vs. 32mm heads ($p=0.37$) (Figure 3). There were no failures due to polyethylene wear and/or osteolysis. A total of nine failures went on to revision arthroplasty: six in the 28mm cohort and three in the 32mm cohort (Table 7). Indications for revisions across both head size groups included four for recurrent instability (4/220, 1.8%), two infections (0.9%) and one each for failure of osseointegration and pain not otherwise specified (0.45%). A physician outside of the treating network revised the patient with a painful THA two years after index THA. It should be noted that thorough workup at our institution did not reveal any lab or radiographic abnormalities to explain his pain. There was no significant difference in failure mechanisms between the two cohorts ($p=0.33$). No significant differences in revisions or wear rates were detected when comparing stem-head size combinations (Table 8).

Discussion

As the rate of younger patients pursuing THA continues to climb [26], there is a growing need to determine factors associated with complications and early failures. Results from our investigation demonstrate that young patients who receive an alumina ceramic-on-HXLPE bearing combination for primary THA can reliably expect improved functional and activity outcomes, undetectable volumetric and linear wear, and excellent survivorship at midterm follow-up. Secondly, we believe this to be the first report of gender-specific wear differences with contemporary polyethylene bearings.

It is well established that HXLPE exhibits better wear characteristics and survivorship in younger patients as a bearing surface than conventional polyethylene [3, 9, 35, 38]. However, debate remains regarding the optimal femoral head composition and size. Long-term results of conventional polyethylene (CPE) suggest that ceramic ball bearings are superior to metal in terms of generating less wear and leading to fewer revisions for osteolysis [20, 34]. Numerous previous studies have examined wear and survivorship differences between varying femoral head sizes. Hernigou and associates compared zirconia and alumina ceramic bearings on CPE and discovered that even with 32mm alumina heads, they displayed a 50% volumetric wear reduction rate compared to 28mm zirconia heads at minimum ten-years [17]. Our findings suggest that young females with similar postoperative activity levels exhibit significantly higher linear and volumetric wear rates at midterm follow-up with 32 compared to 28-millimeter ceramic femoral heads on modern HXLPE liners. It is plausible that this finding is due to marginal differences in extremely small linear and volumetric wear patterns at varying head sizes that reaches statistical but not clinical significance and may somehow relate to gender specific anatomic factors undetected by our database. The clinical importance of such a finding is difficult to capture at this time given the excellent wear across all subjects, but could have clinically important effects on component survivorship and function in this group of patients at long-term follow-up.

Little historic data exists on wear differences between genders in total hip arthroplasty. In a randomized control trial looking at polyethylene use in primary THA, McCalden and

associates found no difference in linear wear between men and women treated with HXLPE, but they also did not note a significant difference in wear between HXLPE compared to conventional polyethylene (CPE) in women [33]. Kim et al demonstrated their five and ten-year results in young patients with ceramic femoral heads on HXLPE and showed no difference between genders in function or failures when compared to the contralateral hip, which was randomized to receive a ceramic-on-ceramic prosthesis. Both groups showed no osteolysis and had 99% survivorship of the acetabular component, with the C-HXLPE cohort demonstrating a linear wear rate of 0.031 ± 0.004 mm/year [23, 24]. This rate is similar to wear rates found in both males (0.024 mm/yr ± 0.084) and females (0.028 mm/yr ± 0.079) from our study, all of which are well below the osteolysis threshold [13].

Limitations of this study include the prospective observational nature in which this data was collected and analyzed. The fact that we relied on two consecutive longitudinal cohorts as opposed to a randomized control design in which subjects would be blinded to a femoral head size likely introduces methodological bias over time. Recent studies of both metal and ceramic heads have demonstrated superior wear properties with larger femoral heads articulating on modern HXLPE liners [13, 14, 28]. A second critique is that neither of our cohorts utilized larger femoral heads (i.e. 36mm), which may limit the generalizability of our findings. In addressing the gender differences in polyethylene wear, we are currently investigating the mechanical environment of the two cohorts. We know that in a native hip, gender and morphology differences account for variation in joint reactive forces [15, 22]. Women tend to have a wider pelvis and relatively longer body weight moment arm, which when coupled with smaller abduction lever arm and smaller femoral head diameter, results in greater contact stresses in the female hip [4]. Therefore, women need a higher abduction force to balance their body weight, resulting in a higher hip joint reaction force. Our future aims will be to determine if pelvic and hip geometry measurements create a lever arm and contact stresses across the replaced joint that are in fact directly related to the wear measurements we have calculated. Lastly, the Martell method for computing polyethylene wear introduces its own limitations in that the software can calculate negative rates when true HXPLE wear is below a detectable threshold, thus incorporating an impossible value into the wear equation [37]. However, we believe that is incorrect to eliminate the negative wear values because doing so increases the mean and median while effecting the standard deviation of measurements. The only statistically valid method to report measurements of a near-zero system is to include the high and the low outliers.

