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Are Ceramic Bearings Becoming Cost-Effective for all Patients?

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Abstract

Background: The purpose of this study was to analyze whether the cost for ceramic-on-polyethylene (C-PE) and ceramic-on-ceramic (COC) bearings used in primary total hip arthroplasty was changing over time, and if the cost differential between ceramic bearings and metal-on-polyethylene (M-PE) bearings was approaching the previously published tipping point for cost-effectiveness of $325. Methods: A total of 245,077 elderly Medicare patients (65+) who underwent primary THA between 2010 and 2015 were identified from the United States Medicare 100% national administrative hospital claims database. The inpatient hospital cost, calculated using cost-to-charge ratios, and hospital payment were analyzed. The differential cost of C-PE and COC bearings, compared to metal-on-polyethylene (M-PE), were evaluated using parametric and nonparametric models. Results: After adjustment for patient and clinical factors, and the year of surgery, the mean hospital cost and payments for primary THA with a C-PE or COC was within ±1% of the cost for primary THA with M-PE bearings ($p<0.001$). From the nonparametric analysis, the median hospital cost was $318-360 more for C-PE and COC than M-PE. The differential in median Medicare payment for THA with ceramic bearings compared to M-PE was <$100. Cost differentials were found to decrease significantly over time ($p < 0.001$). Conclusion: Patient and clinical factors had a far greater impact on the cost of inpatient THA surgery than bearing selection. Because we found that costs and cost differentials for ceramic bearings were decreasing over time, and approaching the tipping point, it is likely that the cost-effectiveness thresholds relative to M-PE are likewise changing over time and should be revisited in light of the present study.

Keywords: Primary total hip arthroplasty, ceramic, bearing, cost, cost-effectiveness, economics

Introduction

Ceramic-on-polyethylene (C-PE) and ceramic-on-ceramic (COC) bearings are widely used around the world as alternatives to metal-on-polyethylene (M-PE) bearings in total hip arthroplasty (THA) [1, 2]. Ceramic bearings have well established long-term survivorship, and recent studies have reported associations between the use of ceramic bearings and reduced metal release, lower risk of dislocation and decreased infection [3-10]. Clinical concerns, such as fracture and squeaking of ceramic bearings have been identified [11-15], but these risks are low and well appreciated today. Consequently, the utilization of ceramics in the U.S., especially with C-PE bearings, increased in hip arthroplasty after the decline of metal-on-metal hips in 2010 [16, 17]. However, researchers have identified cost as an important factor that continues to limit access to ceramic bearing technology [11, 18, 19].

Although cost remains the defining issue for ceramic bearings, relatively few published studies have explored this topic in detail from a health economics perspective [18, 19]. Carnes and colleagues [18] developed Markov models based on data from the 2012 Premier Research Database. Carnes calculated cost-effectiveness thresholds for ceramic- versus metal-on-polyethylene bearings that varied between $325 and $600, based on patient age. Wyles and coworkers performed cost-benefit analyses, in which the incremental cost of a ceramic head was offset by the savings associated with trunnionosis. According to Wyles' complication avoidance analysis, a $500 cost differential for ceramic heads was justifiable on a population basis. Both of these previous cost analyses [18, 19] focused on C-PE bearings and did not consider the cost-effectiveness of COC hips for the US population.

Cost data must be timely to enable the reliable cost effectiveness assessments. Based on an analysis of cost data from up to 180 hospitals, the cost of total hip replacements has fallen between 2010 and 2015, in response to cost-containment pressure in orthopaedics. The previous findings from a hospital network prompted us to examine the inpatient costs and reimbursements associated with ceramic bearings for primary THA in a broader context. We tested the hypothesis that the cost differential of primary THA procedures with ceramic bearings, relative to M-PE, decreased between 2010 and 2015 in the Medicare population. Rather than focusing on the cost of an individual component, we wanted to analyze whether bearing selection impacted the total cost of a procedure from the perspective of a hospital or from a payer. We sought to answer the following research questions: (1) How has utilization of bearings changed over time?; (2) are the costs of THA procedures with ceramic bearings changing over time?; (3) how does ceramic bearing usage compare with patient, clinical, and hospital factors in the total inpatient cost of THA; and (4) what is the cost differential between primary THA procedures with C-PE and COC bearings as compared with M-PE?

