Ceramic-on-Polyethylene Bearing Usage in Primary THA Is Associated with Reduced Readmission Risk for the Medicare Population

Steven M. Kurtz, PhD[1] Edmund Lau, MS[2] Doruk Baykal, PhD[2] Bryan D. Springer, MD[3]

[1] Exponent Inc., Philadelphia, Pennsylvania
[2] Exponent Inc., Menlo Park, California
[3] OrthoCarolina Hip and Knee Center, Charlotte, North Carolina

Address for correspondence S. Kurtz, PhD, 3440 Market Street, Suite 600, Philadelphia, PA 19104 (e-mail: skurtz@exponent.com).

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Abstract

The authors hypothesized that unplanned readmissions, which are often caused by infections and dislocation, may be reduced with ceramic bearing usage. They also sought to confirm that the readmission rates for ceramic bearings were associated with the year of surgery. They identified 245,077 elderly patients (65+) who underwent primary total hip arthroplasty (THA) between 2010 and 2015 with known bearing types (ceramic-on-polyethylene [C-PE] ceramic-on-ceramic [COC], and metal-on-polyethylene [M-PE]) from the Medicare 100% inpatient database. Outcomes included relative risk of 30- and 90-day readmission. Propensity scores were developed to adjust for selection bias in the choice of bearing type at index surgery. Cox regression incorporating propensity score stratification (10 levels) was used to evaluate the impact of bearing selection on outcomes, after adjusting for patient-, hospital-, surgeon-related factors, as well as the year of surgery. With C-PE bearings, the unadjusted (crude) 90-day readmission rate decreased from 8.7% in 2010 to 8.3% in 2015. For COC bearings, the crude 90-day readmission rate decreased from 10.5 to 9.1% from 2010 to 2015. After adjustment, year of surgery was associated with reduced readmission risk for both types of ceramic bearings in 30-day readmissions ($p < 0.05$) and COC in 90-day readmissions ($p < 0.001$). The authors also found that C-PE bearings were associated with significantly reduced readmission risk relative to M-PE at 30 days (hazard ratio [HR]: 0.91, $p < 0.001$) and 90 days (HR: 0.93, $p < 0.001$). In terms of strength of association with 90-day readmission, however, it was ranked the ninth most **associated** independent factor. To the authors' knowledge, this is the first study to demonstrate an association between THA implant characteristics (in this case C-PE bearing usage) and reduced readmission rates in this context along with patient- and clinical-related factors. The readmission rates for COC were found to be comparable to M-PE.

Keywords

- total hip arthroplasty
- Medicare database
- health care reform
- ceramic-on-ceramic
- ceramic-on-polyethylene

Improving long-term clinical outcomes, such as wear resistance and survivorship, have historically been the driving motivation for using ceramic-on-polyethylene (C-PE) and ceramic-on-ceramic (COC) bearings in total hip arthroplasty (THA) as alternatives to metal-on-polyethylene (M-PE). Recently, however, ceramic bearings have also been associated with reductions in dislocation and infection risk in primary[1–5] and revision[6] hip arthroplasty. Ceramic femoral heads have also been shown to mitigate the risk of fretting and corrosion relative to CoCr alloy femoral heads,[7,8] thereby reducing the risk of adverse local tissue reactions. Although the use of C-PE bearings has increased in the United States,[9]

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Table 1 Overall patient demographics

Effect	Level	M-PE	C-PE	COC	Total	% M-PE	% C-PE	% COC	% Total
	Total	161,890	78,156	5,031	245,077	100.0%	100.0%	100.0%	100.0%
Age	65–69	41,309	31,930	1,861	75,100	25.5%	40.9%	37.0%	30.6%
	70–74	43,625	21,768	1,336	66,729	26.9%	27.9%	26.6%	27.2%
	75–79	36,674	13,322	924	50,920	22.7%	17.0%	18.4%	20.8%
	80–84	26,090	7,511	584	34,185	16.1%	9.6%	11.6%	13.9%
	85+	14,192	3,625	326	18,143	8.8%	4.6%	6.5%	7.4%
CCI	00	89,719	46,436	2,947	139,102	55.4%	59.4%	58.6%	56.8%
	1–2	56,262	25,801	1,659	83,722	34.8%	33.0%	33.0%	34.2%
	3–4	12,392	4,820	308	17,520	7.7%	6.2%	6.1%	7.1%
	5+	3,517	1,099	117	4,733	2.2%	1.4%	2.3%	1.9%
Discharge type	Home	31,341	20,201	1,035	52,577	19.4%	25.8%	20.6%	21.5%
	Home w/HHS	55,630	31,599	1,893	89,122	34.4%	40.4%	37.6%	36.4%
	Other facility	1,820	728	58	2,606	1.1%	0.9%	1.2%	1.1%
	Rehab facility	15,103	5,723	522	21,348	9.3%	7.3%	10.4%	8.7%
	SNF	57,996	19,905	1,523	79,424	35.8%	25.5%	30.3%	32.4%
Hospital annual TJA volume	000–149	20,979	10,664	1,039	32,682	13.0%	13.6%	20.7%	13.3%
	150–300	42,341	20,789	1,087	64,217	26.2%	26.6%	21.6%	26.2%
	300–450	31,929	14,732	888	47,549	19.7%	18.8%	17.7%	19.4%
	450–600	18,828	8,278	643	27,749	11.6%	10.6%	12.8%	11.3%
	600+	47,813	23,693	1,374	72,880	29.5%	30.3%	27.3%	29.7%
Hospital beds	001–149	101,318	52,811	3,391	157,520	62.6%	67.6%	67.4%	64.3%
	150–299	25,107	12,665	550	38,322	15.5%	16.2%	10.9%	15.6%
	300–499	20,421	7,411	730	28,562	12.6%	9.5%	14.5%	11.7%
	500+	15,044	5,269	360	20,673	9.3%	6.7%	7.2%	8.4%
Hospital ownership	Nonprofit	74,166	37,302	2,828	114,296	45.8%	47.7%	56.2%	46.6%
	Private	74,265	34,260	1,935	110,460	45.9%	43.8%	38.5%	45.1%
	Public	13,459	6,594	268	20,321	8.3%	8.4%	5.3%	8.3%
Hospital setting	Rural	15,911	5,943	235	22,089	9.8%	7.6%	4.7%	9.0%
	Urban	145,979	72,213	4,796	222,988	90.2%	92.4%	95.3%	91.0%
Hospital stay	1–2	44,680	31,142	1,575	77,397	27.6%	39.8%	31.3%	31.6%
	3–4	101,936	42,006	2,949	146,891	63.0%	53.7%	58.6%	59.9%
	5+	15,274	5,008	507	20,789	9.4%	6.4%	10.1%	8.5%
Hospital teaching	No	56,695	29,972	2,084	88,751	35.0%	38.3%	41.4%	36.2%
	Yes	105,195	48,184	2,947	156,326	65.0%	61.7%	58.6%	63.8%
Medicare buy-in	No buy-in	152,387	74,389	4,766	231,542	94.1%	95.2%	94.7%	94.5%
	State buy-in	9,503	3,767	265	13,535	5.9%	4.8%	5.3%	5.5%
Race	Black	5,993	3,213	236	9,442	3.7%	4.1%	4.7%	3.9%
	Other/Unknown	3,407	2,077	211	5,695	2.1%	2.7%	4.2%	2.3%
	White	152,490	72,866	4,584	229,940	94.2%	93.2%	91.1%	93.8%
Resident region	Midwest	43,977	16,035	1,056	61,068	27.2%	20.5%	21.0%	24.9%
	North East	38,549	16,098	949	55,596	23.8%	20.6%	18.9%	22.7%
	South	42,416	26,551	1,918	70,885	26.2%	34.0%	38.1%	28.9%
	West	36,948	19,472	1,108	57,528	22.8%	24.9%	22.0%	23.5%

