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Original article

Outcomes of Ceramic Bearings After Revision Total Hip Arthroplasty in the Medicare Population

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ABSTRACT

Background: The purpose of this study was to analyze the utilization and outcomes of ceramic bearings used in revision total hip arthroplasty (R-THA) in the Medicare population.
Methods: A total of 31,809 patients aged >65 years at the time of revision surgery who underwent R-THA between 2005 and 2013 were identified from the United States Medicare 100% national administrative claims database. Outcomes of interest included relative risk of readmission (90 days) or infection, dislocation, rerevision, or mortality at any time point after revision. Propensity scores were developed to adjust for selection bias in the choice of bearing type at revision surgery.
Results: The utilization of ceramic-on-polyethylene (C-PE) and ceramic-on-ceramic (COC) bearings in R-THA increased from 5.3% to 26.6% and from 1.8% to 2.5% in between 2005 and 2013, respectively. For R-THA patients treated with C-PE bearings, there was reduced risk of 90-day readmission (hazard ratio, HR: 0.90, $P = .007$). We also observed a trend for reduced risk of infection with C-PE (HR: 0.88) that did not reach statistical significance ($P = .14$). For R-THA patients treated with COC bearings, there was reduced risk of dislocation (HR: 0.76, $P = .04$). There was no significant difference in risk of rerevision or mortality for either the C-PE or COC bearing cohorts when compared with the metal-on-polyethylene bearing cohort.
Conclusion: Medicare patients treated in a revision scenario with ceramic bearings exhibit similar risk of rerevision, infection, or mortality as those treated with metal-on-polyethylene bearings. Conversely, we found an association between the use of specific ceramic bearings in R-THA and reduced risk of readmission (C-PE) and dislocation (COC).

Ceramic bearings, in which a ceramic femoral head articulates against either polyethylene (ceramic on polyethylene [C-PE]) or a ceramic acetabular component (ceramic on ceramic [COC]), have been used for >40 years in primary total hip arthroplasty (THA) as an alternative to metal-on-polyethylene (M-PE) bearings [1-3]. Contemporary ceramic bearings have well-documented, long-term clinical survivorship in primary THA [4,5]. Although ceramic components were initially adopted because of their improved wear resistance relative to M-PE [6,7], recent research has also shown that the use of ceramic mitigates the risk of taper corrosion [8]. Previous studies have also suggested that COC bearings may be associated with reduced risk of dislocation [9,10]. Balancing these advantages, ceramic bearings have well-known drawbacks, namely, their increased cost [11]; the potential risk of fracture [5,12], although substantially diminished for the current generation [13,14]; and, in the case of COC articulations, squeaking [15]. Due partly to concerns about squeaking, COC is currently a less popular bearing choice than C-PE among US surgeons [11].

In the past decade, there have been substantial changes in the usage of alternative bearings in primary THA due, first, to the widespread adoption of metal-on-metal (MOM) articulations up to

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2008, followed by their subsequent decline [16]. In the United States, MOM hips were used in 26%-32% of revision THAs between 2005 and 2008 because of concerns about dislocation, especially in elderly patients [16]. By contrast, comparatively little is known regarding the usage patterns for ceramic bearings during revision surgery in the past decade, especially after the decline of MOM usage that began in 2009.

The outcomes of different ceramic bearings during revision surgery likewise remain poorly understood. Previous studies on ceramic bearing usage during revision have focused on the outcomes of patients who were revised after the rare circumstances of a fracture of the femoral head [17] or who were revised because of squeaking [18]. Wong et al [19] studied 884 aseptic revisions of MOM hip resurfacing arthroplasties in Australia. They observed no difference in the rerevision rate as a function of the bearing surface (M-PE, MOM, COC, or C-PE); however, they cautioned that a larger sample size than what they examined would be likely be necessary to see differences, if there were any [19]. Jack et al [20], also from Australia, followed the outcomes of 165 acetabular cup revisions using COC bearings; however, this observational cohort study did not include a control group with an alternative bearing. In the United States, Cooper et al [21] described the treatment of patients who were revised for adverse locale tissue reactions from taper corrosion in M-PE bearings and later recommended that device components that do not include cobalt or chromium be used in the treatment of such patients at revision, using C-PE or COC bearings [22].

