Effect of Hospital and Surgeon Volume on Hospital Costs for Total Knee Arthroplasty

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Abstract

Purpose: Higher hospital or surgeon volume is shown to be associated with better patient outcomes following primary total knee arthroplasty (TKA). However, little research exists on the relationship between hospital and surgeon volume and inpatient costs of TKA. To explore the volume-cost relationship for primary TKA and to determine whether both hospital volume and surgeon volume are independently associated with lower inpatient costs.

Methods: Statewide Planning and Research Cooperative System (SPARCS) claims data from the New York State Department of Health were used to identify 102,386 adults who underwent primary TKA from 2013 to 2016. Surgeon volume was defined as the number of TKA cases a surgeon had operated during the previous 365 days of the current case. Hospital volume was defined in a similar way. Hospital and surgeon volumes were categorized as tertile groups. Generalized linear models adjusted for patient, hospital, surgeon, and market covariates.

Main Outcome Measures: Inpatient cost calculated as total charges multiplied by cost-to-charge ratios (CCR) and adjusted for inflation.

Results: Compared with patients operated by low-volume surgeons in low-volume hospitals, patients of high-volume surgeons in high-volume hospitals had significantly lower inpatient costs (adjusted cost savings = \$3,384 per TKA case, 95% confidence interval \$3,184 - \$3,583, $P < 0.001$). The inverse volume-cost relationship tended to be stronger in more recent years.

Conclusions: TKAs performed at hospitals and by surgeons with higher volumes had significantly lower inpatient costs, especially in more recent years. Regionalization of TKA to high-volume hospitals and surgeons may achieve both better patient outcomes and cost savings.

Introduction

Total knee arthroplasty (TKA) is a safe and common inpatient procedure that relives pain and improves functional status of patients with advanced knee osteoarthritis [1]. Approximately 750,000 TKA procedures were performed in 2014 in the United States with a total cost of $11.8 billion, making it one of the most expensive surgical procedures among adult patients [2–4]. Demand for primary TKA is projected to increase substantially due to the aging of the population and increased prevalence of obesity, with a projected annual volume of over a million by 2030 [5–7]. The foreseeable rise in TKA expenditures in accordance calls for efforts to improve the cost efficiency of this procedure.

Numerous studies have identified the association of higher surgeon and hospital volume with improved patient outcomes such as improved functional status following primary TKA [8–11]. However, few studies to date have examined the association between hospital or surgeon volume and inpatient costs for primary TKA. Higher-volume surgeons and hospitals might exhibit reduced costs per TKA due to economies of scale. Hollenbeck et al. used the Healthcare Cost and Utilization Project (HCUP) data from the Agency for Healthcare Research and Quality (AHRQ) to identify 1,651,354 total hip or total knee arthroplasties and found that high hospital volume was associated with lower mean charges [9]. Two other studies found that higher volume hospitals had lower mean Medicare inpatient payments for total joint arthroplasty [12, 13]. However, these studies did not examine surgeon volume or other potential confounding characteristics of the surgeon that might be associated with variations in inpatient costs.

To address these issues, this study aimed to determine variations in primary TKA costs and to test the hypothesis that inpatient costs of primary TKAs were lower when performed in higher-volume hospitals and by higher-volume surgeons. We also examined whether this inverse volume-cost relationship changed over time from 2013 to 2016.

Methods

Data and sample

The primary data source was the Statewide Planning and Research Cooperative System (SPARCS) inpatient file, an all-payer administrative database from the New York State Department of Health. We used both International Classification of Diseases, Ninth/Tenth Revision, Clinical Modification (ICD-CM 9/10 CM) primary procedure codes (see Appendix A4) and All Patient Refined Diagnosis Related Group (APR-DRG) code 302 to identify patients undergoing primary TKA in a New York State hospital from 2013 to 2016 [14].

The SPARCS inpatient claims were merged with several supplemental databases including: (1) the Hospital Inpatient Cost Transparency file, a separate part of the SPARCS, to obtain cost-to-charge ratios (CCRs); (2) the Hospital Compare and the Hospital Inpatient Prospective Payment System (IPPS) Impact File of the Centers for Medicare & Medicaid Services (CMS) to identify hospital characteristics; (3) the Office of Professions' official database provided by the New York State to obtain surgeon information; (4) the American Community Survey (ACS) to define market characteristics; and (5) the Medical Care Consumer Price Index from the U.S. Bureau of Labor Statistics (BLS) to adjust for inflation.

