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SYMPOSIUM: ADVANCES IN POLYETHYLENE BIOMATERIALS

Is There a Difference in Revision Risk Between Metal and Ceramic Heads on Highly Crosslinked Polyethylene Liners?

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Abstract

Background The most common bearing surface used among primary THAs worldwide is a metal or ceramic femoral head that articulates against a highly crosslinked ultrahigh-molecular-weight polyethylene (HXLPE) acetabular liner. Despite their widespread use, relatively little is known about the comparative effectiveness of ceramic versus metal femoral heads with respect to risk of revision and dislocation as well as the role of head size in this relationship.

Questions/purposes The purpose of this study was to evaluate the risk of (1) all-cause revision in metal versus ceramic femoral heads when used with an HXLPE liner, including an evaluation of the effect of head size; and (2) dislocation in metal versus ceramic femoral heads when used with an HXLPE liner as well as an assessment of the effect of head size.

Methods Data were collected as part of the Kaiser Permanente Total Joint Replacement Registry between 2001 and 2013. Patients in this study were on average overweight (body mass index = 29 kg/m^2), 67 years old, mostly female (57%), and had osteoarthritis (93%) as the primary indication for surgery. The material of the femoral head (metal, ceramic) was crossed with head size (< 32, 32, 36, > 36 mm), yielding eight device groupings. Only uncemented devices were evaluated. The primary outcome was all-cause revision (n = 28,772) and the secondary outcome was dislocation within 1 year (n = 19,623). Propensity

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scores were used to adjust for potential confounding at the implant/patient level using between-within semiparametric survival models that control for surgeon and hospital confounding and adjust estimates for the within-cluster correlation among observations on the response.

Results For all-cause revision, there was no difference between ceramic versus metal (reference) heads in combination with an HXLPE liner (hazard ratio [HR] = 0.82 [0.65–1.04], p = 0.099). Smaller metal head sizes of < 32 mm were associated with increased risk of revision relative to 36 mm (HR = 1.66 [1.20–2.31], p = 0.002, adjusted p = 0.025). For dislocation, ceramic heads increased risk relative to metal at < 32 mm only (HR = 4.39 [1.72–11.19], p = 0.002, adjusted p = 0.020). Head sizes < 32 mm were associated with increased risk of dislocation relative to 36 mm for metal (HR = 2.99 [1.40–6.39], p = 0.005, adjusted p = 0.047) and ceramic heads (HR = 15.69 [6.07–40.55], p < 0.001, adjusted p < 0.001).

Conclusions The results did not provide evidence for use of one femoral head material over another when used with HXLPE liners for the outcome of revision, but for dislocation, metal performed better than ceramic with < 32-mm heads. Overall, the findings suggest increased risk of revision/dislocation with head sizes < 32 mm.

Level of Evidence Level III, therapeutic study.

Introduction

The most common bearing surface used among primary THAs worldwide is a metal or ceramic femoral head that articulates against a highly crosslinked ultrahigh-molecular-weight polyethylene (HXLPE) acetabular liner [2, 3, 27, 28]. When used in a THA articulation against HXLPE, metal heads typically include an alloy of cobalt, chromium, and molybdenum, whereas ceramic heads may be alumina, zirconia, zirconia-toughened alumina matrix composite, or oxidized zirconium [15]. In the United States and several other countries around the world, the most popular liner is HXLPE (irradiated dose of > 40 kGy) [15, 27, 28]. HXLPE liners typically are used with either a metal-alloy femoral head and less frequently with a ceramic head [15]. The use of HXLPE rather than conventional UHMWPE is supported by simulator studies reporting decreased femoral penetration and wear in HXLPE [9, 22, 24, 25], radiologic evaluations of in vivo liner wear in randomized controlled trials indicating lower wear in HXLPE [6–8, 10, 20, 21, 26, 35], meta-analyses and systematic reviews suggesting that HXLPE has lower femoral penetration and wear [16, 17, 23], and registry-based studies showing a decreased risk of revision in HXLPE [28, 32].