It remains unknown how the patient outcomes after revision using contemporary ceramic bearings compare with the outcomes for patients revised using M-PE bearings in the United States. Accordingly, we addressed the following related research questions: (1) what is the utilization of ceramic bearings for revision total hip arthroplasty (R-THA) in the Medicare population and how has it evolved over time; (2) does the use of C-PE bearings influence outcomes after R-THA as compared with M-PE; and (3) does the use of COC bearings influence outcomes after R-THA as compared with M-PE?

Methods

The Medicare 100% national administrative claims database was used to identify revision THA patients between October 1, 2005, and December 31, 2013. This set of data captures all fee-for-service claims submitted by hospitals for hip revision and other hospitalizations from this group of patients. Patients aged <65 years or beneficiaries enrolled in a health maintenance organization were excluded. A small number of beneficiaries residing outside of the 50 states were also excluded. Thus, our study considered the elderly Medicare population of revision hip arthroplasty patients.

Unique, encrypted Medicare beneficiary identifiers were used to follow patients longitudinally throughout the study period. Patients' Medicare entitlement status and mortality were tracked using a linked "denominator" file provided by the Centers for Medicare and Medicaid Services that accompanied the analytic data sets. International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM: 81.53, 00.70-00.73) procedure codes were used to identify hip revision patients. We did not distinguish between the type of revision surgery (ie, acetabular vs femoral revision) in assigning patients to the study. Previous research has suggested that outcomes after revision are not sensitive to the type of revision surgery [19].

Our focus was to investigate outcomes as a function of the bearing surface used in the revision, which was identified in the revision claim record using an ICD-9-CM code of 00.74 (M-PE); 00.75 (MOM); 00.76 (COC); and 00.77 (C-PE). These bearing surface codes were introduced in October 2005 for M-PE, MOM, and COC bearings. In October 2006, the code for C-PE was introduced. As a result, the C-PE cohort has one less year of follow-up than the other bearing surface cohorts in this study. Between 2006 and 2013, about 31%-33% of revisions recorded in the Medicare database included a bearing surface code (Table 1). We investigated the difference in patient characteristics between those with known vs unknown bearings to better understand the study population. We observed a slight but significant difference in the patient characteristics that received a bearing code in the Medicare database and those that were uncoded. Overall, female patients, older patients, those needing Medicare buy-in (indicative of lower socioeconomic status), those with greater comorbidities (based on their Charlson score [23]), and patients residing in the South census region all had a lower probability of having their bearing type coded. Conversely, a higher total hospital charge was associated with a higher likelihood of having the bearing type coded.

Because MOM bearings are no longer widely used, we focused our research on the comparison of outcomes in patients with known M-PE, C-PE, and COC bearings at the time of revision THA. Outcomes of interest included 90-day readmission for any reason, periprosthetic joint infection, dislocation, rerevision, or death at any time point after the index revision procedure during the study period. Hospital readmission was determined by the appearance of any inpatient claims within 90 days of discharge from the index revision surgery, indicating a rehospitalization episode. The rate of 90-day hospital readmission is a quality measure defined by the Affordable Care Act of 2010 [24]. Periprosthetic joint infection was identified using an ICD-9-CM diagnosis code of 996.66 [25], whereas dislocation was identified using ICD-9-CM diagnosis codes of 718.35, 835.00-835.03, and 996.42 (effective October 2005) [26]. Rerevision was identified using the same revision codes listed previously to assemble the study cohorts, and death was identified using the previously mentioned denominator file accompanying the inpatient analytical data set. We used the Kaplan-Meier approach to inspect the crude (unadjusted) survivorship of the M-PE, C-PE, and COC cohorts for each of the outcomes of interest.

Propensity scores were developed to adjust for selection bias in the choice of bearing type at revision surgery. As discussed in a recent review [27], propensity scores were used to treat large data sets of retrospective registry data, such as are available via Medicare, for selection bias. The application of propensity scores represents an approach to treating Medicare data like a randomized clinical study by effectively balancing patient factors known to be

Table 1
Summary of Revision THAs Coded by Bearing Type in the Medicare Population (2005-2013).