We initially identified 139,628 TKA admissions from 2013 to 2016. In order to minimize the impact of clerical billing errors or unusually complicated cases, we excluded admissions from the initial sample if (1) the patients were younger than 18 years or older than 99 years when receiving knee replacement (n = 32); (2) their hospital charges were above the 99th percentile or below the 1st percentile (n = 2,794); (3) length of stay was above the 99th percentile (10 days, n = 1,901) to avoid undue influence of outliers on estimated associations; (4) the admissions were categorized as emergent, urgent, newborn, trauma, or information not available (n = 3,563); (5) cost to charge ratio was not reported (n = 10); (6) the admissions followed a previous TKA admission (n = 15,423); (7) the admissions represented transferred cases from another acute care facility (n = 123); or (8) the procedures were performed at a specialty orthopedic hospital in New York City (n = 17,345); this hospital had unusually high volume given it specialization and was not comparable to other hospitals in our sample which were all general acute care hospitals. The final analytic dataset consisted of 102,836 TKA admissions.

Inpatient Costs

The SPARCS inpatient claims report total charges for each patient's stay, which is the sum of total accommodation charges and total ancillary charges (all charges not related to accommodation, including professional fees and implants) [15]. The outcome of interest, inpatient costs for each TKA patient, was calculated as total charges multiplied by the cost-to-charge ratio. CCRs are hospital specific, and within each hospital vary over patient groups according to APR-DRG and severity of illness level. Costs were further adjusted for inflation to 2016 dollars using the BLS Medical Care CPI.

Hospital and Surgeon Volume

The explanatory variables of interest were hospital and surgeon annual operative volumes of TKA. We defined annual surgeon volume as the number of TKA procedures that a surgeon had operated in the 365 days prior to the current TKA case. Annual hospital volume was defined in a similar way (i.e. the number of TKA procedures performed in the hospital during the 365 days prior to the current TKA case). As opposed to defining volume as total surgical cases performed in a calendar year, this approach should more accurately reflect the amount of practices the hospital or surgeon has at the time of surgery. We used the initial cohort of 139,628 TKA admissions to construct the two volume measures because they all contributed to the surgical experiences of the hospital and the surgeon. For TKAs performed in 2013, we used the 2012 claims as well to calculate volume.

For ease of interpretation of results in regression analyses, we categorized surgeons and hospitals into low-, medium-, and high-volume groups using their respective tertiles. Then we generated nine volume categories by interacting surgeon and hospital volume tertile groups: low-hospital and low-surgeon (LL) volume, low-hospital and medium-surgeon (LM) volume, low-hospital and high-surgeon (LH) volume, medium-hospital and low-surgeon (ML) volume, medium-hospital and medium-surgeon (MM) volume, medium-hospital and high-surgeon (MH) volume, high-hospital and low-surgeon (HL) volume, high-hospital and medium-surgeon (HM) volume, and high-hospital and high-surgeon (HH) volume.

Covariates

Patient covariates included age (18–44, 45–64, 65–72, 75–99), sex, race (white, black, or other), primary source of payment (Medicare, Medicaid, private, or other), and 31 comorbidity indicators presented on the index admission using algorithms developed by Elixhauser et al [16, 17]. We defined surgeons' years in practice by subtracting their medical school graduation date from the date of the TKA procedure performed. We controlled for several key attributes of hospitals including ownership status (for-profit, non-profit, or government-owned), teaching hospital (yes or no), number of beds, and geographical location (rural, large urban, or other urban). In addition, we defined several market-level characteristics including market structure (highly competitive, un-concentrated, moderately concentrated, or highly concentrated), percent of people who were uninsured in the county, and county median household income. The measure of market structure was derived from the Herfindahl-Hirschman Index (HHI), a measure of market concentration with a range from 0 to 10,000 and calculated at the county level using hospital bed count. The HHI cutoffs for the four market types are 1000, 1500, and 2500, with higher values indicating more concentrated markets.

Statistical Analysis

We first examined the medians (interquartile ranges) of hospital charges and costs and means (standard deviations) of volume, by surgeon and hospital volume groups simultaneously. Second, we summarized patient demographics, comorbid illnesses, surgeon and hospital characteristics, and key market-level features.