Table 1 (*Continued*)

Effect	Level	M-PE	C-PE	COC	Total	% M-PE	% C-PE	% COC	% Total
Sex	Female	101,124	46,709	3,046	150,879	62.5%	59.8%	60.5%	61.6%
	Male	60,766	31,447	1,985	94,198	37.5%	40.2%	39.5%	38.4%
Year	2010	24,957	6,058	831	31,846	15.4%	7.8%	16.5%	13.0%
	2011	26,921	7,828	822	35,571	16.6%	10.0%	16.3%	14.5%
	2012	28,708	10,037	770	39,515	17.7%	12.8%	15.3%	16.1%
	2013	30,271	14,330	723	45,324	18.7%	18.3%	14.4%	18.5%
	2014	28,913	20,219	1,003	50,135	17.9%	25.9%	19.9%	20.5%
	2015	22,120	19,684	882	42,686	13.7%	25.2%	17.5%	17.4%

Abbreviations: CCI, Charlson comorbidity index; HHS, home health service; SNF, skilled nursing facility; TJA, total joint arthroplasty.

the nationwide adoption of COC bearings has remained comparatively low, due to a combination of economic and clinical concerns,[10] including the potential increased cost of ceramic components;[11,12] intermittent squeaking, especially when used in combination with certain stem designs;[13,14] and risk of intraoperative chipping or postoperative component fracture,[15,16] which has decreased since the introduction of alumina matrix composites.

Many previous studies have focused on intermediate- and long-term outcomes,[1–5,17–19] but little is known about the short-term relative outcomes of alternative bearings, especially in light of recent health care reform legislation in the United States. Starting in 2010, the Patient Protection and Affordable Care Act (ACA) has placed a major emphasis on improving short-term clinical outcomes, including 30- and 90-day all-cause readmission rates.[20] In the 5-year period between 2010 and 2014, health care legislation was introduced specifically for joint arthroplasty to not only penalize hospitals if their 30-day readmission rates exceed the (adjusted) national average, but new economic models, such as bundled payments, have also shifted the cost of readmissions up to 90 days after surgery from the payer to the provider. Thus, both 30- and 90-day readmissions are important short-term metrics for contemporary THA performance, albeit for different reasons. Previous research with ceramic bearings after revision surgery[6] has reported an association between C-PE bearing usage and reduced 90-day readmissions relative to M-PE bearings. These findings prompted us to investigate readmission risk of ceramic bearings after primary THA.

We hypothesized that early readmissions, which are also caused by infections and dislocation, may be reduced with ceramic bearing usage in primary THA. Previous research has found that up to 2014, readmission rates after primary THA decreased in the Medicare population,[21] but it remains unknown how (or if) these temporal changes in readmission rates are distributed across different bearing types. Accordingly, for the present study we also sought to determine whether the readmission rates for ceramic bearings were associated with the year of surgery, between 2010 and 2015, when health care reform legislation was implemented.

Materials and Methods

We used the Medicare 100% inpatient analytical dataset for hospital stays to identify primary THA patients between January 1, 2010, and September 31, 2015. We applied the same exclusion criteria as in our previous ceramic bearing studies.[4,6] For example, we excluded patients < 65 years old, those enrolled in a health maintenance organization, and those living outside of the 50 states. A 1-year pre-THA enrollment was also required. This 1-year period was used to compile comorbidities prior to patients presenting themselves for primary THA. Thus, our present study is composed of elderly Medicare beneficiaries for primary hip replacement.

This study was determined by our institutional review board to be exempt.

Unique, encrypted Medicare beneficiary identifiers were used to follow patients longitudinally throughout the study period. Patient's Medicare entitlement status and mortality were tracked using a linked "denominator" file provided by the Centers for Medicare & Medicaid Services that accompanied the analytic datasets. The International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM: 81.53) procedure code was used to identify primary THA patients. Our focus was to investigate outcomes as a function of bearing surface used in the primary THA, which was identified in the primary THA claim record using an ICD-9-CM code of 00.74 (metal-on-polyethylene, M-PE), 00.76 (COC), and 00.77 (C-PE). These ICD-9-CM codes have been employed in many previous studies of bearing surface epidemiology in the United States.[22,23] However, the use of THA bearing codes is optional, and hence were recorded in ~40% of the primary THA procedures captured during the study period. As noted by Bozic et al, the usage of bearing codes appears to be systematic and unlikely to be influenced by reporting bias.

Patients were tracked longitudinally for 30 and 90 days following their primary procedure. We used both 30- and 90-day readmissions as outcomes of this study, because as stated in the Introduction, these individual milestones are either used as a hospital quality measure (at 30 days) or as a bundled payment period (at 90 days). Patients who died within the 30-day or the 90-day period without

encountering readmission were excluded because they did not have the opportunity to be readmitted. We determined readmission as the appearance of new hospital claims record for the patient within 30 or 90 days of the patient's discharge date. Patients who returned to the hospital only for rehabilitation service (ICD-9-CM V57.x) or for a planned staged procedure for replacement of a different hip or knee within the 90-day period were not included in the analysis.