Year	THA Revisions Coded by Bearing Type			Coded, Subtotal[a]	Uncoded, Subtotal	Total	% Coded
	C-PE	COC	M-PE				
2005	0	50	959	1353	16,007	17,360	7.8
2006	64	189	3455	5114	11,001	16,115	31.7
2007	276	91	3400	5183	10,520	15,703	33.0
2008	279	68	3118	4856	10,429	15,285	31.8
2009	302	82	3039	4662	10,345	15,007	31.1
2010	400	75	3089	4626	10,499	15,125	30.6
2011	638	85	3201	4910	11,021	15,931	30.8
2012	922	101	3242	5014	10,900	15,914	31.5
2013	1384	128	3172	5203	11,309	16,512	31.5
Total	4265	869	26,675				

THA, total hip arthroplasty; C-PE, ceramic-on-polyethylene; COC, ceramic-on-ceramic; M-PE, metal-on-polyethylene.

[a] In addition to C-PE, COC, and M-PE, this subtotal also includes those revisions that were coded with a metal-on-metal bearing.

related to bearing surface selection. Specifically, the propensity score calculates a patient's chance of receiving a C-PE or COC implant, given certain patient and hospital factors. The actual bearing material received is independent of this propensity score. If different types of bearings were implanted for patients having identical propensity, the choice of bearing material can be thought of as randomly assigned. This ensures that the outcomes associated with each bearing type are not confounded by patient factors. The propensity score was calculated for each patient using the following predictors: age, sex, region, race, Medicare buy-in (a proxy for socioeconomic status), Charlson Comorbidity Score, revision calendar year, length of stay, charge amount, hospital volume, surgeon volume, principal diagnosis, hospital location (urban or rural), hospital type (eg, public, private), size of the hospital, and 2-way interactions among age, gender, race, Charlson score, hospital size, and hospital type.

Cox regression incorporating propensity score stratification (10 levels) was then used to evaluate the impact of bearing surface selection on outcomes, after adjusting for patient-, hospital-, and surgeon-related factors. The Cox model was stratified into 10 propensity strata. The Cox model combined the likelihood functions from each stratum and estimated an overall hazard ratio and corresponding confidence intervals. The Cox regression model incorporated the main study variables: bearing type (C-PE, COC, or M-PE) and the following potential confounding variables: patient age; race; census region; patient diagnosis of diabetes, heart disease or obesity; patient's Charlson Comorbidity Index; hospital type, location, and size; hospital procedure volume; surgeon procedure volume; total hospital charges; length of stay; Medicare buy-in; operating room charges; and calendar year. All statistical analyses were performed using SAS version 9.4 (Cary, NC).

Results

A total of 31,809 Medicare patients who underwent R-THA between 2005 and 2013 with known bearing types were identified from the Medicare 100% inpatient sample administrative database, including 4,265 patients who received C-PE, 869 patients who received COC, and 26,675 patients who received M-PE bearings (Table 1). The relative usage of ceramic bearings varied over time (Fig. 1). In 2007, the first calendar year in which all 4 bearing codes (including MOM) were fully implemented; C-PE and COC usage was 5.3% and 1.8%, respectively. By 2013, C-PE and COC bearings usage increased to 26.6% and 2.5%, respectively (Fig. 1). During this time

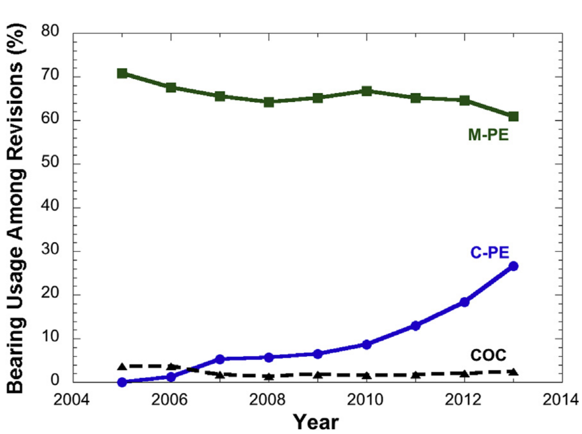

Fig. 1. Reported bearing usage of C-PE, COC, and M-PE in revision total hip arthroplasty in the Medicare population between 2005 and 2013. C-PE, ceramic on polyethylene; COC, ceramic on ceramic; M-PE, metal on polyethylene.

period, the relative usage of MOM bearings declined from 27.3% to 10% among R-THAs.