Methods

We used the Medicare 100% inpatient analytical dataset for hospital stays to identify 245,077 primary THA patients between January 1, 2010, and September 31, 2015 (Table 1). 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 costs 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 (ceramic-on-ceramic, COC); and 00.77 (ceramic-on-polyethylene, C-PE). We applied the same exclusion criteria as in our previous ceramic bearing studies [8, 10]. Specifically, we excluded patients <65y old; those enrolled in a health maintenance organization (HMO); and those living outside of the 50 states. A one-year pre-THA enrollment was also required to compile health status and comorbidities prior to patients presenting themselves for primary THA. According to the cost analysis of Carnes et al. [18], the Medicare population we selected for the current study, being all greater than 65 years, would have an expected cost-effectiveness threshold of less than $600 for a ceramic vs. metal head. A small subset of the study population (7.4%, Table 1), was greater than 85 years, and would have an expected cost-effectiveness threshold of $325 [18], according to Carnes and coworkers.

Propensity scores were developed to adjust for selection bias in the choice of bearing type for primary THA surgery [8, 10]. A 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 buy-in (a proxy for 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, private), size of hospital, diabetes, heart disease, obesity and two-way interactions among age, sex, race, Charlson score, hospital size, and hospital type. Separate scores were calculated for patients receiving C-PE and COC implants.

We used hospital costs and payments as economic outcomes of our analysis, reflecting differing hospital and CMS perspectives. The Medicare dataset includes the aggregate inpatient charges as well as their payments received from CMS for the primary THA procedure. Hospital costs were calculated from charges using a publicly available, hospital-specific cost-to-charge ratio, which reflects their institutional overhead. Cost-to-charge data for hospitals were determined using the Medicare hospital cost reports published annually online by CMS. Costs were inflation adjusted to January 2017 USD using the medical service component of the consumer price index published monthly by the US Bureau of Labor Statistics.

The hospital cost and payment data were analyzed using parametric and nonparametric statistical methods to determine the cost-differential between procedures incorporating C-PE vs M-PE bearings or COC vs M-PE bearings. For each economic outcome, separate models were constructed to compare C-PE with M-PE and COC with M-PE. Because the cost and payment data were not normally distributed, in parametric models, the cost data were fitted using a gamma distribution. The nonparametric models, on the other hand, did not rely upon any assumed distribution of the cost data. Together, the two modeling approaches provided complementary perspectives on the cost differential for THA procedures with ceramic bearings relative to M-PE.

For the parametric approach, the cost differential was modeled as a ratio in a general linear model in which the year, as well as patient, clinical, and hospital factors, were treated as covariates. Propensity score weighting was incorporated into the general linear model regression model, along with 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 buy-in; operating room charges; and surgery calendar year. For the parametric analysis, the outcome was the cost differential, expressed as a ratio of the conditional mean costs between ceramic bearing surface and conventional bearing surface or between other comparison groups (e.g., male vs female).

For the nonparametric approach, we used the quantile regression method to examine difference in the median difference in costs between THA procedures with C-PE or COC bearings and M-PE bearings. The nonparametric quantile regression approach does not involve logarithmic transformation, and the cost differences were determined in the original (dollar) unit. Expressing the cost differentials both as a ratio (for the parametric approach) as well as in actual arithmetic difference (for the nonparametric approach) allows the absolute US$ magnitude of the difference to be better appreciated. All statistical analyses were performed using SAS statistical software (Version 9.4, Cary, NC).

Results

C-PE procedures increased between 2010-2015 while the number of COC or M-PE procedures was relatively unchanged (Table 1). Of the primary THA surgeries considered in this study, 6,058 patients received C-PE bearings in 2010 (representing 19.0% of the study population), whereas 19,684 patients (46.1%) received C-PE bearings in Q1-Q3 2015. The majority of patients receiving C-PE and COC implants for their primary surgery belonged to the youngest cohort; the 65-69 year-old cohort constituted 40.9% of C-PE and 37.0% of COC implants while constituting only 25.5% of M-PE (Table 1). The incidence of COC ranged between 1.6% and 2.6% of the study population. M-PE, on the other hand, declined in incidence from 78.4% to 51.8% of the study population between 2010 and 2015. More than half of the patients considered in this study had Charlson scores of zero while different bearing types were equally utilized within each Charlson score cohort. For each bearing type, the majority of patients were white and did not receive Medicare buy-in. Urban and teaching hospitals performed the majority of primary THA surgeries for all bearing types while public hospitals had the least amount of primary THA surgeries.