In multivariable analyses, we examined the relations between both hospital and surgeon volume and total inpatient costs using generalized linear model (GLM) with a log link function and Gamma distribution. The distribution of inpatient costs for TKA was skewed due to very high costs for a relatively small number of patients. The GLM approach allows flexibility to model the skewed distribution of health care costs [18]. In the model the interactive effects of hospital and surgeon volume were examined, with the group of low surgeon volume and low hospital volume as the reference group. Average marginal effects were calculated for the other 8 volume groups after model fit. The GLM regression adjusted for patient, surgeon, hospital, and market characteristics, as well as indicators for years. The average marginal effects obtained from the GLM were used to compare differences in adjusted hospital costs by provider volume. We also fit separate GLM models on each of the four procedure years to examine possible changes in the volume-cost relationship over time. All analyses were performed using Rstudio Version 1.2.5033. This project was approved by the University of Rochester Medical Center.

Results

Study Population

Altogether, 139,628 inpatient stays for TKA in New York State between 2013 and 2016 were identified. Of them, 26.4% were excluded and our final analytic sample consisted of 102,836 (73.6%) TKA cases performed by 1,285 surgeons at 161 hospitals between 2013 and 2016.

Table 1 reports summary statistics for our study cohort. The median charge and inpatient costs for patients undergoing primary TKA were $45,429 and $17,800 (interquartile rage [IQR] $31,831-$70.230 and $14,137-$23,608), respectively. Two age groups (between 45–74 years old) represented 78% of the cohort. The cohort was largely female (68%) and consisted of 74% of white and 11% of black patients. The most common payer types were Medicare (47%) and private insurance (43%). With regard to comorbidities, uncomplicated hypertension (63%) and obesity (31%) were the two most prevalent conditions present on admission. The mean years in practice of surgeons were 25.34 (SD: 9.82). The majority of procedures were performed in non-profit (95%), teaching (75%), and large urban (66%) hospitals. More than half (61%) of TKAs were performed in highly concentrated markets (61%). The mean county-level insurance rate and median household income (in thousands) were 73.37% (SD: 4.77%) and $64.44 (SD: $17.3 thousands), respectively.

Inpatient Costs by Volume Categories

Table II presents the unadjusted mean volume and median costs by hospital and surgeon volume categories. The hospital tertile groups of annual volume were defined as 0-255 TKAs (low-volume hospitals), 256–574 TKAs (medium-volume hospitals), and 575-1,649 (high-volume hospitals). Similarly, surgeon tertile groups of annual volume were define as 0–61 TKAs (low-volume surgeons), 62–135 TKAs (medium-volume surgeons), and 136–430 TKAs (high-volume surgeons). Throughout the study period, high-volume hospitals performing TKAs were 15% less costly than low-volume hospitals (median costs: $16,801 vs $19,699). TKAs performed by high-volume surgeons costed 14% less relative to these of low-volume surgeons (median costs: $16,373 vs $20,865). Table III summarizes the unadjusted median costs by both surgeon and hospital volume subgroups. TKAs performed by high-volume surgeons at high-volume hospitals had significantly lower costs than surgeries performed by low-volume surgeons at low-volume hospitals (median costs: $14,014.35 vs $19,715.51; $p < 0.001$). Within high-volume hospitals (surgeons), notably, higher volume surgeon (hospital) categories consistently had lower median costs.

Table IV presents adjusted cost differentials by hospital and surgeon volume groups. The average patient treated by high-volume surgeons at high-volume hospitals costed $3, 384 ($P < 0.001$) less than patients treated by low-volume surgeons who performed these procedures at low-volume hospitals, after adjustment for patient, hospital, surgeon, and county covariates. Furthermore, there was a trend to lower costs for TKAs performed by higher-volume surgeons within the group of high-volume hospitals (cost differentials: $1,763 vs $2,354 vs $3,384, $p < 0.001$). The same trend was not observed within low- and medium-volume hospitals, but medium- and high-volume hospitals were less costly than low-volume hospitals overall. TKAs performed by high-volume surgeons didn't yield cost savings at low-volume hospitals. In contrast, they costed $1,398 more ($p < 0.001$) per TKA relative to these performed by low-volume surgeons. An additional year of practice of surgeons since their medical school graduation was associated with $50 ($p < 0.001$) in cost savings per TKA.