The R-THA patients in this study were 60% female, on average (±standard deviation) 75 (±10) years old, 94% white, and 50% had no comorbidities (corresponding to a Charlson score of 0, Table 2). The usage of C-PE implants in R-THA was the highest in the 65- to 69-year cohort (21% of revision operations in that cohort) and lowest for the 85+ year cohort (7% of revision operations). The opposite trend was observed for M-PE implants: 76% of patients in the 65- to 69-year cohort received M-PE implants compared with 90% of the 85+ year cohort. Percentage of patients receiving COC implants, on the other hand, was uniform among all age cohorts. Utilization of C-PE, COC, and M-PE was comparable in male and female patients. Although patients with bearing codes were dominantly white in this study, the utilization of ceramic bearings was homogeneous across races. For instance, 13% of white patients, 14% of black patients, and 10% of patients of unknown/other races received C-PE bearings, whereas the utilization of COC bearings were 3%, 4%, and 4% for white, black, and unknown/other races, respectively. While patients in the Midwest received the largest number of M-PE implants (7615), patients in the South received the

Table 2
Overall Patient Demographics.

Demographic	C-PE		COC		M-PE		Total
	N	%	N	%	N	%	
Age (y)							
65-69	1705	21	270	3	6206	76	8181
70-74	1050	15	188	3	5884	83	7122
75-79	753	11	155	2	6187	87	7095
80-84	488	9	154	3	5006	89	5648
85+	269	7	102	3	3392	90	3763
Gender							
M	1712	14	308	2	10,545	84	12,565
F	2553	13	561	3	16,130	84	19,244
Gender, age (y)							
M, 65-69	720	20	111	3	2691	76	3522
M, 70-74	437	14	70	2	2520	83	3027
M, 75-79	297	11	58	2	2437	87	2792
M, 80-84	176	9	50	2	1779	89	2005
M, 85+	82	7	19	2	1118	92	1219
F, 65-69	985	21	159	3	3515	75	4659
F, 70-74	613	15	118	3	3364	82	4095
F, 75-79	456	11	97	2	3750	87	4303
F, 80-84	312	9	104	3	3227	89	3643
F, 85+	187	7	83	3	2274	89	2544
Race							
White	4034	13	796	3	25,205	84	30,035
Black	179	14	53	4	1022	81	1254
Other/unknown	52	10	20	4	448	86	520
Census region							
Midwest	896	10	179	2	7615	88	8690
North East	767	11	193	3	5745	86	6705
South	1517	16	325	4	7440	80	9282
West	1085	15	172	2	5875	82	7132
Charlson score							
0	2464	15	476	3	13,888	83	16,828
1-2	1453	13	291	3	9808	85	11,552
3-4	280	11	74	3	2282	87	2636
5+	68	9	28	4	697	88	793
Medicare buy-in							
No buy-in	3985	14	778	3	24,522	84	29,285
With buy-in	280	11	91	4	2153	85	2524
Reason for revision[a]							
Infection	223	13	41	2	1423	84	1687
Dislocation	482	9	138	3	4680	88	5300
Loosening	783	10	159	2	6625	88	7567
Other	2491	16	454	3	12,173	81	15,118

M, male; F, female; C-PE, ceramic-on-polyethylene; COC, ceramic-on-ceramic; M-PE, metal-on-polyethylene.

[a] Reason for revision is only listed for most common revisions (>1%).

largest number of C-PE (1517) and COC (325) implants. Among infection, dislocation, and loosening as reasons for revision, loosening occurred most frequently among all 3 bearing types.