Propensity scores were developed to adjust for selection bias in the choice of bearing type for primary THA surgery.[4,6] We employed the same approach with the application of propensity scores as in our previous studies.[4,6] Specifically, the propensity score calculates a patient's chance of receiving a C-PE or COC implant, given certain patient and hospital factors. The propensity score was calculated for each patient using the following predictors: age, sex, region, race, Medicare–Medicaid eligibility (which indicated that state subsidy was requested for the patients' Medicare premium and this was used as a proxy for the patients' socioeconomic status), Charlson comorbidity score, surgery calendar year, length of stay, hospital charge amount, hospital and surgeon joint replacement volume, hospital location (urban/rural), hospital type (e.g., public and private), size of hospital, diabetes, heart disease, obesity, and two-way interactions among age, gender, race, Charlson score, hospital size, and hospital type. Separate scores were calculated for patients receiving C-PE and COC implants.

Cox regression incorporating propensity score stratification (10 levels) was then used to evaluate the impact of bearing surface selection on outcomes,[4,6] after adjusting for patient-, hospital-, and surgeon-related factors. The Cox model was stratified into 10 propensity strata and overall hazard ratios (HRs) were estimated as the relative risk of readmission in 30- and 90 days between the ceramic and conventional bearing. Because the Medicare data afford the study with a large cohort of THA patients, a 10-level stratification provides reasonably well-matched propensity levels between ceramic and conventional bearing patients. The Cox regression model incorporated the main study variables: bearing type (C-PE, COC, or M-PE); as well as the following potential confounding variables: patient age; sex; race; resident census region; patient diagnosis of diabetes, heart disease or obesity; patient Charlson comorbidity index; hospital type, location, and size; hospital procedure volume; surgeon procedure volume; total hospital charges; length of stay; Medicare–Medicaid eligibility; operating room charges; and surgery calendar year. All statistical analyses were performed using SAS statistical software (Version 9.4).

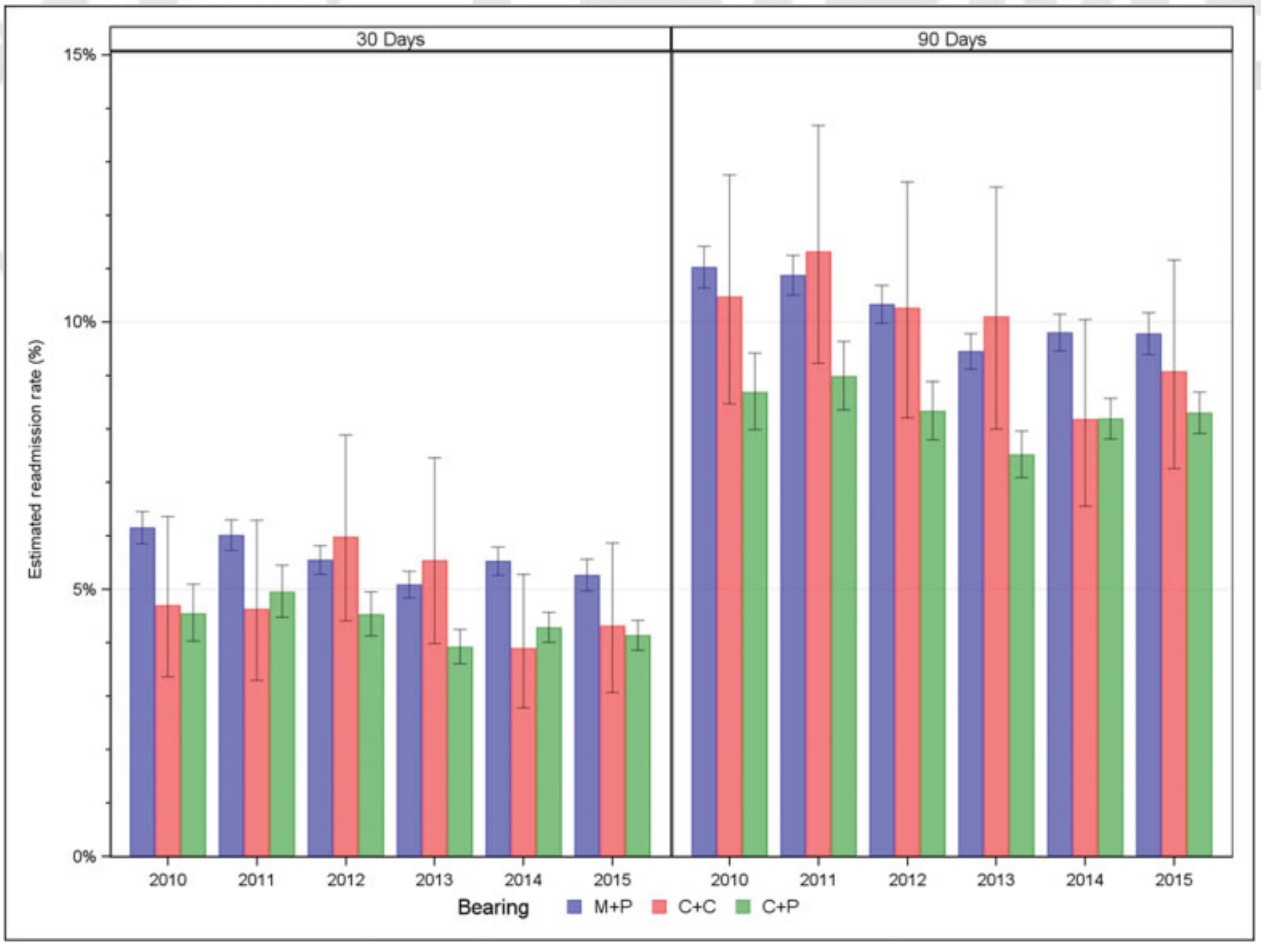

Fig. 1 Percent of patient readmitted in 30 or 90 days after primary total hip arthroplasty (2010–2015), by bearing type.

Results

Our study included 245,077 elderly Medicare patients who underwent primary THA between 2010 and September 2015 with known bearing types, including 78,156 patients who received C-PE, 5,031 patients who received COC, and 161,890 patients who received M-PE bearings (►**Table 1**). These patients were 62% female, 94% white, and 57% had no major comorbidities (corresponding to a Charlson score of 0, ►**Table 1**). Over 50% of the patients were between 65 and 75 years old, and the age distribution varied only slightly by bearing type (►**Table 1**).