The regression model also shows that average inpatient costs for TKA were higher in for-profit ($11,328, $p < 0.001$) and teaching hospitals ($434, $p < 0.001$). TKAs performed in highly concentrated markets were $14,116 ($p < 0.001$) less costly than these performed in highly competitive markets.

We also tested the sensitivity of the inverse volume-cost relationship by estimating the GLM model with volume groups as key independent variables, and that sequentially adjusted for procedure year (model1); patient characteristics (model 2); surgeon's years of practice (model 3); hospital characteristics (model 4); market-level covariates (model 5, see Appendix Table A2). We also used alternative cutoffs – the top quartile and median – to define high and low volume groups and re-estimated model 5 (see Appendix Table A2-1 and A2-2). The results from these models were similar to the main results described above.

Volume-Cost Relation over Time

Table V shows the results of stratified analyses by year. The overall cost savings associated with TKAs performed by high-volume surgeons at high-volume hospitals tended to be greater in more recent years: $2,412 in 2013, $4,593 in 2014, $4,678 in 2015, and $3,030 in 2016.

Discussion

The association between higher procedure volume and cost savings for total knee arthroplasty has been understudied. Our study filled this gap by examining the volume-cost association among TKA recipients in New York State, and found that TKAs performed by higher-volume orthopaedic surgeons at higher-volume hospitals tended to have lower costs than TKAs performed by lower-volume surgeons at lower-volume hospitals. The magnitude of cost savings associated with higher volume varied by years (2013–2016), and volume groups. For example, higher-volume surgeons seemed to be able to achieve cost savings only in medium- and high-volume hospitals.

Previous studies demonstrated that, for primary TKA, higher hospital surgical volume was associated with lower charges and Medicare payment [9, 19, 20]. However, charges are inflated dollar amounts that do not reflect the actual expenditures of the procedure. The charge-to-cost ratios of most hospitals ranged from 1.5 to 4.0, with the maximum of 12.6 [21]. Compared with previous studies, our analysis has several important strengths. First, we converted total charges to inpatient costs to better measure the true costs of primary TKA. Second, our choice of an all-payer administrative database allowed us to examine the volume-cost association in a more diverse adult population, not just Medicare beneficiaries in several previous studies. Third, we investigated the joint effects of both surgeon and hospital volume, and were able to control for the cumulative experience of surgeons.

Both surgeon volume and hospital volume demonstrated economies of scale in our sample. Surgeons with more operations may possess better surgical skills and have shorter operative time, leading to lower risk of complications and shorter length of stay of patients. Previous studies examined Medicare claims data and found shorter procedure duration for primary TKA as hospital and surgeon volume increased, which was associated with lower infection rate [22, 23]. Other studies reported a significant increase in LOS of TKAs performed by low-volume surgeons [24–27]. Furthermore, higher-volume institutions may have more efficient resource allocations and utilization through dedicated orthopedic operating room (OR) unit, and have more negotiating power with implant companies, both of which help to reduce input costs [28–30]. For example, the investment in a dedicated OR unit, in which staff commits only to surgical cases of one specialty, can be considered as fixed costs. Higher-volume hospitals can spread the costs over a larger volume of orthopedic surgeries, therefore realizing cost savings relative to other hospitals. It was estimated that highest-volume hospitals spent $2,600 less in labor in the operating room for total joint replacements and paid $1,500 less for knee implants compared with lower-volume hospitals [31]. Finally, the inverse volume-cost relationship was also observed in other procedures. For example, a study found persistent cost savings associated with high-volume surgeons for four different cancer resections [32]. Other studies found that higher-volume hospitals tended to perform gastric bypass surgery with lower costs [33].

A significant association between surgeon experience, measured by the time since they graduated from medical school, and lower costs was also identified. Given two orthopaedic surgeons who have performed the same number of TKAs in the past year, the surgeon with more practicing years is more likely to deliver less costly care. This phenomenon may be explained by the human capital theory in economics – surgeons accumulate a lifetime stock of human capital through learning, which improves their performance in operating room. Increasing surgeon experience, either measured by years since residency or after medical school, was associated with improved patient outcomes for alimentary tract and rectal cancer [34, 35]. It would be reasonable to assume that more experienced surgeons are also more efficient in resource utilization, as supported by the finding in this study. However, the accumulated human capital might depreciate if surgeons have temporal breaks in their practice, which in turn impairs their productivity [11]. Our volume measures capture the amount of practices in the past year, and the inverse volume-cost relationship after controlling for experiences since medical school graduation indicates the importance of maintained surgical practices in avoiding deterioration of orthopaedic surgeons' human capital.