For R-THA patients treated with C-PE bearings, there was reduced risk of 90-day readmission (hazard ratio [HR]: 0.90, 95% CI: 0.84-0.96, $P = .007$; Fig. 2). We also observed a trend for reduced risk of infection with C-PE (HR: 0.88, 95% CI: 0.74-1.04) that did not reach statistical significance ($P = .14$). Based on Kaplan-Meier analysis, the crude (unadjusted) survivorship at 5 years, using rerevision as an end point (with 95% CIs), was 83.7% (82.8%-84.6%) for M-PE, 82.2% (79.0%-84.9%) for C-PE, respectively. After propensity score stratification and adjustment for confounders, there was no significant difference in risk of rerevision ($P = .99$) or mortality ($P = .51$) for the C-PE bearing cohorts when compared with M-PE. When recipients of C-PE and M-PE are compared, reason for revision was a risk factor for all 5 outcomes (death, dislocation, rerevision, infection, readmission) analyzed in this study (Fig. 2). Charlson score and length of stay were risk factors for all outcomes except rerevision. Finally, race was a risk factor for all outcomes except infection.

For R-THA patients treated with COC, there was reduced risk of dislocation (HR: 0.76, 95% CI: 0.58-0.99, $P = .04$; Fig. 3). Based on Kaplan-Meier analysis, the crude (unadjusted) survivorship at 5 years, using rerevision as an end point (with 95% CIs), was 85.0% (79.7%-88.9%) for the COC cohort. After propensity score stratification and adjustment for confounders, there was no significant difference in risk of rerevision ($P = .31$) or mortality ($P = .45$) for the COC bearing cohorts when compared with the M-PE cohort. When C-PE and M-PE cohorts were compared, reason for revision was a risk factor for all 5 outcomes (death, rerevision, infection, readmission) analyzed in this study (Fig. 3). Charlson score and length of stay were risk factors for all outcomes except rerevision. Race and year of implantation were risk factors for all outcomes except infection. Finally, age was a risk factor for all outcomes except dislocation.

Overall, age was the highest relative importance predictor of mortality, whereas reason for revision was the predictor with highest relative importance for dislocation, infection, readmission, rerevision for COC bearings for both COC and C-PE bearings (Figs 2 and 3).

Discussion

In this study of all comers for revision total hip surgery in the elderly Medicare population, we asked how the use of ceramic bearings changed over time and whether the type of ceramic bearing influenced outcomes relative to M-PE. Between 2006 and 2013, we observed an increase in the reported usage of C-PE