The hospital cost and the hospital payment decreased every year between 2010 and 2015 for all bearing types (Figures 1 and 2). After adjustment for patient factors, hospital factors, clinical factors, and the year of surgery, the mean hospital cost and payments for primary THA with a C-PE were 1% more than primary THA with M-PE (cost ratio: 1.01, 95% CI: 1.01 to 1.02, $p<0.001$). Based on F-model statistics, length of stay, census region, and hospital location (urban/rural) were found to be the most important drivers of hospital cost in primary THA procedures with C-PE and M-PE bearings while the year of surgery was the seventh most important driver (Figure 3). Bearing selection was amongst the least important drivers of hospital cost. Similarly, for Medicare payment, length of stay, census region, hospital type (teaching/not teaching) were found to be most important drivers while year of surgery ranked seventh most important driver of hospital payment. Bearing selection was found to be the least important driver of hospital payment.

Compared to a THA with M-PE, the mean hospital cost for a THA with COC was 1% less (cost ratio: 0.99, 95% CI: 0.99-1.00, $p< 0.001$) after adjusting for all covariates. The Medicare payments were 1% more with COC compared to M-PE (cost ratio: 1.01, 95% CI: 1.01-1.02, $p<0.001$). Based on F-model statistics, length of stay, census region, hospital location (urban/rural), and year of surgery were found to be the most important drivers of hospital cost in primary THA procedures with COC and M-PE bearings (Figure 4). Bearing selection was the second least important driver of hospital cost among the covariates we considered. Similarly, for Medicare payment, length of stay, census region, and hospital THA surgery volume were found to be most important drivers while year of surgery was ranked the seventh most important driver of hospital payment. Bearing selection was found to be among the least important drivers of hospital payment.

From the nonparametric analysis, the median hospital cost was \$360 more for C-PE (95% CI: \$319-410, $p < 0.001$) and \$318 more for COC (95% CI: \$118-448, $p < 0.001$), respectively, when compared with M-PE. The differential in median Medicare payment for THA with ceramic bearings compared to M-PE was \$55.10 for C-PE (95% CI: \$31.50-78.70, $p < 0.001$) and \$76.40 for COC (95% CI: \$2.20-150.70, $p < 0.001$), respectively, when compared with M-PE. Cost differentials were found to decrease significantly over time ($p < 0.001$). The differential in median hospital cost between ceramic bearings and M-PE decreased by \$238-389 every year while the differential in median hospital payment between ceramic bearings and M-PE decreased by \$206-226 every year ($p < 0.001$).

Discussion

Since 2010, health care reform legislation, including the ACA, has emphasized quality improvement and cost containment as major themes for the practice of Medicine, including in orthopaedics. As expected, we observed clear evidence of cost reduction in terms of the hospital cost and CMS reimbursement for primary THA during the 2010-2015 study period. However, we were surprised to see that not only are the costs of primary THA declining over time, regardless of bearing type, but also the cost differential between ceramic bearings and M-PE bearings was also decreasing over time. Although previous studies [11, 18, 19] identify cost as a factor limiting the usage of ceramic bearings in total joint replacement, the results of our study suggest, to the contrary, that bearing selection has a relatively slight association with either the total cost or reimbursement associated with primary THA in the Medicare population. Clinical factors, most notably length of stay, has far greater impact on the costs (and payments) associated with primary THA than bearing selection.

The increased utilization of C-PE bearings in the Medicare population, displacing M-PE as the bearing of choice by 2014, is consistent with our findings and a general cost effectiveness argument as posed by Carnes and coauthors [18]. We report here that C-PE costs $360 more than M-PE, which is similar to the lower cost-differential range of $325 used by Carnes et al. We also report that COC costs $318 more than M-PE. If one accepts the same assumptions that Carnes et al. used, a cost-differential of $360 for C-PE and $318 for COC would mean that both of these bearing surfaces are cost-effective implant choices for patients younger than approximately 87 years of age. If the prices of ceramic bearings continue to decrease, they will be cost-effective regardless of patient age.

