The Potential Influence of Regionalization Strategies on Delivery of Care for Elective Total Joint Arthroplasty

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ABSTRACT

Regionalization of total joint arthroplasty (TJA) to high volume hospitals (HVHs) may affect access to care and complication risk. Using administrative data, 2,560,314 patients who underwent primary total hip or knee arthroplasty from 1991 to 2006 were categorized by whether an HVH (>200 annual TJAs) was available locally. Associations among patient characteristics, hospital utilization, and in-hospital complications were estimated using regression modeling. The complication risk was higher (Odds Ratio 1.18 [95% CI: 1.16, 1.20]) if patients went to a local low volume hospital. Black and Medicaid patients were more likely to utilize the local low volume hospital than a local HVH. Utilizing a local HVH is associated with lower complication risks. However, patients from vulnerable groups were less likely to utilize these patterns.

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The rapidly growing utilization of total joint arthroplasty (TJA) [1,2] and increasing emphasis on value [3] substantiate the need for strategies to continuously improve efficiency and quality. The literature demonstrates the benefits of undergoing TJA at high volume institutions with high volume surgeons, as summarized in two systematic reviews [4,5]. The volume–outcomes relationship has prompted calls for selectively referring patients to high volume centers for total hip and knee arthroplasty [6–8], also referred to as regionalization [9,10]. While selective referral could potentially improve outcomes after TJA, previous work indicates that there may be unintended consequences for access to care and complication risk [7,11–14].

Although many patients undergo TJA at high volume hospitals (HVHs), 5%–8% of patients of all insurance types [15,16] and 10%–37% of Medicare beneficiaries received care at low volume hospitals (LVHs) [9,12,13,17,18]. While patients often attribute this pattern to convenience and proximity [13,18,19], 13-34% of the patients who underwent total knee arthroplasty at an LVH had traveled further than a local HVH [12,19]. Although it is expected that this pattern of care (choosing an LVH when an HVH was closer) would have a negative effect on outcomes, this relationship has not been directly evaluated. The factors contributing to selection of a hospital and a surgeon are multifactorial [18,20] and may not be entirely under the patient's control. However, this evaluation of complication rates for patients who underwent surgery at an LVH instead of HVH within the same vicinity is needed to guide future decision making.

Empirical data demonstrating the possible effects of regionalization will influence future health policy. Both Losina et al [19] and FitzGerald et al [12] implied the negative consequences of "bypassing" an HVH, but did not directly evaluate the effects on outcomes. In the current investigation, we used data from 14 states to identify the frequency and predictors of hospital utilization for TJA, while considering the options available to each patient. We asked the following research questions: (1) Are vulnerable patient populations (elderly, non-white, Medicaid, and those from communities with lower socioeconomic status) less likely to receive care at high volume centers? and (2) What is the association between hospital utilization patterns and the risk of in-hospital complications after TJA?

Materials and Methods

State-specific Healthcare Cost and Utilization Project (HCUP) data from 14 states (Arizona, California, Colorado, Florida, Iowa, Massachusetts, Maryland, Michigan, New York, North Carolina, New Jersey, Oregon, Washington, and Wisconsin) were used. Patients who underwent total hip arthroplasty (THA) or total knee arthroplasty (TKA) from 1991 to 2006 were identified using ICD-9-CM procedure codes (81.51 for THA; 81.54 for TKA). Patients with a diagnosis code indicating a

prior knee or hip arthroplasty (ICD-9-CM V43.64 and V43.65) were excluded. A total of 2,560,314 patients undergoing THA or TKA were included in the current study (THA: 976,068; 38%; TKA: 1,584,246; 62%).

Hospital volumes for primary THA and TKA were determined from HCUP data. Hospitals performing ≥200 THAs during the four quarters prior to each patient's surgery were designated as "high volume", with the remaining hospitals categorized as "low volume". The same criteria were used for TKA. The patient's ZIP code was used to determine whether an HVH was available within their surrounding hospital service area (HSA; as defined by the Dartmouth Atlas of Health Care; hereafter referred to as "local") [21].

Definition of Hospital Utilization Patterns

To best replicate decisions that patients face before undergoing TJA, we created two base scenarios. In the first scenario, there was no HVH within the HSA where the patient lived ("local"). In the second scenario, there was an HVH within the patient's HSA.

Scenario 1: No HVH Within the Patient's HSA

There were 1,512,069 patients (59.1% of study cohort) without a local HVH. These patients followed these patterns (Fig. 1): undergoing TJA at a local LVH (Pattern 1A), a non-local HVH (Pattern 1B), or a non-local LVH (Pattern 1C). There were 2591 (0.2% of study cohort) patients living in HSAs where no TJAs were performed in the preceding 12 months and 199,741 (13% of study cohort) patients where data for the maximum TJA volume for their HSA were missing. Both of these groups were included in Scenario 1 (no local HVH).

Scenario 2: A High Volume Hospital Within the Patient's HSA

There were 1,048,245 patients (41% of study cohort) who had a local HVH. These patients followed these patterns (Fig. 1): undergoing TJA at a local HVH (Pattern 2A), a local LVH (Pattern 2B), a non-local HVH (Pattern 2C), or a non-local LVH (Pattern 2D).