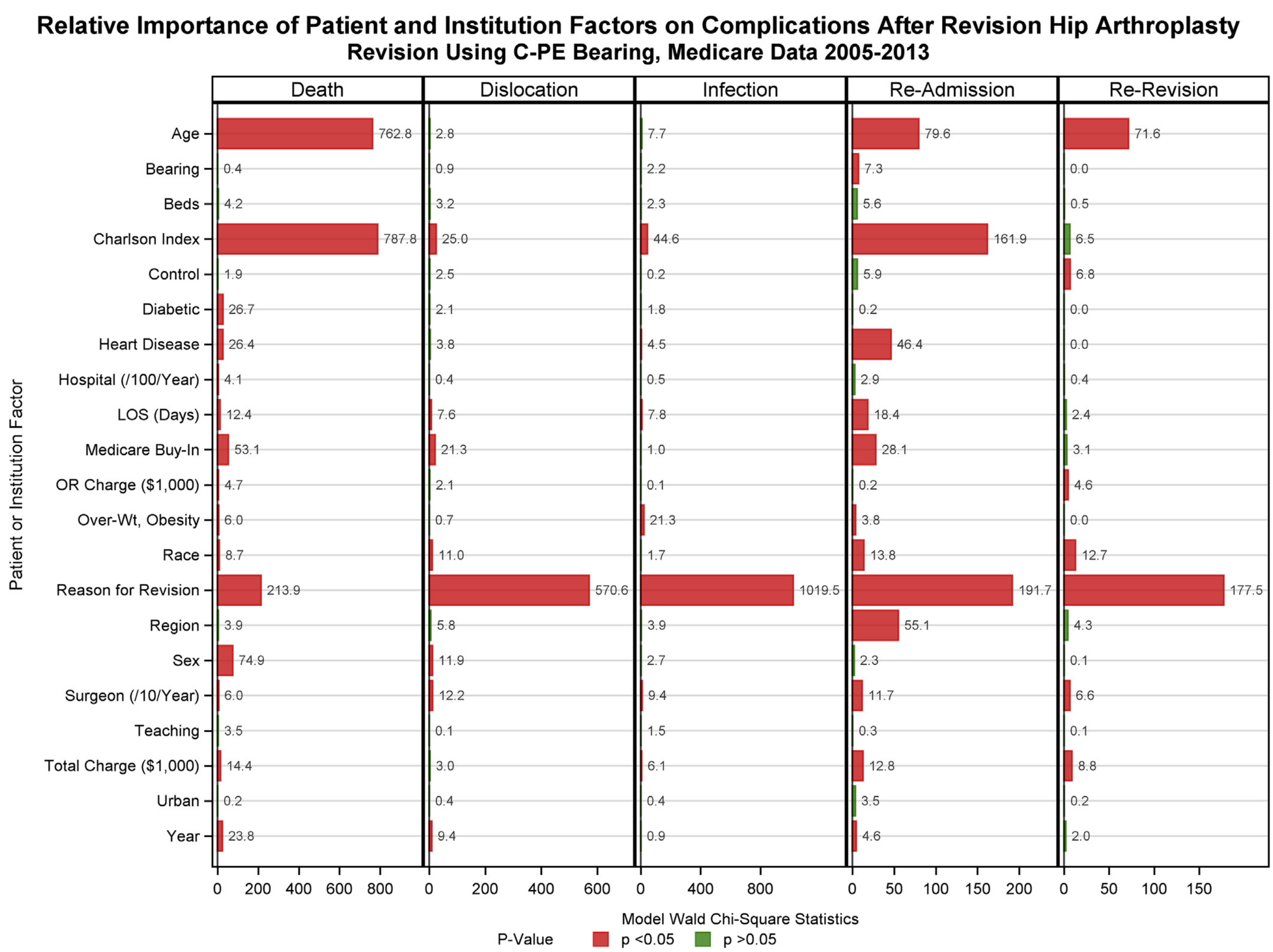

Fig. 2. Relative importance of patient, clinical, and institution factors on risk of mortality, dislocation, infection, 90-day readmission, and re-revision after revision total hip arthroplasty using C-PE vs M-PE bearings. The effect size for each factor is judged by the relative magnitude of the model Wald chi-squared statistic. LOS, length of stay; OR, operating room.

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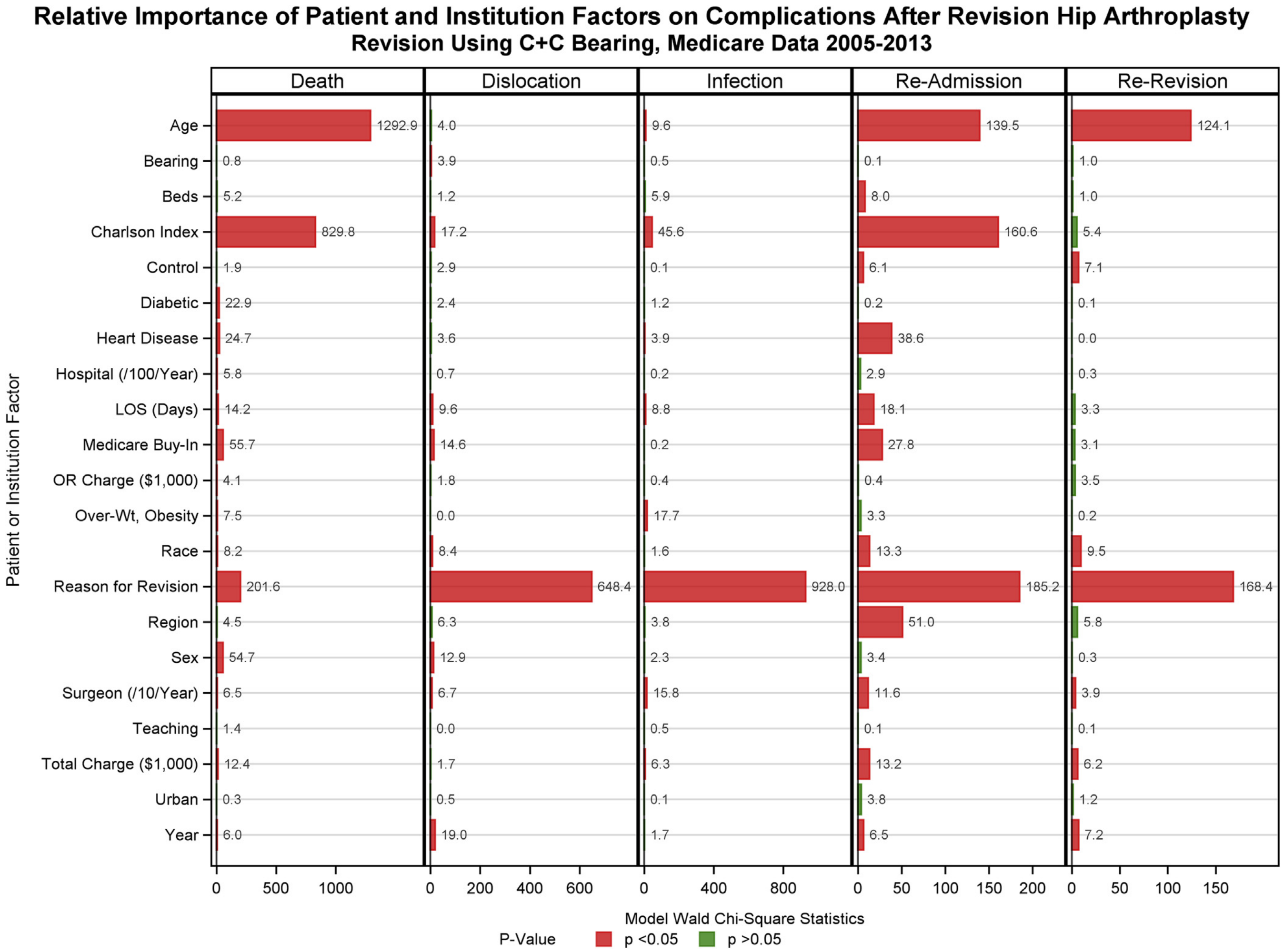