With C-PE bearings, the unadjusted (crude) 90-day readmission rate decreased from 8.7% in 2010 to 8.3% in 2015 (►**Fig. 1**). For COC bearings, the crude 90-day readmission rate decreased from 10.5% to 9.1% from 2010 to 2015 (►**Fig. 1**). After adjustment, year of surgery was associated with reduced readmission risk for both types of ceramic bearings in 30-day readmissions (HR: 0.97, 95% confidence Interval [CI]: 0.95–1.00, $p = 0.036$ for C-PE; HR: 0.96, 95% CI: 0.95–0.98, $p < 0.001$ for COC) and COC in 90-day readmissions (HR: 0.97, 95% CI: 0.96–0.98, $p < 0.001$).

We also found that C-PE bearings were associated with significantly reduced readmission risk relative to M-PE at 30 days (HR: 0.91, 95% CI: 0.87–0.95, $p < 0.001$) and 90 days (HR: 0.93, 95% CI: 0.90–0.96, $p < 0.001$) (►**Tables 2** and **3**). In terms of strength of association with 90-day readmission, however, it was ranked the ninth most associated independent factor (►**Fig. 2**). Patient factors, such as age, Charlson comorbidity index, heart disease diagnosis, obesity, region, and socioeconomic status; and clinical variables, such as length of stay and total joint arthroplasty (hip and knee) surgeon volume were ranked higher in effect size than bearing usage for 30- and 90-day readmissions ($p < 0.001$, ►**Fig. 2**). For the COC bearing cohort, the readmission risk at 30- ($p = 0.06$) or 90 days ($p = 0.97$) after primary THA was not significantly different from M-PE bearings.

The principal diagnosis associated with the readmission was similar at 30 and 90 days. Device-related malfunctions, which include loosening and dislocation, followed by infection, were found to be the most frequent diagnosis of readmissions for all cohorts (►**Fig. 3**). Readmissions due to dislocations and infections were found to be similar in all cohorts.

Discussion

The results of this study support the hypothesis that ceramic bearings are associated with comparable

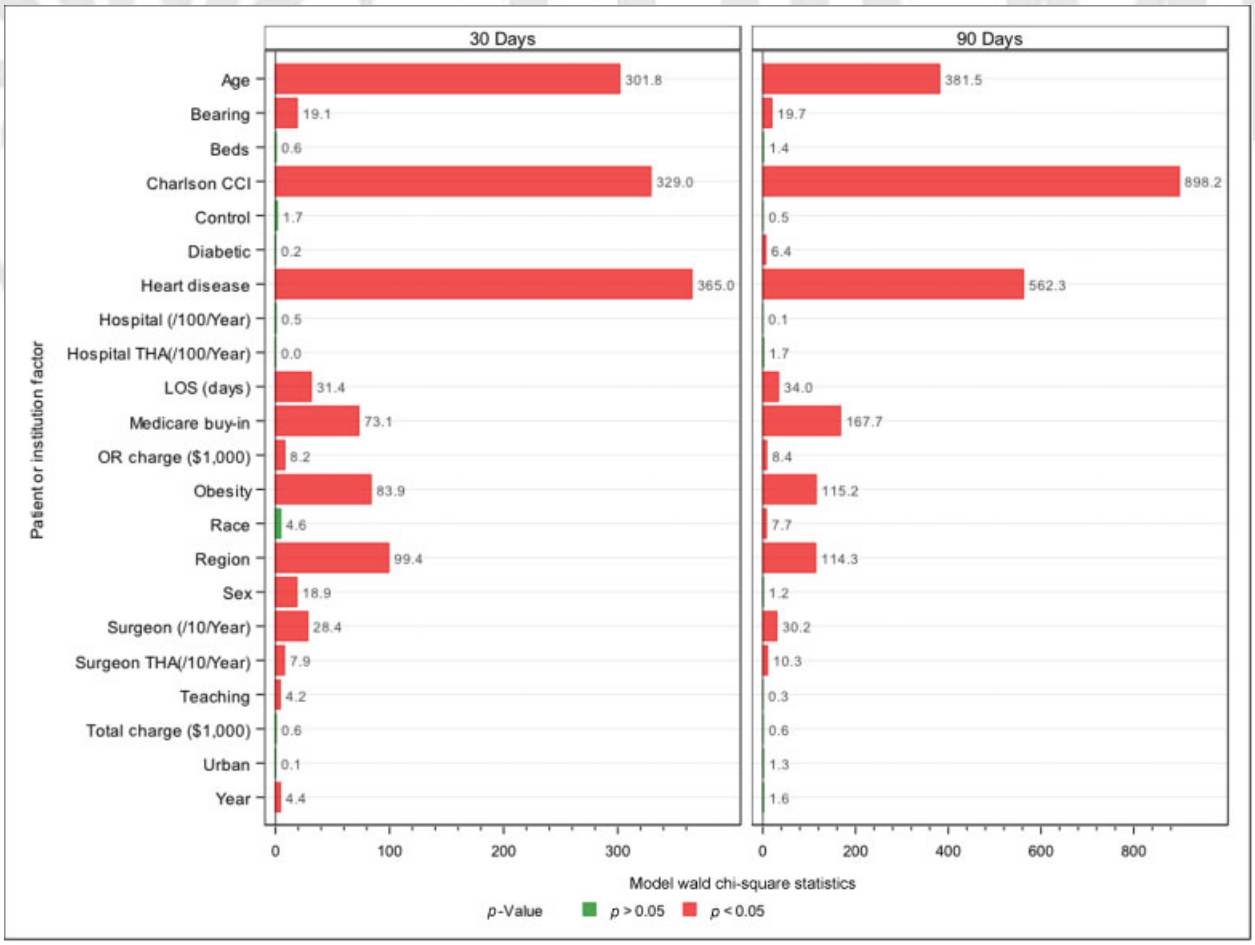

Fig. 2 Relative significance of bearing, patient, hospital, and clinical factors for 90-day readmission comparing C-PE to M-PE in the 100% Medicare dataset (2010–2015), based on the F-statistics of fixed effect model. Abbreviations: CCI, Charlson comorbidity index; C-PE, ceramic-on-polyethylene; M-PE, metal-on-polyethylene; OR, odds ratio; THA, total hip arthroplasty.