There has been limited research related to the comparative safety/effectiveness of metal versus ceramic heads in combination with HXLPE liners. Theoretical advantages of ceramic compared with metal heads are that the smooth finish, hardness, and wettability lead to less friction, more lubrication, and less scratching between the bearing surfaces and thus lower rates of liner wear and osteolysis [37], although this is based on use of historical UHMWPE (gamma air-sterilized polyethylene) and older manufacturing processes of femoral heads that may not generalize to contemporary implants. One of the major concerns about ceramic heads, especially in ceramic-on-ceramic articulation, is the risk of component fracture; however, this has shown to be decreased in ceramic-on-polyethylene bearing surfaces [1, 39]. Results from the Australian registry suggest that ceramic heads have a slightly higher revision risk among patients with osteoarthritis over a 10-year period when used with HXLPE (gender/age-adjusted hazard ratio [HR], 1.03; 95% confidence interval, 0.94–1.13) [28]. Although informative, these results only adjust for age and gender, not considering the possible differential or confounding effects of head size or other factors on revision risk. Femoral head size is particularly relevant to the extent that larger heads have been shown to improve stability and thereby reduce risk of dislocation and revision [4, 5, 14, 27]. Collectively, there is relatively little research that can inform clinical practice about the most safe/effective femoral component types in the most common practice settings.

The current study evaluates risk of all-cause revision (primary endpoint) as well as dislocation (secondary endpoint) comparing metal and ceramic heads when used with HXLPE liners. To the extent that size is an attribute of a femoral head, any bearing effect could depend on size, but even in the absence of such interactive effects, it would be important to adjust for possible confounding head size effects (as well as confounding effects of other variables). Separately from any effect of the bearing, it is also of interest to determine to what extent changes in head size lead to improved implant performance. Specifically, we evaluated the risk of (1) all-cause revision in metal versus ceramic femoral heads when used with an HXLPE liner, including an evaluation of the effect of head size; and (2) dislocation in metal versus ceramic femoral heads when used with an HXLPE liner as well as an assessment of the effect of head size.

Materials and Methods

An integrated healthcare system total joint replacement registry (Kaiser Permanente Total Joint Registry) was used to identify a cohort of patients with primary elective unilateral THAs from April 1, 2001, to December 31, 2013, who were followed longitudinally. The study sample included arthroplasties from 358 surgeons at 50 medical

centers in seven US geographic regions (southern and northern California, Colorado, Georgia, Hawaii, Northwest, mid-Atlantic). During the study period, the membership population in these regions was between 8.3 and over 9 million. A subsample consisting of operative dates from January 1, 2007, to December 31, 2013, for southern California, northern California, and Hawaii was used to evaluate dislocations because information on this outcome in the healthcare system only became available at this later time. The Registry consists of standardized operative data collected from the surgeon by paper or electronically at the time of surgery [30, 31, 33, 34]. The participation of surgeons is voluntary and was 95% for the THAs. The registry is able to follow 91% of primary elective unilateral THAs with the remainder lost to followup as a result of membership termination. The forms capture information on patient demographics, surgical technique, implant characteristics, and patient outcome. Registry data are validated using the hospital utilization database and independent chart review.

Included in the sample were only individuals with uncemented fixation (and HXLPE liners), because cement fixation on either the cup or stem was rarely used in combination with ceramic heads in the registry. We also only included patients with a diagnosis of osteoarthritis, avascular necrosis, rheumatoid arthritis, inflammatory arthritis, and posttraumatic arthritis.

The exposure of interest was based on crossing femoral material (ceramic versus metal) and head size (< 32 mm, 32 mm, 36 mm, > 36 mm), yielding a total of eight groups. Ceramic heads were either alumina (N = 222) or zirconia-toughened alumina matrix composite (N = 5875). Ceramic and metal heads were predominantly from the following manufacturers: Zimmer/Biomet (Warsaw, IN, USA), Smith & Nephew (Memphis, TN, USA), DePuy (Warsaw, IN, USA), and Stryker/Howmedica (Kalamazoo, MI, USA) with three or fewer implants from each of the following: Wright Medical (Memphis, TN, USA), OMNIlife science (East Taunton, MA, USA), and Link (Hamburg, Germany). Similar to reports from another registry [28], oxidized zirconium was not included in the ceramic head group for several reasons: the material is proprietary to a single company, the volume of use in the registry is too low to form its own set of groups, and the effectiveness of the material may be substantially better than other ceramics, which would introduce treatment heterogeneity if pooled with other ceramic materials [28]. Zirconia was not included because it is no longer being used, corresponding to a recall in 2001 resulting from increasing component fractures attributable to a change in the manufacturing process from the largest supplier [15].