Fig. 3. Relative importance of patient, clinical, and institution factors on risk of mortality, dislocation, infection, 90-day readmission, and re-revision after revision total hip arthroplasty using COC vs M-PE bearings. The effect size of each factor is judged by the relative magnitude of the model Wald chi-squared statistic.

bearings in revision surgeries for Medicare beneficiaries. We found no evidence to suggest that ceramic bearings were associated with worse outcomes than M-PE bearings when used in revisions. Conversely, we found support for our hypotheses that ceramic bearings may improve certain outcomes after revision surgery, such as 90-day readmission, dislocation, and perhaps infection; however, the results were bearing- and outcome-specific.

We would like to highlight several limitations of our study for the reader. First, our analysis was based on a retrospective analysis of administrative billing data, which was limited to the ICD-9-CM classification of procedures and diagnoses. Because the Medicare data set does not include clinical information, it was not possible for us to evaluate clinical factors such as soft tissue damage, the presence of metal-related pathology, or osteolysis in our study. We attempted to include and adjust for revision procedure complexity and difficulty due to patient and clinical factors by considering the patients' Charlson Comorbidity Index and length of stay as proxies. Furthermore, our analysis methodology including propensity scores was designed to adjust for selection bias in the assignment of ceramic bearings in the comparison with M-PE bearings and overcome the limitation of a restrospective nonrandomized study design.

Second, our study was limited to 31%-33% revision patients in Medicare with known billing codes, which are optional and not required for hospital reimbursement [28]. We addressed this limitation using propensity scores to adjust for selection bias among the patients who were coded for bearing type. Third, the patient population was limited to those >65 years in age who were covered by Medicare; our findings may not necessarily apply to younger patients. Fourth, we included all comers to revision in this analysis and did not subclassify the treated population into septic vs aseptic revisions, for example. Fifth, our analysis was limited to outcomes recorded in an inpatient setting, which may have underestimated the risk of dislocation because not all of these events may be treated with clinical intervention requiring an overnight stay.