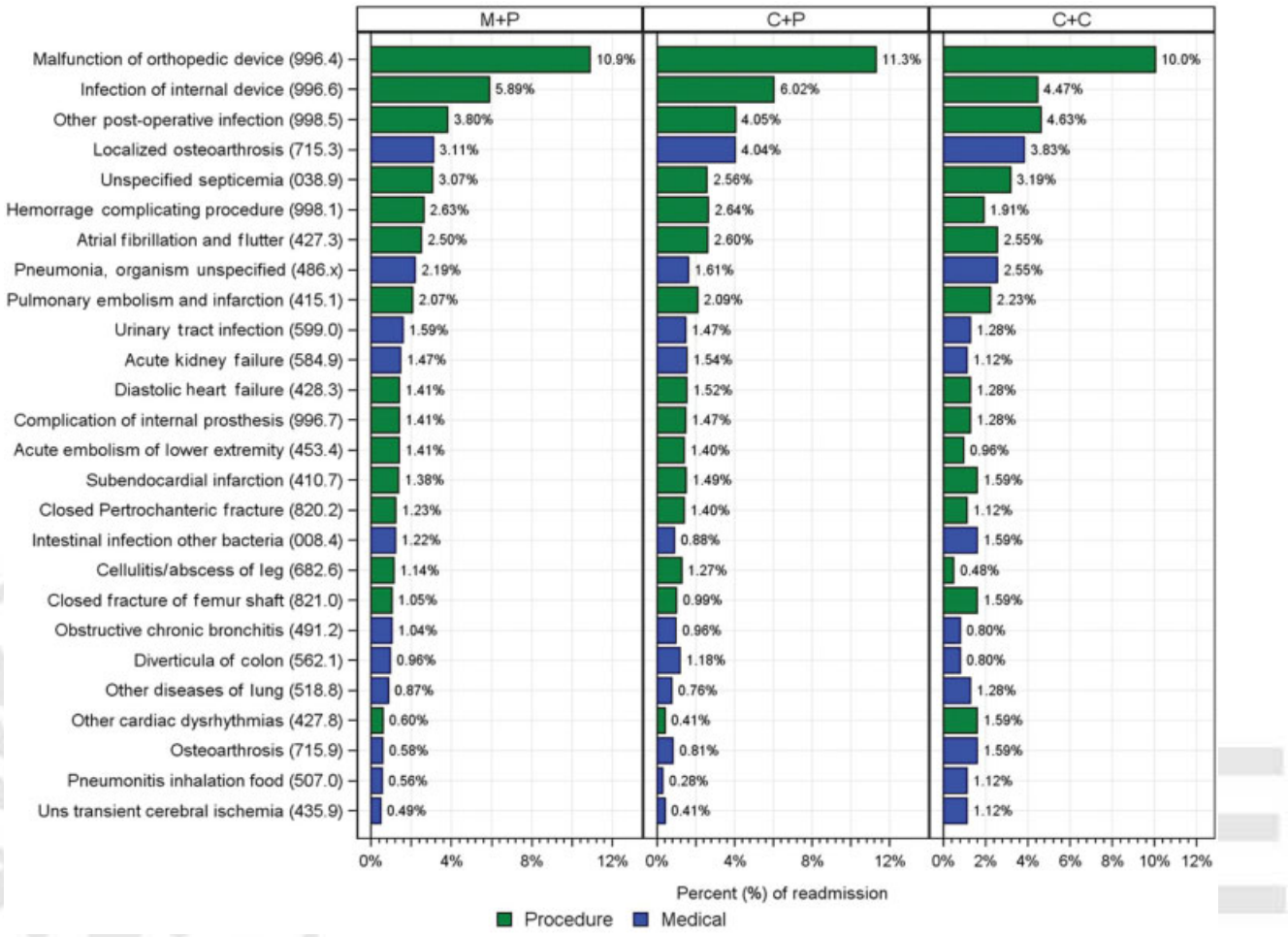

Fig. 3 Principal diagnosis associated with 90-day readmission after primary total hip arthroplasty by bearing type. The proportion of device malfunctions (including dislocation and loosening) and infection did not differ significantly among bearing types.

readmission rates, and in the case of C-PE bearings, lower readmission rates as compared with traditional M-PE bearings for THA in the Medicare population. In a previous study,[6] researchers found an association between C-PE bearing usage and lower 90-day readmission risk after revision THA. However, to our knowledge, this is the first study to demonstrate an association between primary THA implant characteristics (in this case C-PE bearing usage) and reduced 30- and 90-day readmission rates. Historically, ceramic bearings were considered especially useful for younger active patients since the clinical benefits of wear performance, reduced osteolysis, and decreased loosening would most likely be realized in patients with a longer life span.[24–26] Thus, this study is noteworthy because of its focus on comparing short-term outcomes for ceramic bearings in older Medicare patients.

After the introduction of the ACA in 2010, 30-day readmission rates emerged as an important new quality measure for hospital discharges following treatment for acute myocardial infarction, heart failure, and pneumonia.[27] However, it was not until October 1, 2014, that readmission rates became an official quality measure for hip and knee replacement procedures.[27] According to current health care legislation, embodied by the Medicare Hospital Readmissions Reduction Program (HRRP),[27–29] hospitals that exceed the risk adjusted national average 30-day readmission rates following primary THA will be financially penalized by up to 3% of their annual payments. Furthermore, during the time period between 2010 and 2015, the gradual introduction of new value-based payment models,[30–32] including bundled payments, incorporated the cost of hospital readmissions up to 90 days after the index total joint replacement. A previous study[21] has shown that THA readmission rates decreased between 2010 and 2014 in the Medicare population, but the types of bearings associated with the reduction over time were not reported. With the most recent Medicare data currently available in the present study, we now show that the decline in readmission rates is across the board with respect to different ceramic bearing surfaces, and that the earlier observed downward trend up to 2014 extends into 2015. Thus, the results of this study not only demonstrate that C-PE and COC bearings are following a similar (and expected) decreasing trend in readmission rates over time, but that the trend in readmission rates extends 1 year beyond the final rule established in the HRRP. In theory, there should be a lower limit or plateau in hospital

Table 2 Risk of 30-day readmission following primary THA, comparing hip bearing material and other risk factors comparing C-PE versus M-PE cohorts