Variables regarded as potential confounders of the relationship between the treatment and the outcomes of interest included: age, sex, race (white versus other), diagnosis (osteoarthritis versus other), body mass index, height, American Society of Anesthesiologists score (< 3 versus ≥ 3), diabetes (yes versus no), operative time, and surgical approach (posterior versus any other approach) (Table 1). The outcome of primary interest was time to first revision, defined as replacement of any component for any

Table 1. Descriptive characteristics of the sample (listwise deleted data)

Characteristic	Revision sample, number (%)	Dislocation sample, number (%)
Total	28,772 (100.0)	19,623 (100)
Diabetes	5324 (19)	3607 (18)
ASA score ≥ 3	10,637(38)	7378 (38)
Male	12,260 (43)	8280 (42)
White	22,960 (80)	15,255 (78)
Osteoarthritis	26,770 (93)	18,359 (94)
Posterior approach	21,124 (77)	15,311 (81)
Characteristic	**Mean (SD)**	**Mean (SD)**
Height (inches)	67 (4)	67 (4)
Age (years)	67 (11)	67 (11)
BMI (kg/m^2)	29 (6)	29 (6)
Operative time (minutes)	90 (33)	88 (32)
Surgeries performed by surgeon at the time of surgery	191 (179)	201 (187)

Revision sample, number, missing: 771 ASA, 84 race, 1326 approach, 514 height, 2989 operative time, 517 BMI; dislocation sample, number, missing: 410 ASA, 3 race, 768 approach, 16 height, 976 operative time, 15 BMI; ASA = American Society of Anesthesiologists; BMI = body mass index.

reason, which was confirmed by chart review. The secondary outcome of interest was dislocation within 1 year of implantation (Table 2). Dislocations were identified based on International Classifications of Disease, 9th Revision, Clinical Modification codes 718.35, 835*, or 996.42.

Statistical Analysis

Survival analysis was performed with a semiparametric between-within model [38]. The model included an unspecified baseline hazard, fixed effects corresponding to patient treatment group (seven coefficients corresponding to the eight treatment groups), surgeon and hospital means that reflect the proportion of patients receiving treatment in each cluster, propensity score weights, and normal cross-classified random effects for surgeon and hospital. This between-within model allows interpretation of patient treatment effects as within-patient effects that cannot be confounded by fixed surgeon and hospital characteristics. Loss to followup (either date of membership termination or death) was treated as censored cases with survival time based on the time those cases exited the study sample. For member terminations, this approach assumes that those who terminate membership have a survival prospect similar to those experiencing events. In contrast, death represents a competing event, suggesting a competing risk model would be more appropriate. A competing risk model, however, would conflate the treatment effect with the probability of experiencing the competing event; therefore, the approach taken in this study was a more direct estimate of treatment effectiveness [18]. To account for missing values of some variables, multiple imputations (20 imputations, 10 iterations) were performed using chained equations [40]. Imputations were undertaken separately for each of the two outcomes. Generally, the imputation model for each outcome included patient treatment assignment and covariates, surgeon and facility means corresponding to these variables as well as the event indicator, and the Nelson-Aalen estimator of the cumulative baseline hazard at the time of the event being modeled or censoring for each case [41]. Average treatment effect propensity score weights [12, 13] were calculated separately for each imputed data set using a multinomial logistic regression model that included all covariates as predictors of treatment assignment. This approach to calculating propensity score weights ensures each group has comparators in each of the other treatment groups (ie, within 0.20 SDs of the logit propensity score), which reduces bias, and calculating weights through stratification (six strata) has the advantage of being less sensitive to misspecification of the propensity score model [12, 13]. There was notable improvement in balance after applying the propensity score weights. For example in the revision sample for 10 bearing/head size comparisons on each of the 10 covariates, before applying weights, the mean standardized difference was 0.20 (SD = 0.21), but after applying weights, the mean standardized difference was 0.04 (SD = 0.04).