The costs of TKA increased from 2013 to 2016: even after adjusting for inflation, the median costs of TKA increased by 1.4% during this period (see Table A3 for median costs by calendar year). Despite the overall increased procedural costs, we found that higher-volume surgeons and higher-volume hospitals might have achieved more cost savings in more recent years, compared to their respective counterparts. Future research is needed to determine if this trend continues in more recent years and how the cost efficiencies achieved by high-volume providers may help slow down the overall increasing costs for TKA.

Our analysis has several potential limitations. First, the administrative data lack more granular information on clinical conditions and severity of disease that may influence inpatient costs. However, although the unmeasured confounding may bias our estimates of the inverse volume-cost association, it is unlikely that unmeasured patient characteristics would alter the direction of this association. In addition, when we examined differences in observed patient characteristics by provider volume, higher volume providers tended to have patients with a higher prevalence of obesity (see Table A1), a risk factor associated with complications and higher hospital cost [36]. Thus, if higher-volume hospitals and surgeons tended to have TKA patients with more comorbidities (measured or unmeasured) or disease severity, the unmeasured confounding would bias the inverse volume-cost associations towards null and our estimated associations represent conservative estimates of the true associations.

Another limitation of this study is potential measurement errors in inpatient costs. Because we only had information on total charges of inpatient stays and the cost to charge ratios (CCRs) at the hospital level, our cost estimates may not accurately reflect actual payments to orthopaedic surgeons [37]. Since CCRs are not payer-specific, we might have over-estimated the inpatient costs for private-pay patients and under-estimated the inpatient costs for Medicaid patients because Medicaid specific CCRs are typically higher than hospital-level average CCRs. Furthermore, our cost measures did not include costs incurred for services before or after the inpatient stay. Future studies should evaluate the costs associated with the entire episode of care. It's important to note that our study doesn't investigate factors that contribute to the cost savings of TKA by high-volume providers. Further studies should investigate individual training of surgeons, operation room management, and other institutional factors that may underline the volume-cost associations we found.

In conclusion, our study revealed lower costs of TKA performed by higher-volume surgeons at higher-volume hospitals in New York State. The findings suggest that selective referral of TKA to high-volume orthopaedic surgeons and hospitals would enhance the value of care to patients undergoing TKA.

Declarations

Funding

The authors did not receive support from any organization for the submitted work.

Conflicts of interest/Competing interests

The authors have no relevant financial or non-financial interests to disclose.

Availability of data and material

The data that support the findings of this study are available from the New York State Department of Health but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of from the New York State Department of Health.

Authors' Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Yechu Hua. The first draft of the manuscript was written by Yechu Hua and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Ethics approval

This research study was conducted retrospectively from a secondary insurance claims data. We consulted extensively with the IRB of University of Rochester who determined that our study did not need ethical approval. An IRB official waiver of ethical approval was granted from the IRB of University of Rochester.

Consent to participate

Not applicable

Consent for publication

Not applicable

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Tables

Table I. Descriptive Statistics at the Time of Total Knee Arthroplasty

Variable	N = 102,836
Charge and Costs	
Charge Price, median (IQR)	45,428.88 (31,830.72, 70,229.81)
Costs, median (IQR)	17,799.92 (14,137.28, 23,608.00)
Volume	
Surgeon Volume, mean (SD)	113.07 ± 84.06
Hospital Volume, mean (SD)	487.17 ± 363.21
Patient Characteristics	
Age	
18-44: n (%)	1,548 (2)
45-64: n (%)	42,981 (42)
65-74: n (%)	36,567 (36)
75-99: n (%)	21,740 (21)
Sex	
Female: n (%)	66,092 (64)
Male: n (%)	36,744 (36)
Race	
White: n (%)	76,533 (74)
Black: n (%)	11,154 (11)
Other Race: n (%)	15,149 (15)
Elixhauser Comorbidities	
Congestive heart failure: n (%)	2,524 (2)
Cardiac arrhythmias: n (%)	11,185 (11)
Valvular disease: n (%)	4,275 (4)
Pulmonary circulation disorders: n (%)	985 (1)
Peripheral vascular disorders: n (%)	2,258 (2)
Hypertension, uncomplicated: n (%)	65,066 (63)
Paralysis: n (%)	65 (0)
Other neurological disorders: n (%)	2,073 (2)