It is difficult, however, to obtain cost data for ceramic components in the peer reviewed literature, because hospitals and implant manufacturers generally consider such information proprietary. Carnes and coauthors derived the cost of ceramic bearings using 3 different methods. Both the lowest and highest cost-differences between C-PE and M-PE, $325 and $1,003, respectively, were obtained from a national group purchasing organization database. The middle value of $600 was obtained from the 2013 Orthopedic Network News [23]. More recently, Mendenhall [24] has reported cost data up to 2015 for ceramic components for a network of approximately 180 hospitals. According to Mendenhall’s database [24], the cost of ceramic and metal femoral heads has decreased between 2010 and 2015, supporting the results of our study. Because the cost of individual heads varies by size of the components (with larger head sizes associated with a higher average selling price), as well as by hospital, it is not possible to generalize the results of Mendenhall’s dataset to the nationwide Medicare population. Overall, available cost trends are consistent with our study findings, that ceramic implant costs, and the cost differentials relative to M-PE bearings, are decreasing over time.

Our study was limited to the analysis of total inpatient costs, which were calculated using an institution's cost-to-charge ratio. This approach is used by CMS and the scientific literature [20-22] so that hospital costs can be compared across institutions around the country. Alternative approaches, such as analyzing an individual hospital's direct costs, are not readily generalizable across institutions, especially with regard to implant prices. The economic data captured by the Medicare Limited Data Set (LDS) is limited to total hospital charges and payments, and did not include cost information for implant components or other costs (e.g., surgeon, post-op care, rehabilitation) associated with a hip arthroplasty. We focused on analyzing the total hospital cost of these procedures, which after adjustment for selection bias (with propensity scores) and hospital and patient confounders, would allow us to examine the cost-differential between ceramic bearings and M-PE in primary THA procedures. Because of the large number of patients in the study, we have sufficient statistical power to detect even small cost differentials (<$100) that fall below the published cost effectiveness threshold for C-PE bearings in the literature.

The cost and payment data of this study are limited to the Medicare population, and likely underestimate the costs associated with treating younger patients covered by private insurance. It is well appreciated that patients less than 65y in age are associated with significantly higher costs and reimbursements than patients covered by Medicare [21]. Thus, it is unclear whether the cost differentials derived here will be reflected in the younger patient population. On the other hand, the Medicare patient population represents approximately half of the overall volume of primary THAs in the US [21], and according to cost-effectiveness studies, older patients have a lower cost-effectiveness threshold than younger patients with private insurance. The present study also shares all of the limitations associated with administrative datasets [20-22], which are intended for billing purposes, and are not designed to capture clinical outcome measures, such as hip society scores, pain scores, or radiographic information.

In summary, our findings demonstrate that the utilization of C-PE implants is increasing and the cost analysis of primary THA with alternative bearings is not static, but a moving target after 2010. These findings have important implications for cost-effectiveness analyses, in which economic conditions are assumed to be constant over time. We also found that the cost differential between ceramic bearings and M-PE was less than $360, which compares favorably with the cost-effectiveness threshold of ceramic heads reported by Carnes ($325) for patients less than 85 years old. We are unaware of similar cost-effectiveness thresholds for COC in the Medicare population, making such comparisons difficult. The results of this study will provide a useful basis for future cost-effectiveness analyses of ceramic bearings in the Medicare population.