Factor	Wald chi-square	*p*-Value	Level	HR	Lower HR	Upper HR	Chi-square	*p*-Value
Age	301.84	< 0.001	65–69	1.00	–	–	–	–
			70–74	1.14	1.07	1.22	15.86	< 0.001
			75–79	1.43	1.32	1.54	74.40	< 0.001
			80–84	1.70	1.55	1.87	124.15	< 0.001
			85+	2.22	2.00	2.46	231.94	< 0.001
Bearing	19.13	< 0.001	C-PE	0.91	0.87	0.95	19.13	< 0.001
			M-PE	1.00	–	–	–	–
Beds	0.59	0.899	001–149	1.00	–	–	–	–
			150–299	1.00	0.94	1.06	0.00	0.954
			300–499	1.00	0.93	1.07	0.00	0.970
			500+	1.03	0.95	1.12	0.47	0.494
CCI	329.05	< 0.001	00	1.00	–	–	–	–
			1–2	1.36	1.30	1.42	185.90	< 0.001
			3–4	1.67	1.56	1.79	227.61	< 0.001
			5+	2.00	1.81	2.21	184.53	< 0.001
Control	1.65	0.438	Nonprofit	1.02	0.97	1.07	0.58	0.447
			Private	1.00	–	–	–	–
			Public	1.04	0.98	1.11	1.51	0.219
Diabetic	0.22	0.638	No	1.00	–	–	–	–
			Yes	0.99	0.94	1.04	0.22	0.638
Heart disease	365.03	< 0.001	No	1.00	–	–	–	–
			Yes	1.80	1.70	1.91	365.03	< 0.001
Hospital (/100/year)	0.48	0.489		0.99	0.97	1.02	0.48	0.489
Hospital THA(/100/year)	0.00	0.971		1.00	0.95	1.05	0.00	0.971
LOS (Days)	31.42	< 0.001		1.05	1.03	1.06	31.42	< 0.001
Medicare buy-in	73.07	< 0.001	No buy-in	1.00	–	–	–	–
			State buy-in	1.34	1.25	1.43	73.07	< 0.001
OR charge ($1,000)	8.22	0.004		1.00	1.00	1.01	8.22	0.004
Obesity	83.87	< 0.001	No	1.00	–	–	–	–
			Yes	1.25	1.19	1.31	83.87	< 0.001
Race	4.65	0.098	Black	1.07	0.98	1.16	2.26	0.133
			Oth/Unk	0.90	0.79	1.03	2.20	0.138
			White	1.00	–	–	–	–
Region	99.42	< 0.001	Midwest	0.95	0.89	1.01	2.44	0.118
			North East	0.96	0.90	1.02	1.63	0.201
			South	1.00	–	–	–	–
			West	0.76	0.71	0.81	80.24	< 0.001
Sex	18.86	< 0.001	Female	0.92	0.89	0.96	18.86	< 0.001
			Male	1.00	–	–	–	–
Surgeon (/10/year)	28.42	< 0.001		0.99	0.99	0.99	28.42	< 0.001
Surgeon THA(/10/year)	7.91	0.005		0.99	0.99	1.00	7.91	0.005
Teaching	4.15	0.042	No	1.00	–	–	–	–

(*Continued*)

Table 2 (*Continued*)

Factor	Wald chi-square	*p*-Value	Level	HR	Lower HR	Upper HR	Chi-square	*p*-Value
			Yes	0.96	0.91	1.00	4.15	0.042
Total charge ($1,000)	0.59	0.444		1.00	1.00	1.00	0.59	0.444
Urban	0.09	0.761	Rural	0.99	0.93	1.06	0.09	0.761
			Urban	1.00	–	–	–	–
Year	4.41	0.036		0.97	0.95	1.00	4.41	0.036

Abbreviations: CCI, Charlson Comorbidity Index; C-PE, ceramic-on-polyethylene; M-PE, metal-on-polyethylene; HR, hazard ratio; LOS, length of stay; OR, odds ratio; THA, total hip arthroplasty.

Table 3 Risk of 90-day readmission following primary THA, comparing hip bearing material and other risk factors comparing C-PE versus M-PE cohorts

Factor	Wald chi-square	*p*-Value	Level	HR	Lower HR	Upper HR	Chi-square	*p*-Value
Age	381.50	< 0.001	65–69	1.00	–	–	–	–
			70–74	1.07	1.02	1.12	6.92	0.009
			75–79	1.28	1.20	1.36	59.05	< 0.001
			80–84	1.50	1.39	1.61	111.09	< 0.001
			85+	1.90	1.75	2.05	246.39	< 0.001
Bearing	19.70	< 0.001	C-PE	0.93	0.90	0.96	19.70	< 0.001
			M-PE	1.00	–	–	–	–
Beds	1.40	0.706	001–149	1.00	–	–	–	–
			150–299	1.00	0.96	1.05	0.00	0.985
			300–499	1.02	0.97	1.08	0.60	0.440
			500+	1.03	0.97	1.10	1.15	0.283
CCI	898.21	<0.001	00	1.00	–	–	–	–
			1–2	1.40	1.36	1.45	430.14	< 0.001
			3–4	1.87	1.78	1.96	644.38	< 0.001
			5+	2.31	2.15	2.49	506.29	< 0.001
Control	0.46	0.794	Nonprofit	1.00	0.96	1.04	0.00	0.996
			Private	1.00	–	–	–	–
			Public	1.02	0.97	1.07	0.41	0.523
Diabetic	6.42	0.011	No	1.00	–	–	–	–
			Yes	0.95	0.92	0.99	6.42	0.011
Heart disease	562.32	< 0.001	No	1.00	–	–	–	–
			Yes	1.74	1.66	1.82	562.32	< 0.001
Hospital (/100/year)	0.15	0.703		1.00	0.99	1.02	0.15	0.703
Hospital THA(/100/year)	1.68	0.195		0.97	0.94	1.01	1.68	0.195
LOS (days)	34.01	< 0.001		1.05	1.03	1.06	34.01	< 0.001
Medicare buy-in	167.68	< 0.001	No buy-in	1.00	–	–	–	–
			State buy-in	1.39	1.32	1.46	167.68	< 0.001
OR charge ($1,000)	8.43	0.004		1.00	1.00	1.00	8.43	0.004
Obesity	115.16	< 0.001	No	1.00	–	–	–	–
			Yes	1.21	1.17	1.26	115.16	< 0.001
Race	7.73	0.021	Black	0.99	0.93	1.06	0.04	0.837

Table 3 (*Continued*)