Our findings add to the literature and support the use of alumina ceramic-on-highly cross-linked polyethylene in young, active patients because it is associated with reductions in linear and volumetric wear and demonstrates an excellent survivorship. Some surgeons have predicted that C-HXLPE bearings will continue to rise in popularity, especially the young, high-demanding patient cohort, given their early greater improvement in wear when combined with contemporary polyethylene liners [11, 25]. Furthermore, a cost analysis conducted by Callaghan and Liu determined that C-HXLPE would be a cost-effective component choice in patients less than fifty even with higher upfront implant costs (36%) due to improved tribology (less prosthetic head fracture risk) and wear, as well as the expectation of future savings from a lower rate of revisions [8]. Longer-term follow-up will need to be conducted to establish whether significant gender differences in linear and

volumetric wear persist in young females with ceramic femoral heads and if such differences ultimately affect clinical survivorship.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
 Steady-state linear and volumetric wear rates in female subjects by head size.

Figure 2. Kaplan-Meier estimates of revision free survival (RFS) and when considering all-cause revisions and infectious versus non-infectious etiologies.

Figure 3.
Survival plot by ceramic femoral head size (28 versus 32 millimeter).

Table 1

Twenty-eight and thirty-two millimeter femoral head study group demographic characteristics.

Variable	Cohort		28 mm		32 mm		p-value
	Number	%	Number	%	Number	%	
Hips	220	100	101	45.9	119	54.1	0.225
Age* (N=220)	Cohort		28 mm		32 mm		0.881
	Mean	SD	Mean	SD	Mean	SD	
BMI* (N=213)	39.3		10.5		39.4		0.129
	29.3		6.6		29.9		
Operative Side							
Left	Cohort		28 mm		32 mm		0.513
	Number	%	Number	%	Number	%	
Right	108		49.1		56		0.513
	112		50.9		63		
Gender							
Female	Cohort		28 mm		32 mm		0.180
	Number	%	Number	%	Number	%	
Male	109		49.5		54		0.180
	111		50.5		65		
Diagnosis							
AVN/ON	Cohort		28 mm		32 mm		0.394
	Number	%	Number	%	Number	%	
OA	64		29.8		30		0.394
	134		62.3		76		
Other	17		7.9		10		0.394
			7.1		8.6		

* p value for age and body mass index (BMI, kg/m²) based on Student's t distribution. All other p values based on χ^2 distribution

Table 2

Least square means of patient-reported outcome measures adjusted for age, gender, BMI, diagnosis and length of follow up.

<i>Modified Harris Hip</i>				<i>WOMAC Pain</i>			
Head Size (mm)	Pre	Post	P value	Head Size (mm)	Pre	Post	P value
28	44.20	81.17	<0.001	28	43.04	82.45	<0.001
32	47.62	83.32	<0.001	32	39.98	80.18	<0.001
P value	0.09	0.471	0.703	P value	0.230	0.526	0.84
<i>UCLA</i>				<i>WOMAC Stiffness</i>			
Head Size (mm)	Pre	Post	P value	Head Size (mm)	Pre	Post	P value
28	4.02	6.12	<0.001	28	39.60	74.98	<0.001
32	4.74	6.42	<0.001	32	39.45	75.90	<0.001
P value	0.035	0.3253	0.275	P value	0.966	0.803	0.819
<i>SF-12 Physical</i>				<i>WOMAC Function</i>			
Head Size (mm)	Pre	Post	P value	Head Size (mm)	Pre	Post	P value
28	31.73	45.38	<0.001	28	46.15	85.30	<0.001
32	32.11	47.63	<0.001	32	45.20	83.77	<0.001
P value	0.795	0.2463	0.39	P value	0.739	0.6523	0.88
<i>SF-12 Mental</i>							
Head Size (mm)	Pre	Post	P value				
28	50.79	52.90	0.113				
32	49.02	51.71	0.0522				
P value	0.373	0.494	0.765				

Table 3

Linear and volumetric wear differences based on head size and dichotomous activity level.

	All Head Sizes		28 mm Heads		32mm Heads	
	UCLA1-7 vs. 8-10		UCLA1-7 vs. 8-10		UCLA1-7 vs. 8-10	
Linear	Low Activity	High Activity	Low Activity	High Activity	Low Activity	High Activity
Mean linear rate	0.018	0.012	0.013	0.005	0.022	0.017
Median linear rate	0.032	0.033	0.017	0.028	0.043	0.045
std dev. Linear	0.108	0.106	0.109	0.088	0.109	0.118
n	88	46	41	19	46	27
Volumetric	Low Activity	High Activity	Low Activity	High Activity	Low Activity	High Activity
Mean vol. rate	28.558	23.9974	21.002	17.529	35.893	28.549
Median vol. rate	11.592	12.4705	9.416	10.217	19.224	17.173
std dev. Vol.	39.346	30.829	32.485	23.056	43.944	34.997
n	88	46	41	19	46	27
P-values:						
Students t-test	0.763	0.495	0.768	0.676	0.838	0.461
Mann-Whitney	0.863	0.676	0.962	0.765	0.794	0.535

Table 4

Gender differences in average polyethylene wear rates after adjusting for age and BMI.