Sixth, the bearing codes for both types of ceramic bearings and the control (M-PE) bearings are general and do not distinguish between the types of polyethylene formulations, different types of ceramic biomaterials, or head size that were used clinically during the study period. In the first decade of the 2000s, many different formulations of highly cross-linked and thermally stabilized polyethylene were clinically introduced, including second-generation materials [29]. In addition, the type of ceramics available in the United States also varied in the time period of this study, with the increased adoption of zirconia-toughened alumina after 2003 [30]. Furthermore, changes in femoral head size were clinically introduced during this time period to improve joint stability and reduce dislocation risk [26]. Thus, the granularity of the administrative bearing codes limits our ability to answer questions about specific formulations of bearing materials and head size.

Nevertheless, these limitations are offset by the use of the largest (100%) nationally representative data set available for the elderly population, in which ceramic bearings were used in about a quarter of revisions for any reason. The smallest cohort in our study (for revision COC patients) is approximately the same size as the entire study population of revision resurfacings considered by Wong et al [19] in their analysis of the Australian registry data. Because of the sample sizes necessary to identify potentially subtle trends in administrative data, very large data sets, such as orthopedic registries or the Medicare data set we used, are well suited to examining the outcomes after revision surgery.

The utilization of alternative bearings has been previously examined in the context of primary THA and as a result of concerns with MOM. Although the usage of MOM bearings has previously been studied in revision surgeries, we are aware of no previous utilization studies of ceramic bearings in revision for US patients, making comparison of our results difficult. Clinicians were attracted to alternative bearings because of the larger head sizes that could be achieved with MOM to improve joint stability and reduce dislocation risk. Since that time, larger diameter ceramic heads (up to 44 mm in diameter) are now clinically available in the United States. Also, there is greater understanding based on international registry data that head sizes >36 mm diameter may not necessarily provide improved dislocation risk in clinical practice. Finally, concerns with taper corrosion using cobalt-chromium femoral heads may also be playing a role in surgeon decisions to increasingly adopt ceramic heads in both a primary and revision scenario. Although it is not possible for us to identify from claims data which of the aforementioned trends are responsible for the increase in ceramic bearing usage among Medicare beneficiaries undergoing revision, the trends are temporally coincident with the reduction of utilization of MOM bearings and, to a growing extent, reduced usage of M-PE bearings as well.

Few studies have examined the rates of THA rerevision for large populations [19,31]. Based on the Australian registry, Wong et al [19] found a 26% rerevision rate at 10 years, with no significant effect of the bearing surface. Examining the elderly Medicare population, Ong et al [31] reported 81% survivorship at 5 years after revision, which is comparable to the survivorship for the 3 cohorts recorded in the present study. The difference in lower rerevision rates between the study by Wong et al and the Medicare studies is most likely due to differences in the patient mix in the 2 studies. In the study by Wong et al [19], the patients were all revisions of hip resurfacing performed in Australia, which according to the 2014 registry report [5] was most often performed in male patients aged <65 years.

For the C-PE cohort, the reduced 90-day admission rates and trend for reduced risk of infection were independent findings. Recent studies presented at national conferences suggest that ceramics may be more resistant to infection than cobalt-chromium surfaces [32-35], which would help explain these results viewed here. Further analysis is needed to better understand the association between infection, early readmission, and the use of C-PE bearings.

Previous studies have reported that COC bearings have a lower risk of dislocation than M-PE bearings in primary THA [9,10] and revision THA [36]. Hernigou et al [9] specifically addressed this topic with primary THA, comparing the risk of dislocation in C-PE and COC bearings that were implanted between 1972 and 1982. Interestingly, they noted biologic factors that differed between the C-PE and COC bearings, which enabled significantly greater capsular thickening and, hypothetically, greater long-term dislocation resistance in the COC cohort. Also, the C-PE incorporated historical, gamma-air-sterilized polyethylene for the acetabular liner that would generate biologically active wear particles.

In summary, our results indicate that, after adjusting for selection bias and various confounding patient-, surgeon-, and hospital-related factors, Medicare patients treated in a revision scenario with ceramic bearings exhibit similar risk of rerevision or mortality as those treated with M-PE bearings. Conversely, we found an association between the use of specific ceramic bearings in R-THA and reduced risk of readmission (C-PE) and dislocation (COC). The findings of this study support further research into the association between ceramic bearings in R-THA and lower risk of hospital readmission, dislocation, and, potentially, infection.

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