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Figure 1

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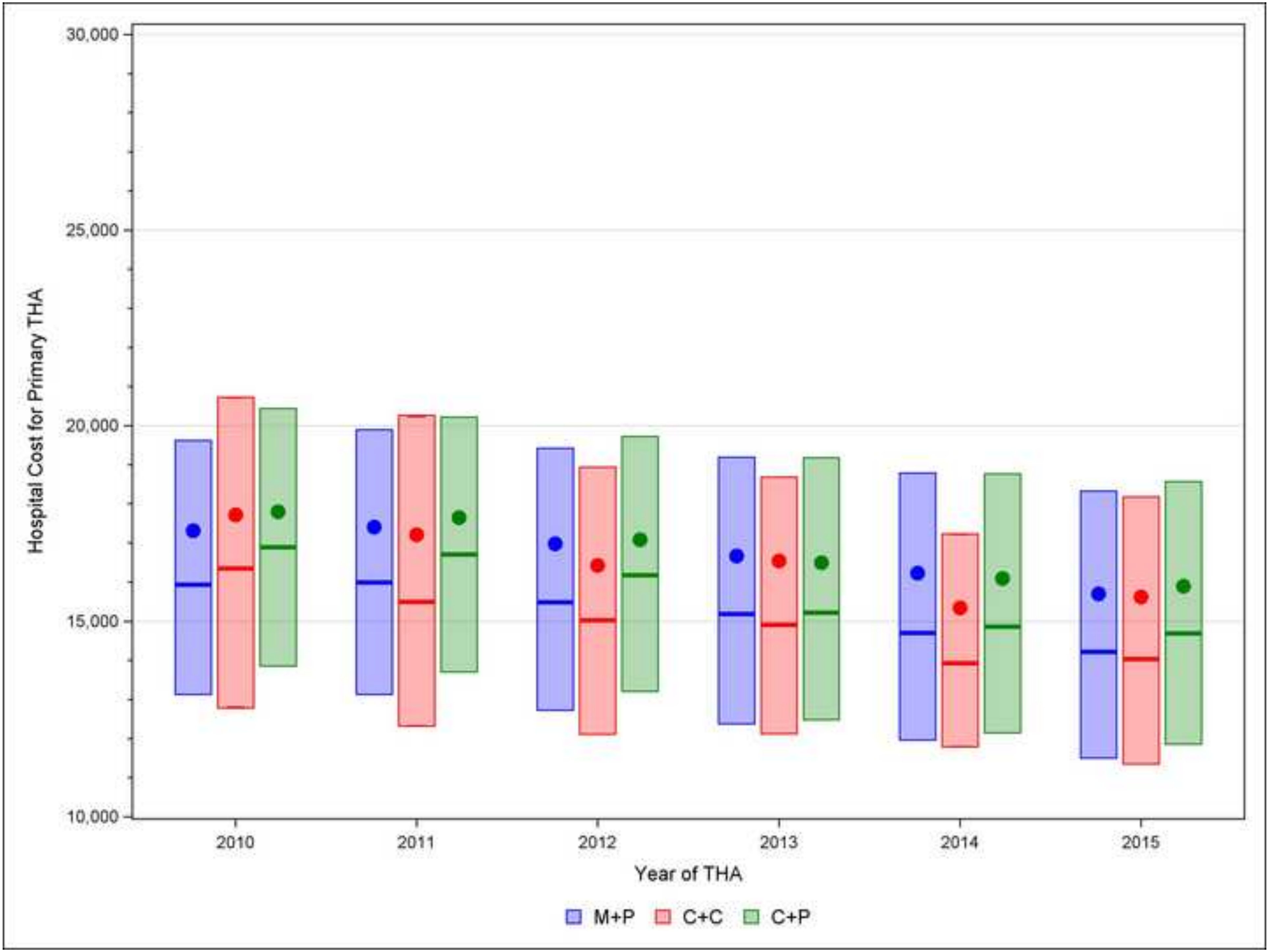