Potential Predictors of Regionalization

Patient Demographics

Age, gender, race, comorbidity, and insurance status were considered potential patient-level predictors for regionalization. Race was defined as white, black, other, or unknown. Comorbidity scores were calculated using the Elixhauser comorbidity index [22]. Insurance status was defined as private, Medicare, Medicaid, other, or unknown.

Community Characteristics

Education (percentage of residents with a college degree), household income poverty (percentage of residents living below poverty level), and population density (persons per square mile) of communities were estimated based on patient residential zip code using 2000 US Census data.

Complications after TJA

To determine implications of hospital utilization, we identified in-hospital complications after each TJA using ICD-9-CM diagnostic coding (Appendix A). The complications were grouped into categories: orthopaedic, cardiovascular/cerebrovascular, thromboembolic, infection, and other medical complications.

Statistical Analysis

For patients without a local HVH (Scenario 1), the effects of patient and community characteristics on hospital utilization were estimated using a multinomial logistic regression model. A separate multinomial model was constructed for patients with a local HVH (Scenario 2) to examine the potential predictors for hospital utilization.

The effect of hospital utilization on likelihood of post-surgical complications was estimated using a regression model while adjusting for other patient and community characteristics. The comparisons in complication risk for patients without a local HVH (Scenario 1; Fig. 1) were based on the hospital patterns available to those patients:

- Local LVH (1A) vs. non-local HVH (1B)
- Local LVH (1A) vs. non-local LVH (1C)

The comparisons in complication risk for patients with an HVH within their HSA (Scenario 2; Fig. 1) were based on the hospital patterns available to those patients:

- Local HVH (2A) vs. local LVH (2B)
- Local HVH (2A) vs. different, non-local HVH (2C)
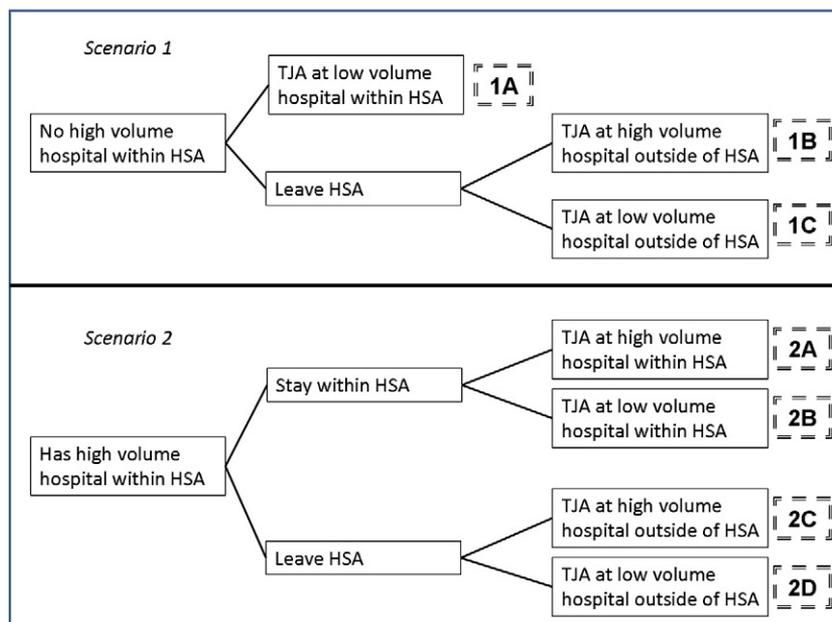- Local HVH (2A) vs. non-local LVH (2D)

Fig. 1. Scenarios and patterns of hospital utilization for total joint arthroplasty.

All eligible variables were included in the model. All analyses were performed using SAS 9.2 (Cary, NC). The current project was verified as exempt from further review by our institution under the categories of the data being publically available and not identifiably linked to individual patients.

Results

Among the 2,560,314 patients who underwent TJA during the study period, the median age was 69 years (interquartile range: 61, 76). The majority were between the ages of 50 and 75 years (66%), female (61%), and white (68%) (Table 1). Medicare was the most common insurance (61%), followed by private (32%), other insurance (4%), and Medicaid (3%). Among all patients, the most commonly-utilized types of hospitals for TJA were a local LVH (26% of all TJA) and a local HVH (22% of all TJA). In-hospital complications occurred in 9% of all cases, with orthopaedic complications being the most common (4% of all cases; 49% of complications) (Table 1).

Scenario 1 (No HVH Within HSA): Predictors of Hospital Utilization and Association With Complication Rates

Among the patients without a local HVH, 44% had surgery at a local LVH (Fig. 1; Pattern 1A), 33% had surgery at a non-local HVH (Pattern 1B), and 23% had surgery at a non-local LVH (Pattern 1C).

After adjusting for patient and community characteristics, the overall risk of complications was significantly lower (odds ratio 0.93, 95% confidence interval 0.92, 0.95) if patients underwent TJA at a non-local HVH compared to a local LVH (Table 2). This was particularly pronounced for orthopaedic complications (OR 0.73 [0.71, 0.75]). However, there was a significantly higher rate of PE/DVT (OR: 2.87 [2.75, 2.99]).