Factor	Wald chi-square	*p*-Value	Level	HR	Lower HR	Upper HR	Chi-square	*p*-Value
			Oth/Unk	0.87	0.79	0.96	7.73	0.005
			White	1.00	–	–	–	–
Region	114.27	< 0.001	Midwest	0.91	0.87	0.96	13.43	< 0.001
			North East	0.91	0.87	0.96	13.11	< 0.001
			South	1.00	–	–	–	–
			West	0.78	0.75	0.82	106.02	< 0.001
Sex	1.22	0.270	Female	0.98	0.96	1.01	1.22	0.270
			Male	1.00	–	–	–	–
Surgeon (/10/year)	30.16	< 0.001		0.99	0.99	1.00	30.16	< 0.001
Surgeon THA(/10/year)	10.27	0.001		0.99	0.99	1.00	10.27	0.001
Teaching	0.29	0.593	No	1.00	–	–	–	–
			Yes	0.99	0.96	1.02	0.29	0.593
Total charge ($1,000)	0.56	0.455		1.00	1.00	1.00	0.56	0.455
Urban	1.31	0.252	Rural	0.97	0.92	1.02	1.31	0.252
			Urban	1.00	–	–	–	–
Year	1.56	0.212		0.99	0.97	1.01	1.56	0.212

Abbreviations: CCI, Charlson Comorbidity Index; C-PE, ceramic-on-polyethylene; M-PE, metal-on-polyethylene; HR, hazard ratio; LOS, length of stay; OR, odds ratio; THA, total hip arthroplasty.

readmission rates achieved when avoidable readmissions have been effectively minimized, because there are some hospital readmissions that are unavoidable, especially involving high-risk patients.[33,34] Our current data would suggest that, at least up to 2015, a plateau in readmission rates has not yet been achieved, at least not for the Medicare population. Hospitals and accountable care organizations that are concerned with the effect of ceramic bearings on their hospital quality measures and potential financial claw backs from Medicare can be further assured that the usage of C-PE or COC bearings will not negatively impact their 30- or 90-day readmission rates.

We would like to draw the reader's attention to some of the strengths and limitations of our study. We used the Medicare inpatient dataset as the basis for our research, which has the advantage of population size and national representativeness across a large segment of THA patients in the United States. Although we were unable to measure how readmissions would be impacted for patients less than 65 years in age, as previous research has shown,[35] the Medicare patient population has a higher rate of readmissions as compared with younger patients reimbursed by private insurance. Thus, the Medicare population is the most "at risk" of readmissions, by virtue of their advanced age and decreasing health status. A further strength of this study is the use of propensity score stratification, to adjust for surgeon bias in bearing usage selection. However, even with the use of propensity scores, we are unable to adjust for unmeasured sources of bias in the same manner as a prospective randomized trial, and thus our findings are limited to association rather than causation. Although our findings suggest that C-PE bearing usage mitigates readmissions at 30- and 90 days relative to M-PE, prospective randomized studies are needed to establish the causality of this finding. Like all administrative data studies, our analyses were limited to ICD-9-CM diagnosis codes, and we were unable to incorporate clinical outcome measures, such as the Harris hip score, for example, into our study.

Conclusion

In summary, our findings for ceramic bearings add to the growing body of research on readmissions after primary THA. We found that primary THA patients who were treated with C-PE bearings were associated with significantly lower risk of readmission, after statistical adjustment for patient-, hospital-, and surgeon factors. Our risk adjustment model was also stratified using propensity scores, to address potential surgeon bias in the selection of hip bearings. Previous studies have reported that ceramic bearings were associated with the lower risk of long-term infection or dislocation.[1–5] We found that the reasons for readmission of ceramic bearings due to dislocations and infections were similar to traditional M-PE bearings.

Note

Each author certifies that all investigations were conducted in conformity with ethical principles of research.

This work was performed at Exponent, Inc., Philadelphia, PA.

Conflict of Interest
Dr. Baykal reports institutional support received from CeramTec associated with the submitted work. Dr. Baykal further reports that he is an employee of Exponent, Inc.

Mr. Lau reports institutional support received from CeramTec associated with the submitted work. Mr. Lau further reports that he is an employee of Exponent, Inc., and that institutional support is received from Stryker Orthopaedics, Ferring Pharmaceuticals, Paradigm Spine, Medtronic, Boston Scientific, Alcon, and Pacira Pharmaceuticals.

Dr. Kurtz reports institutional support received from CeramTec associated with the submitted work. Dr. Kurtz further reports that he is an employee and shareholder of Exponent, Inc., and that institutional support is received as a PI from CeramTec, Smith & Nephew, Stryker, Zimmer Biomet, Depuy Synthes, Medtronic, Invibio, Stelkast, Formae, Kyocera Medical, Wright Medical Technology, DJO, Celanese, Aesculap, Spinal Motion, Active Implants, and Ferring Pharmaceuticals outside the submitted work.