Figure 2

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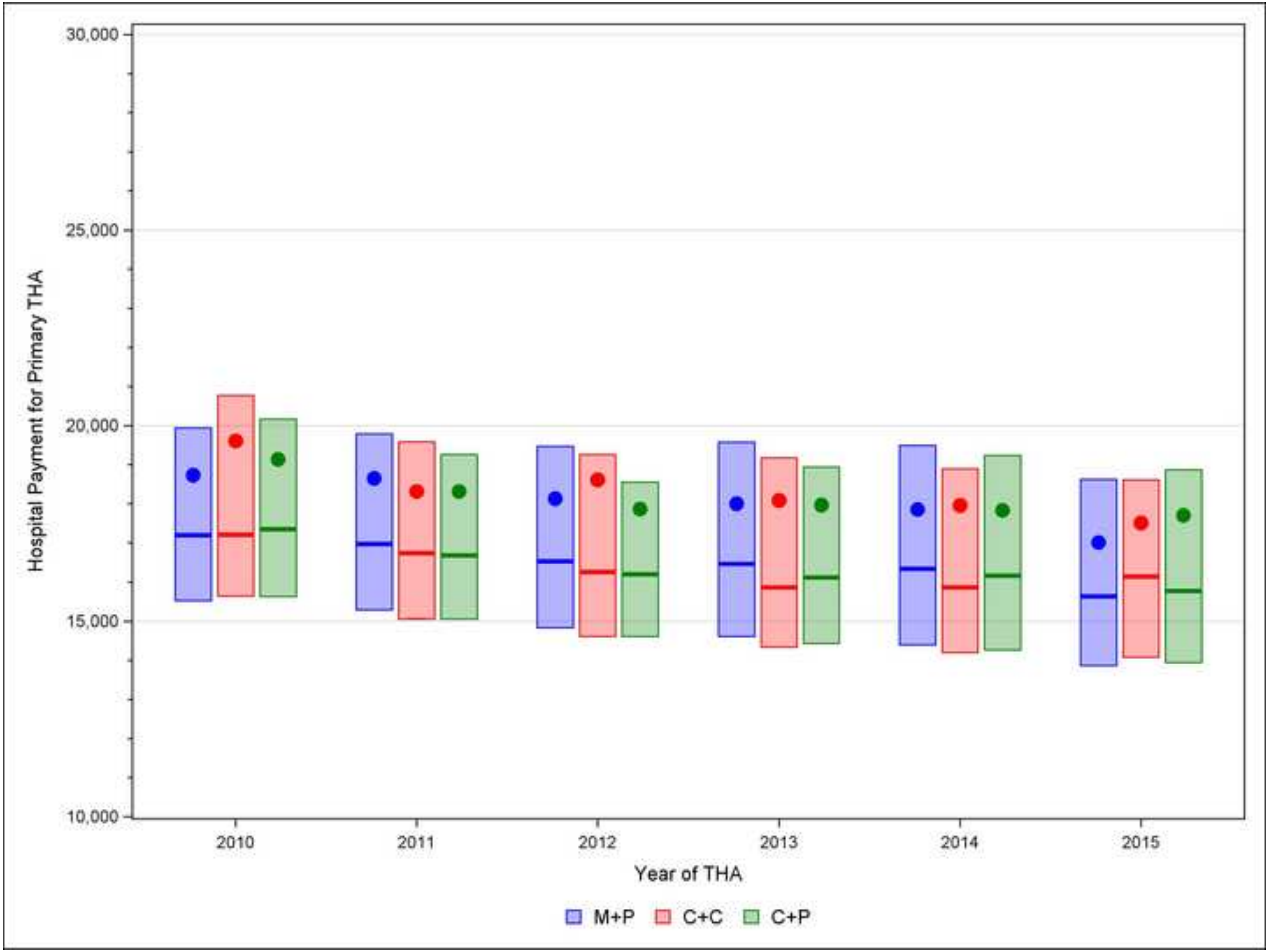