Chronic pulmonary disease: n (%)	17,649 (17)
Diabetes, uncomplicated: n (%)	19,901 (19)
Diabetes, complicated: n (%)	2,415 (2)
Hypothyroidism: n (%)	16,677 (16)
Renal failure: n (%)	4,600 (4)
Liver disease: n (%)	1,356 (1)
Peptic ulcer disease excluding bleeding: n (%)	415 (0)
AIDS/HIV: n (%)	6 (0)
Lymphoma: n (%)	211 (0)
Metastatic cancer: n (%)	63 (0)
Solid tumor without metastasis: n (%)	466 (0)
Rheumatoid arthritis/Collagen vascular: n (%)	4,683 (5)
Coagulopathy: n (%)	1,961 (2)
Obesity: n (%)	32,066 (31)
Weight loss: n (%)	77 (0)
Fluid and electrolyte disorders: n (%)	7,819 (8)
Blood loss anemia: n (%)	420 (0)
Deficiency anemia: n (%)	1,233 (1)
Alcohol abuse: n (%)	1,065 (1)
Drug use: n (%)	1,056 (1)
Psychoses: n (%)	449 (0)
Depression: n (%)	13,346 (13)
Hypertension, complicated: n (%)	4,667 (5)
Primary Source of Payment	
Medicare: n (%)	48,540 (47)
Medicaid: n (%)	2,851 (3)
Private: n (%)	44,644 (43)
Other: n (%)	6,801 (7)
Surgeon Characteristics	

Years of Practice, mean (SD)	25.34 ± 9.82
Hospital Characteristics	
Ownership	
Government: n (%)	2,603 (3)
For Profit: n (%)	1,736 (2)
Non Profit: n (%)	88,052 (95)
Teaching Hospital	
Yes: n (%)	69,066 (75)
No: n (%)	23,301 (25)
Beds, mean (SD)	402.85 ± 308.64
Urban/Rural	
Rural: n (%)	5,185 (6)
Large Urban: n (%)	61,235 (66)
Other Urban: n (%)	25,947 (28)
Market Characteristics	
Market Structure	
Highly Competitive: n (%)	3,256 (4)
Unconcentrated: n (%)	25,618 (28)
Moderately Concentrated: n (%)	6,892 (7)
Highly Concentrated: n (%)	56,601 (61)
Percent Insured, mean (SD)	73.27 ± 4.77
Median County Household Income in Thousands, mean (SD)	64.44 ± 17.30

Table II. Hospital and Surgeon Volume Categories

Hospital-Volume Categories		Mean Volume	Median Costs (IQR)
Low	0-255	146.00	19,699 (15,580, 26,771)
Medium	256-574	391.78	17,041 (14,445, 22,195)
High	575-1649	925.13	16,801 (12,672, 21,868)
Surgeon-Volume Categories		**Mean Volume**	**Median Costs (IQR)**
Low	0-61	33.47	19,138 (14,874, 25,278)
Medium	62-135	94.13	18,343 (14,564, 24,355)
High	136-430	213.32	16,373 (13,229, 20,865)

Note: Median costs are adjusted for inflation but unadjusted for patient, surgeon, hospital, and market-level covariates

Table III. Median Hospital Costs by Surgeon and Hospital Volume Categories

		Surgeon-Volume Categories		
		Low	Medium	High
Hospital-Volume Categories	Low	19,715.51	19,741.41	19,591.34
	Medium	18,219.45	16,259.55	17,044.56
	High	19,090.20	18,943.54	14,014.35

Note: Median costs are adjusted for inflation but unadjusted for patient, surgeon, hospital, and market-level covariates

Table IV. Adjusted Differences in Costs by Hospital and Surgeon Volume Categories