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References

1 Hernigou P, Homma Y, Pidet O, Guissou I, Hernigou J. Ceramic-on-ceramic bearing decreases the cumulative long-term risk of dislocation. Clin Orthop Relat Res 2013;471(12):3875–3882
2 Hu D, Tie K, Yang X, Tan Y, Alaidaros M, Chen L. Comparison of ceramic-on-ceramic to metal-on-polyethylene bearing surfaces in total hip arthroplasty: a meta-analysis of randomized controlled trials. J Orthop Surg 2015;10(01):22
3 Pitto RP, Sedel L. Periprosthetic joint infection in hip arthroplasty: is there an association between infection and bearing surface type? Clin Orthop Relat Res 2016;474(10):2213–2218
4 Kurtz SM, Lau E, Baykal D, Springer BD. Outcomes of ceramic bearings after primary total hip arthroplasty in the Medicare population. J Arthroplasty 2017;32(03):743–749
5 Shah SM, Walter WL, Tai SM, Lorimer MF, de Steiger RN. Late dislocations after total hip arthroplasty: is the bearing a factor? J Arthroplasty 2017;32(09):2852–2856
6 Kurtz SM, Lau EC, Baykal D, Springer BD. Outcomes of ceramic bearings after revision total hip arthroplasty in the Medicare population. J Arthroplasty 2016;31(09):1979–1985
7 Kurtz SM, Kocagöz SB, Hanzlik JA, et al. Do ceramic femoral heads reduce taper fretting corrosion in hip arthroplasty? A retrieval study. Clin Orthop Relat Res 2013;471(10):3270–3282
8 Kocagoz SB, Underwood RJ, MacDonald DW, Gilbert JL, Kurtz SM. Ceramic heads decrease metal release caused by head-taper fretting and corrosion. Clin Orthop Relat Res 2016;474(04):985–994
9 American Joint Replacement Registry. 2016 Annual Report. Available at http://www.ajrr.net/publications-data. Accessed April 8, 2018
10 Nandi S, Austin MS. Choosing a femoral head: a survey study of academic adult reconstructive surgeons. J Arthroplasty 2017;32(05):1530–1534
11 Carnes KJ, Odum SM, Troyer JL, Fehring TK. Cost analysis of ceramic heads in primary total hip arthroplasty. J Bone Joint Surg Am 2016;98(21):1794–1800
12 Wyles CC, McArthur BA, Wagner ER, Houdek MT, Jimenez-Almonte JH, Trousdale RT. Ceramic femoral heads for all patients? An argument for cost containment in hip surgery. Am J Orthop 2016;45(06):E362–E366
13 Owen DH, Russell NC, Smith PN, Walter WL. An estimation of the incidence of squeaking and revision surgery for squeaking in ceramic-on-ceramic total hip replacement: a meta-analysis and report from the Australian Orthopaedic Association National Joint Registry. Bone Joint J 2014;96-B(02):181–187
14 Tai SM, Munir S, Walter WL, Pearce SJ, Walter WK, Zicat BA. Squeaking in large diameter ceramic-on-ceramic bearings in total hip arthroplasty. J Arthroplasty 2015;30(02):282–285
15 Howard DP, Wall PDH, Fernandez MA, Parsons H, Howard PW. Ceramic-on-ceramic bearing fractures in total hip arthroplasty: an analysis of data from the National Joint Registry. Bone Joint J 2017;99-B(08):1012–1019
16 Lee GC, Kim RH. Incidence of modern alumina ceramic and alumina matrix composite femoral head failures in nearly 6 million hip implants. J Arthroplasty 2017;32(02):546–551
17 Cafri G, Paxton EW, Love R, Bini SA, Kurtz SM. Is there a difference in revision risk between metal and ceramic heads on highly crosslinked polyethylene liners? Clin Orthop Relat Res 2017;475(05):1349–1355
18 Jeffers JR, Walter WL. Ceramic-on-ceramic bearings in hip arthroplasty: state of the art and the future. J Bone Joint Surg Br 2012;94(06):735–745
19 Wyles CC, Jimenez-Almonte JH, Murad MH, et al. There are no differences in short- to mid-term survivorship among total hip-bearing surface options: a network meta-analysis. Clin Orthop Relat Res 2015;473(06):2031–2041
20 Kurtz SM, Lau EC, Ong KL, Adler EM, Kolisek FR, Manley MT. Hospital, patient, and clinical factors influence 30- and 90-day readmission after primary total hip arthroplasty. J Arthroplasty 2016;31(10):2130–2138
21 Kurtz SM, Lau EC, Ong KL, Adler EM, Kolisek FR, Manley MT. Has health care reform legislation reduced the economic burden of hospital readmissions following primary total joint arthroplasty? J Arthroplasty 2017;32(11):3274–3285
22 Bozic KJ, Kurtz S, Lau E, et al. The epidemiology of bearing surface usage in total hip arthroplasty in the United States. J Bone Joint Surg Am 2009;91(07):1614–1620
23 Kurtz SM, Ong KL, Lau E, Greenwald AS, Bozic K. Prevalence of metal-on-metal bearings in the United States. In: Kurtz SM, Greenwald AS, Mihalko WM, Lemons J, eds. Metal-on-Metal Total Hip Replacement Devices, STP 1560. Conshohocken, PA: ASTM; 2013:3–18
24 Kim YH, Park JW, Kulkarni SS, Kim YH. A randomised prospective evaluation of ceramic-on-ceramic and ceramic-on-highly cross-linked polyethylene bearings in the same patients with primary cementless total hip arthroplasty. Int Orthop 2013;37(11):2131–2137
25 Meftah M, Klingenstein GG, Yun RJ, Ranawat AS, Ranawat CS. Long-term performance of ceramic and metal femoral heads on conventional polyethylene in young and active patients: a matched-pair analysis. J Bone Joint Surg Am 2013;95(13):1193–1197
26 Cash DJ, Khanduja V. The case for ceramic-on-polyethylene as the preferred bearing for a young adult hip replacement. Hip Int 2014;24(05):421–427
27 Readmissions. Reduction Program (HRRP). https://wwwcmsgov/medicare/medicare-fee-for-service-payment/acuteinpatientpps/readmissions-reduction-programhtml.Accessed: September 6, 2017
28 Boozary AS, Manchin J III, Wicker RF. The Medicare Hospital Readmissions Reduction Program: Time for Reform. JAMA 2015;314(04):347–348
29 James J. Health policy brief: Medicare hospital readmissions reduction program. Health affairs. 2013; November 12, 2013. http://www.healthaffairs.org/healthpolicybriefs/brief.php?brief_id=102. Accessed February 21, 2018
30 Bozic KJ, Ward L, Vail TP, Maze M. Bundled payments in total joint arthroplasty: targeting opportunities for quality improvement and cost reduction. Clin Orthop Relat Res 2014;472(01):188–193

31 Cutler DM, Ghosh K. The potential for cost savings through bundled episode payments. N Engl J Med 2012;366(12):1075–1077
32 Iorio R. Strategies and tactics for successful implementation of bundled payments: bundled payment for care improvement at a large, urban, academic medical center. J Arthroplasty 2015;30 (03):349–350
33 Weinberg DS, Kraay MJ, Fitzgerald SJ, Sidagam V, Wera GD. Are readmissions after THA preventable? Clin Orthop Relat Res 2017; 475(05):1414–1423
34 Edwards PK, Jacobs CA, Hadden KB, Barnes CL. A perioperative patient support system was unable to mitigate the risk of hospital readmission for total hip arthroplasty patients with high American Society of Anesthesiologists grades. J Arthroplasty 2017;32 (04):1100–1102
35 Kurtz SM, Lau EC, Ong KL, Adler EM, Kolisek FR, Manley MT. Which clinical and patient factors influence the national economic burden of hospital readmissions after total joint arthroplasty? Clin Orthop Relat Res 2017;475(12):2926–2937