Figure 3

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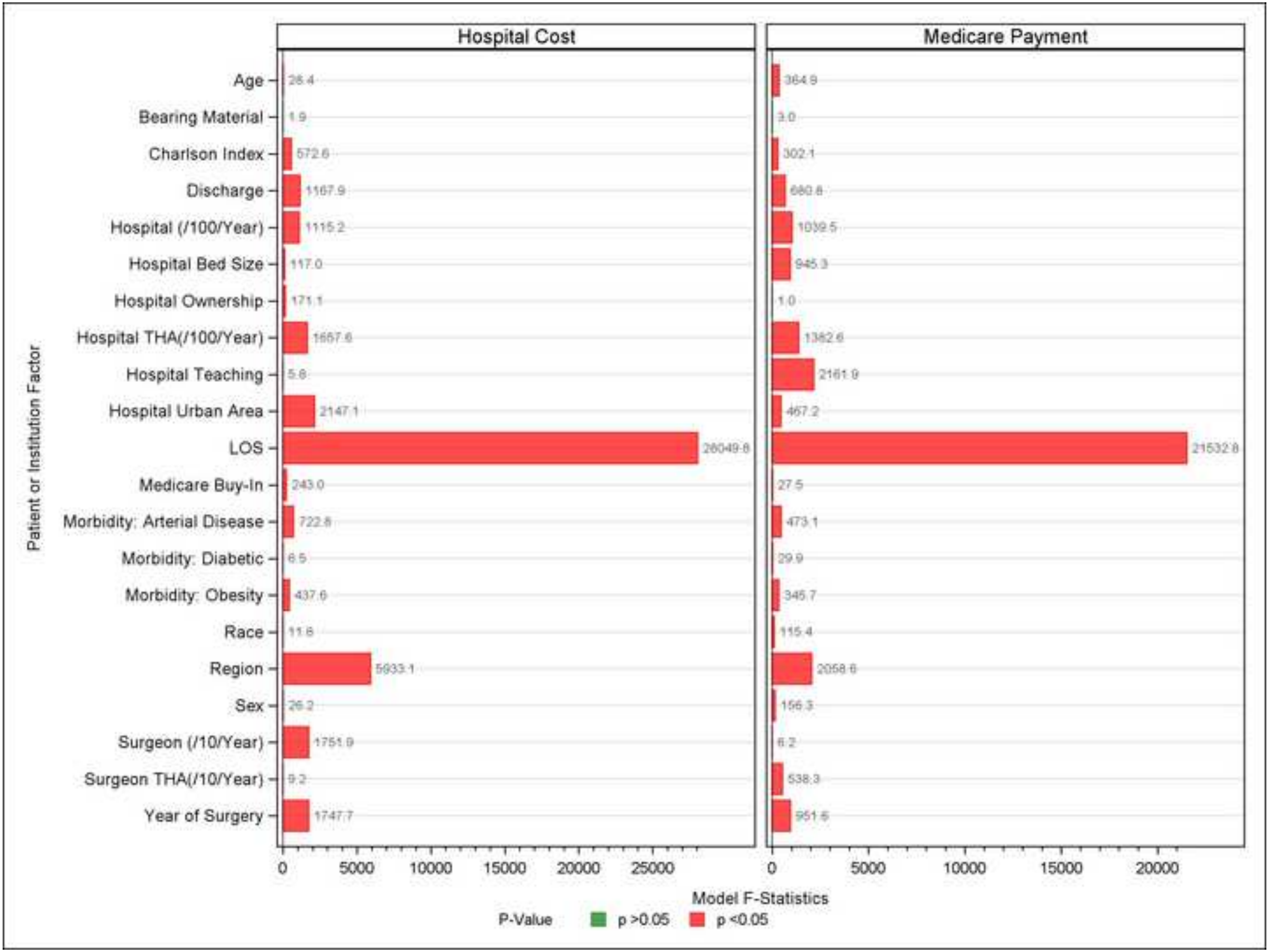