	Female (N=80)		Male (N=82)		<i>P Value</i>
	<i>Mean</i>	<i>SD</i>	<i>Mean</i>	<i>SD</i>	
<i>Linear Wear Rate</i> (mm/yr)	0.028	0.079	0.024	0.084	0.755
<i>Volumetric Wear Rate</i> (mm ³ /yr)	21.718	29.495	27.652	30.991	0.250

* BMI = body mass index; mm= millimeter, yr = year

Mean polyethylene wear by head size and p-value of head size difference after adjusting for age and BMI for female and male, separately

Table 5

	Mean	SD	Mean	SD	P Value
Female					
	28 mm (N=41)		32 mm (N=39)		
<i>Linear Wear Rate</i> (mm/yr)	0.01	0.073	0.048	0.08	0.004
<i>Volumetric Wear Rate</i> (mm ³ /yr)	14.114	16.337	29.712	37.412	0.009
Male					
	28mm (N=34)		32mm (N=48)		
<i>Linear Wear Rate</i> (mm/yr)	0.033	0.074	0.018	0.091	0.787
<i>Volumetric Wear Rate</i> (mm ³ /yr)	24.397	26.021	29.958	34.157	0.336

* BMI = body mass index; mm= millimeter, yr = year

Patient-reported outcomes (PRO) for those forty-four subjects excluded for failure to achieve minimum five-year follow-up. UCLA activity score (both pre and postoperatively) were the only PROs that significantly differed between those included and excluded from the study.

Table 6

28mm Excluded Subgroup (Insufficient follow-up or Death)	Months follow-up achieved	Post mHHS	UCLA Score	WOMAC pain score (F)	WOMAC Stiffness score (F)	WOMAC Physical function score (F)	SF12 Physical	SF12 Mental
Average	25.11	67.78	4.36	71.36	67.05	71.45	42.12	44.39
Min	11.24	4.40	3.00	30.00	25.00	9.00	14.81	12.12
Max	58.38	100.10	6.00	100.00	100.00	100.00	67.62	64.64

32mm Excluded Subgroup (Insufficient follow-up or Death)	Months follow-up achieved	Post mHHS	UCLA Score	WOMAC pain score (F)	WOMAC Stiffness score (F)	WOMAC Physical function score (F)	SF12 Physical	SF12 Mental
Average	25.11	79.40	5.68	75.00	72.22	79.22	43.74	51.10
Min	8.55	39.60	2.00	25.00	25.00	26.00	18.30	27.93
Max	50.66	100.10	9.00	100.00	100.00	100.00	57.76	62.39

Patient-Reported Outcome Differences	mHHS	UCLA	WOMAC pain score	WOMAC Stiffness score	WOMAC Physical function	SF12 Physical	SF12 Mental
Pre-op P-values	0.40	<0.0001	0.32	0.23	0.06	0.79	0.47
Post-op P-values	0.49	0.001	0.45	0.67	0.55	0.46	0.13

Table 7

Causes for ceramic-on-highly cross-linked polyethylene total hip arthroplasty failure and subsequent revision procedures

Subject	Head Size (mm)	Time to Revision (months)	Diagnosis	Revision Extent
1	28	69	Recurrent Instability (R)	Zimmer Longevity® constrained liner with 28mm head
1	28	75	Recurrent Instability (L)	Zimmer Longevity® constrained liner with 28mm head
2	28	33	Recurrent Instability	40mm Zimmer VerSys® cobalt-chromium head with Zimmer Trilogy® Acetabular 58mm cup with Longevity® liner
3	28	63	Late Infection (MSSA, <i>streptococcus pneumoniae</i>)	Explantation, 2-stage revision
4	28	0.75	Acute Infection (MSSA)	Irrigation & Debridement, head and liner exchange
5	28	29	Aseptic Loosening	Complete revision of all components – upsized cup and decreased abduction angle
6	32	25	Infection (<i>Streptococcus dysgalactiae</i>)	Explantation, 2-stage revision
7	32	51	Recurrent Instability	Zimmer VerSys® 32 mm femoral head, Zimmer Longevity® liner.
8	32	26	Pain NOS (prior THA for post-traumatic OA)	Complete revision of all components (outside institution)

Table 8

Femoral head and stem combinations with a list of all-cause revisions among the various stem and head pairings.

Femoral Stem Size:	28 mm Head Group	28mm Group Revisions	32mm Head Group	32 mm Group Revisions
4	1	1	1	
5	0		2	
6	4		8	
7	0		0	
7.5	8		10	
9	12		14	
10	15	2	19	2
11	18		19	
12	9		10	
12.5	8		13	1
13	12	2	11	
13.5	2		6	
14	10		5	
15	12		11	
16	4	1	2	
16.25	0		5	
17	1		1	
17.5	3		7	
18	0		1	
Total	119	6	145	3