	Average Marginal Effect	Low 95% CI	High 95% CI	P value
Volume Groups				
Low Hospital Volume				
Low Surgeon Volume	Reference Group			
Medium Surgeon Volume	683.8232	477.4218	890.2247	<0.001
High Surgeon Volume	1397.6061	1091.1963	1704.0160	<0.001
Medium Hospital Volume				
Low Surgeon Volume	-1789.7295	-2001.7369	-1577.7220	<0.001
Medium Surgeon Volume	-1999.0626	-2198.5157	-1799.6096	<0.001
High Surgeon Volume	-1085.5129	-1275.3828	-895.6430	<0.001
High Hospital Volume				
Low Surgeon Volume	-1763.3928	-2019.3122	-1507.4734	<0.001
Medium Surgeon Volume	-2353.8010	-2574.5275	-2133.0744	<0.001
High Surgeon Volume	-3383.6317	-3582.9900	-3184.2733	<0.001
Patient Characteristics				
age				
18-44	Reference Group			
45-64	-396.1436	-819.6454	27.3581	0.0668
65-74	-603.8941	-1031.2663	-176.5218	0.0056
75-99	-647.1030	-1082.6318	-211.5742	0.0036
Sex				
Female	Reference Group			
Male	175.2647	67.4985	283.0309	0.0014
Race				
White	Reference Group			
Black	913.8574	733.0021	1094.7128	<0.001
Other	3746.3694	3568.2692	3924.4697	<0.001
Surgeon Characteristics				
Years of Practice	-49.6860	-54.8523	-44.5197	<0.001

Hospital Characteristics				
Ownership				
Non Profit	Reference Group			
Government	-831.5217	-1127.4338	-535.6097	<0.001
For Profit	11327.9569	10700.3987	11955.5151	<0.001
Teaching Hospital				
No	Reference Group			
Yes	434.0996	280.1353	588.0638	<0.001
Beds	-1.5857	-1.7793	-1.3921	<0.001
Urban/Rural				
Rural	Reference Group			
Large Urban	-1811.5641	-2100.4258	-1522.7025	<0.001
Other Urban	-3196.3516	-3481.4614	-2911.2418	<0.001
Market Characteristics				
Market Structure				
Highly Competitive	Reference Group			
Unconcentrated	-7296.2709	-7812.0292	-6780.5125	<0.001
Moderately Concentrated	-9493.3202	-9988.9621	-8997.6783	<0.001
Highly Concentrated	-14115.5717	-14601.9763	-13629.1670	<0.001
Percent Insured (%)	41.3611	22.0387	60.6835	<0.001
Median Household Income (in thousands)	52.7025	47.4727	57.9323	<0.001
Year				
2013	Reference Group			
2014	-71.8329	-218.7524	75.0865	0.3379
2015	733.9038	549.6215	918.1862	<0.001
2016	467.7014	250.3010	685.1019	<0.001
31 Comorbidity Indicators	Yes	Yes	Yes	Yes

Table V. Adjusted Differences in Costs by Hospital and Surgeon Volume Categories: 2013-2016

	Average Marginal Effects (Confidence Interval)			
Low Hospital Volume	**2013**	**2014**	**2015**	**2016**
Low Surgeon Volume	Reference Group			
Medium Surgeon Volume	283 (-87, 653)	467 (74, 860)	997 (555, 1440)	449 (16, 881)
High Surgeon Volume	3853 (3274, 4432)	353 (-202, 907)	-959 (-1606, -311)	930 (299, 1561)
Medium Hospital Volume				
Low Surgeon Volume	-526 (-940, -111)	-2474 (-2873, -2076)	-2728 (-3176, -2281)	-2574 (-3000, -2149)
Medium Surgeon Volume	-1005 (-1381, -628)	-2826 (-3198, -2453)	-2240 (-2696, -1784)	-2655 (-3052, -2259)
High Surgeon Volume	-111 (-484, 262)	-1178 (-1549, -808)	-1514 (-1914, -1114)	-2223 (-2596, -1849)
High Hospital Volume				
Low Surgeon Volume	-945 (-1446, -444)	-3052 (-3534, -2569)	-2464 (-2996, -1933)	-1914 (-2427, -1401)
Medium Surgeon Volume	-1297 (-1717, -876)	-2700 (-3143, -2257)	-3213 (-3691, -2735)	-3053 (-3483, -2623)
High Surgeon Volume	-2412 (-2805, -2019)	-4593 (-4978, -4208)	-4678 (-5096, -4260)	-3030 (-3428, -2633)

Supplementary Files

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