Figure 4

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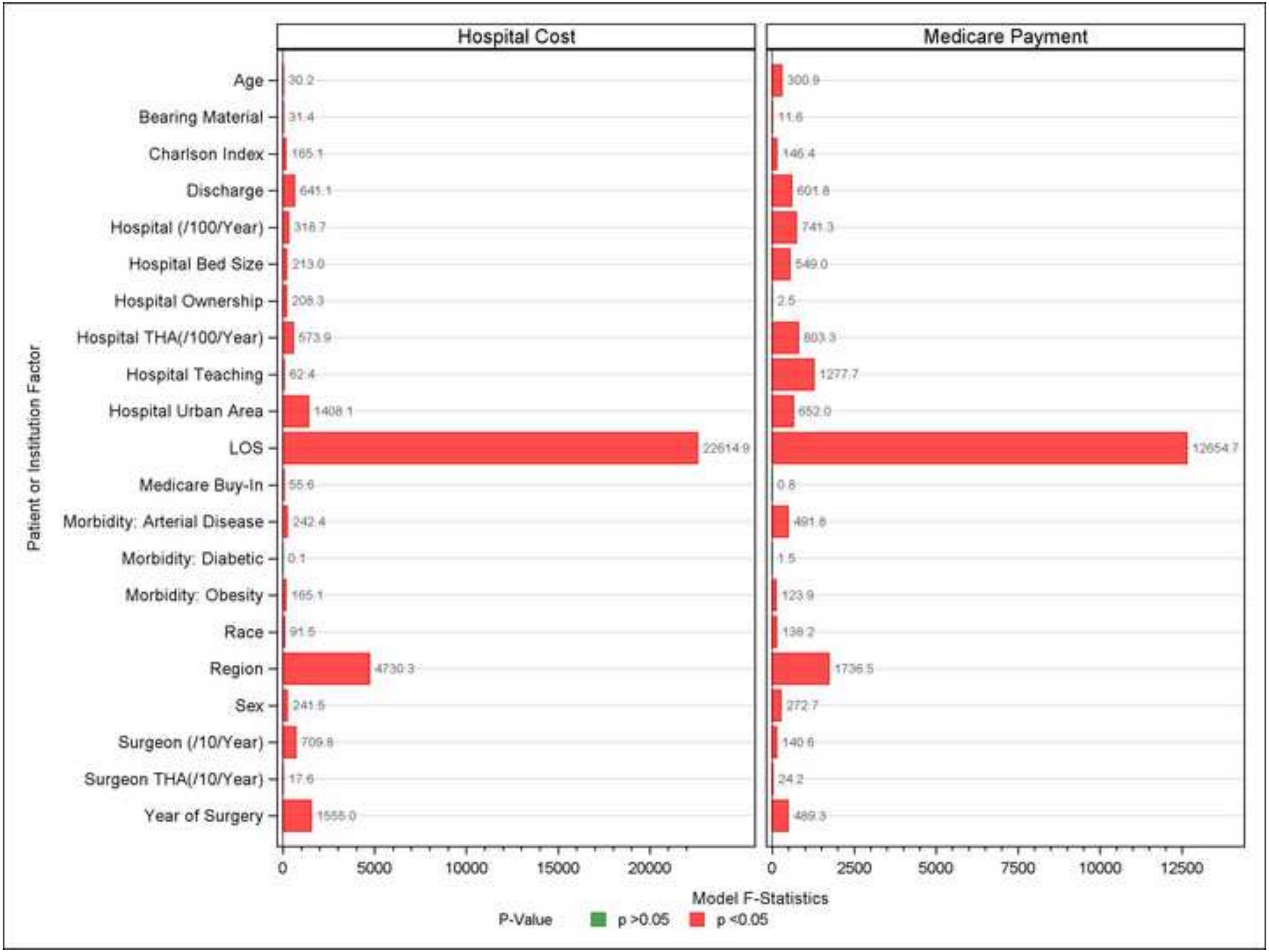

Figures and Captions

Figure 1. Box plot and mean hospital cost for primary THA incorporating M-PE, COC, and C-PE bearings. Source: 2010-2015 100% Medicare LDS.

Figure 2. Box plot and mean hospital payment (reimbursement from CMS) for primary THA incorporating M-PE, COC, and C-PE bearings. Source: 2010-2015 100% Medicare LDS.

Figure 3. Relative importance of patient, hospital, and clinical factors on the hospital costs and payments for primary THA procedures with C-PE and M-PE bearings. The choice of bearing materials (C-PE vs. M-PE) was among the *least* important drivers of hospital cost or payment for THA procedures based on the model F-statistics.

Figure 4. Relative importance of patient, hospital, and clinical factors on the hospital costs and payments for primary THA procedures with COC and M-PE bearings. The choice of bearing materials (COC vs. M-PE) was among the *least* important drivers of hospital cost or payment for THA procedures based on the model F-statistics.

Table 1

Table 1

Effect	*Level*	*M+P*	*C+P*	*C+C*	*Total*	*% MP*	*% CP*	*% CC*	*% 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%
Charlson Index (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	Non-Profit	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	N	56,695	29,972	2,084	88,751	35.0%	38.3%	41.4%	36.2%
	Y	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%

Effect	*Level*	*M+P*	*C+P*	*C+C*	*Total*	*% MP*	*% CP*	*% CC*	*% Total*
	Oth/Unk	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%
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%