To limit Type I errors, global tests were used with followup pairwise comparisons conducted conditional on a statistically significant global test. Probabilities from these pairwise comparisons were adjusted using Holm's sequential Bonferroni procedure [11] based on the total number of pairwise comparisons conducted. Global tests and pairwise comparisons were based on results aggregated

Table 2. Analytical sample sizes and cases revised by femoral head material and head size

Head size	Femoral head material	
	Ceramic	Metal
Revision	N = 6097, revised = 128 (2.1%)	N = 22,675, revised = 515 (2.3%)
< 32 mm	N = 468, revised = 9 (1.9%)	N = 2880, revised = 101 (3.5%)
32 mm	N = 2072, revised = 61 (2.9%)	N = 8476, revised = 193 (2.3%)
36 mm	N = 3239, revised = 49 (1.5%)	N = 10,242, revised = 194 (1.9%)
> 36 mm	N = 318, revised = 9 (2.8%)	N = 1077, revised = 27 (2.5%)
Dislocation	N = 4331, dislocation = 42 (1.0%)	N = 15,292, dislocation = 196 (1.3%)
< 32 mm	N = 249, dislocation = 7 (2.8%)	N = 1215, dislocation = 16 (1.3%)
32 mm	N = 1507, dislocation = 17 (1.1%)	N = 5633, dislocation = 80 (1.5%)
36 mm	N = 2363, dislocation = 17 (0.7%)	N = 7620, dislocation = 85 (1.2%)
> 36 mm	N = 212, dislocation = 1 (0.5%)	N = 824, dislocation = 15 (2.1%)

Followup time for implants as it pertains to revision (in years): median = 4.6, SD = 3.4, maximum = 11.6 (ceramic < 32); median = 3.2, SD = 2.8, maximum = 11.2 (ceramic = 32); median = 2.05, SD = 1.8, maximum = 9.9 (ceramic = 36); median = 1.9, SD = 1.2, maximum = 5.5 (ceramic > 36); median = 5.9, SD = 3.5, maximum = 12.7 (metal < 32); median = 3.8, SD = 2.9, maximum = 12.6 (metal = 32); median = 2.8, SD = 2.2, maximum = 11.5 (metal = 36); and median = 2.8, SD = 1.7, maximum = 9.9 (metal > 36).

over imputed data sets [36]. When reporting the bearing effect averaged over head size, the effect of the bearing was first estimated within each head size stratum and then averaged over strata using inverse variance weights. Data were analyzed using the mice, miceadds, and coxme packages of R (R Version 3.1.2; R Foundation for Statistical Computing) with $\alpha = 0.05$ (two-tailed).

Results

All-cause Revision

The first research question pertains to whether there is a difference between metal and ceramic heads with respect to risk to all-cause revision. Generally, there was insufficient evidence of a difference in revision risk between metal and ceramic heads in the statistical model that adjusted for potential confounding variables. The ceramic versus metal (reference) effect averaged over head size groups was not significant (HR = 0.82 [0.65–1.04]; p = 0.099) (reasons for revision are in Table 3).

With regard to whether increasing head size reduces risk of revision, after adjusting for potential confounders, there was evidence that among metal heads, going from 36 mm to < 32 mm was harmful (HR = 1.66 [1.20–2.31], p = 0.002, adjusted p = 0.025). See Appendix 1 for further details regarding the analysis (Supplemental materials are available with the online version of *CORR*®.).

Dislocation

There was evidence of a difference between metal and ceramic heads with respect to risk of dislocation, but the effect was not the same across the head size groups. It was found that ceramic heads performed notably worse than metal at < 32 mm only (HR = 4.39 [1.72–11.19], p = 0.002, adjusted p = 0.020). Generally, there was evidence that < 32 mm relative to 36 mm increased risk of dislocation for both metal (HR = 2.99 [1.40–6.39], p = 0.005, adjusted p = 0.047) and ceramic heads (HR = 15.69 [6.07–40.55], p < 0.001, adjusted p < 0.001). See Appendix 1 for further details regarding the analysis.

Discussion

A study such as this one is important in the postmarket surveillance of orthopaedic devices because the femoral head of a THA is an important determinant of device survival. Relatively little is known about the comparative effectiveness of ceramic versus metal femoral heads when used with HXLPE liners with only one registry report

Table 3. Reasons for revision

	Overall	Metal	Ceramic
Number	28,772	22,675	6097
Revision	643 (2.2)	515 (2.3)	128 (2.1)
Reason	Number (%)	Number (%)	Number (%)
Leg length inequality	8 (1.2)	8 (1.6)	0 (0.0)
Acetabular fracture	2 (0.3)	2 (0.4)	0 (0.0)
Aseptic loosening	71 (11)	61 (12)	10 (8)
Component fracture	10 (1.6)	6 (1.2)	4 (3)
Femoral fracture	25 (4)	20 (4)	5 (4)
Infection	155 (24)	126 (25)	29 (23)
Instability	236 (37)	198 (38)	38 (30)
Polyethylene insert wear	26 (4)	16 (3)	10 (8)
Osteolysis	5 (0.8)	2 (0.4)	3 (2)
Other	32 (5)	29 (6)	3 (2)
Periprosthetic fracture	83 (13)	68 (13)	15 (12)
Wound dehiscence	2 (0.3)	2 (0.4)	0 (0.0)
Wound drainage	22 (3)	18 (4)	4 (3)
Hematoma/seroma	37 (6)	29 (6)	8 (6)
Cup malposition	3 (0.5)	3 (0.6)	0 (0.0)
Metallosis	2 (0.3)	1 (0.2)	1 (0.8)

There may be multiple reasons for revision.

providing evidence [28] but with limited adjustment of potential confounders. Similar gaps in the literature can be found as they relate to the effect of femoral head size and the outcome of dislocation. Collectively, increased research into the most effective hip components should lead to the reduction of adverse events experienced by patients. The results suggest no difference between metal and ceramic heads with respect to all-cause revision, but increased risk of dislocation in < 32-mm heads for ceramic relative to metal heads. Furthermore, use of head sizes < 32 mm (relative to 36 mm) led to increased risk of all-cause revision for metal and increased risk of dislocation for both metal and ceramic heads.

Our study has several limitations. First, in this study, dislocations were limited to within 1 year of the index procedure, which may miss later occurring instances of these adverse events [19, 20, 29, 30]. Therefore, any conclusions should be restricted to early dislocations. Furthermore, our study included only uncemented implants. Although this limits generalizability of the results, uncemented implants are most commonly used. Another limitation is the possibility of residual confounding resulting from unmeasured confounders. One such potential confounder is physical activity. For instance, the use of ceramic heads may be used preferentially with more physically active individuals because of the presumed benefit of reduced liner wear. Although physical activity may be difficult to quantify, it would be an interesting factor to pursue in future studies.

For the primary endpoint of all-cause revision, there was a lack of evidence for a difference between ceramic and metal (reference) heads (HR = 0.82 [0.65–1.04]), which is similar to findings from the Australian registry (HR = 1.03 [0.94–1.13]) [28]. It should be noted, however, that there are differences among these two studies, including differences in patient/surgeon/hospital populations, distribution of ceramic types (Australia's ceramic group includes zirconia [28]), length of followup, and different statistical models. With respect to modeling, we believe our approach was somewhat more rigorous in addressing confounding given the adjustment to a greater number of measured variables and a modeling approach that controls for cluster-level confounders. For the secondary endpoint of dislocation, the results also indicate increased risk with < 32-mm heads relative to 36 mm. Generally, reduction of revision risk and dislocation with a larger head size is consistent with results reported elsewhere [4, 14], but again we believe our approach to handling confounding was more rigorous in the current study, suggesting greater accuracy in the reported results. Although we observed improved performance with respect to dislocation with 36-mm heads relative to < 32 mm, it should be noted that longer term followup may suggest a different result. Notably, the more intermediate head size of 32 mm was found most effective with respect to reducing risk of revision among metal and ceramic heads used with polyethylene liners with up to 11 years followup [27], but without any adjustment for potential confounders.

Based on our findings, several recommendations can be made for clinical practice and research. Generally, our findings suggest cautious use of head sizes < 32 mm. Furthermore, we cannot recommend one femoral head material over another (ceramic, metal) when used with HXLPE liners in head sizes ≥ 32 mm, but this topic should be investigated further in future studies. Future studies could also examine the effectiveness of femoral head material under more diverse practice settings, for example when used with different bone fixation methods and in older patient populations.

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