Compared to patients less than 50 years, older patients were less likely to undergo TJA at a non-local HVH (age 50–75: OR 0.82 [0.82, 0.83]; age >75: OR 0.71 [0.71, 0.72]) (Table 3). Women (OR 0.94 [0.94, 0.94]), black (OR 0.90 [0.89, 0.91]), and other nonwhite (OR 0.95 [0.95, 0.96]) patients were also less likely to utilize a non-local HVH. Patients with Medicare, Medicaid, and other insurances were less likely than those with private insurance to leave their HSA for an HVH (Table 3). Patients from communities with the highest percentage of college graduates were more likely to undergo TJA at an HVH outside of their HSA.

Compared to local LVH, patients who had surgery at a non-local LVH had an increased risk of overall complications (OR 1.05 [1.04, 1.06]), particularly infection (OR 1.15 [1.08, 1.23]), PE/DVT (OR 1.20 [1.15, 1.26]), and cardiovascular/cerebrovascular (OR 1.08 [1.05, 1.12]) complications (Table 2) after adjusting for patient and community characteristics.

Older patients were also less likely (age 50–75: OR 0.89 [0.88, 0.89]; age >75: OR 0.81 [0.80, 0.82]) to leave their HSA for TJA at an LVH. Female (OR 0.95 [0.95, 0.96]), black (OR 0.96 [0.95, 0.97]), and other nonwhite patients (OR 0.96 [0.95, 0.96]) (Table 3) were also less likely to pursue this pattern of care. Compared to privately insured patients, Medicare patients were less likely to leave their HSA for an LVH (OR 0.89 [0.88, 0.89]), but this effect was not seen for Medicaid patients.

Scenario 2 (HVH Within HSA): Predictors of Hospital Utilization and Association With Complication Rates

Among the patients with an HVH within their HSA, 54% had surgery at a local HVH (Fig. 1; Pattern 2A), 22% had surgery at a local LVH (Pattern 2B), 15% had surgery at a non-local HVH (Pattern 2C), and 9% had surgery at a non-local LVH (Pattern 2D).

After adjusting for patient and community characteristics, the risks of overall complications were higher if patients had surgery anywhere other than a local HVH. This risk was highest if TJA was performed at a non-local LVH (OR 1.28 [1.24, 1.30]) or at a local LVH (OR 1.18 [1.16,

Table 1
Patient Characteristics, Hospital Selection Patterns, and In-Hospital Complications After Total Joint Arthroplasty (Total Hip Arthroplasty and Total Knee Arthroplasty).

	Total Joint Arthroplasty (Total Hip Arthroplasty and Total Knee Arthroplasty) (n = 2,560,314)
Patient factors	
Age	
Mean age, years ± SD	68 ± 20
Median age, years (IQR)	69 (61,76)
Age group	
<50	186,800 (7%)
50–75	1,699,019 (66%)
>75	673,728 (26%)
Female, n (%)	1,558,153 (61%)
Race, **n** (%)	
White	1,733,000 (68%)
Black	103,506 (4%)
Other	618,692 (24%)
Unknown	105,116 (4%)
Insurance type, n (%)	
Medicare	1,566,630 (61%)
Medicaid	66,292 (3%)
Private	825,792 (32%)
Other	101,149 (4%)
Unknown	451 (0%)
Elixhauser comorbidities, n (%)	
Chronic pulmonary disease	275,872 (11%)
Diabetes without chronic complications	289,059 (11%)
Hypertension	1,237,012 (48%)
Hypothyroidism	249,928 (10%)
Rheumatoid arthritis/collagen vascular diseases	73,576 (3%)
Congestive heart failure	66,422 (3%)
Depression	106,610 (4%)
Valvular disease	93,330 (4%)
Community factors	
Education (% with college degree)	
Mean ± SD	26% ± 15%
Median (IQR)	22% (15%, 33%)
Poverty (% below federal poverty level)	
Mean ± SD	9% ± 6%
Median (IQR)	7% (5%, 11%)
Population density (persons per sq mile)	
Mean ± SD	4502 ± 10,910
Median (IQR)	1453 (250, 4361)
Regionalization pattern	
Scenario 1 (n, % of Scenario 1)	
LVH Within HSA (1A)	663,974 (44%)
HVH Outside of HSA (1B)	354,158 (33%)
LVH Outside of HSA (1C)	493,937 (23%)
Scenario 2 (n, % of Scenario 2)	
HVH Within HSA (2A)	566,836 (54%)
LVH Within HSA (2B)	226,944 (22%)
HVH Outside of HSA (2C)	155,710 (15%)
LVH Outside of HSA (2D)	98,755 (9%)
Inhospital complications, n (% of all patients)	
Overall complication	225,654 (9%)
Infection	8038 (0.3%)
Orthopaedic	109,849 (4%)
Cardiovascular and cerebrovascular	32,114 (1%)
Pulmonary embolism/Deep venous thrombosis	21,965 (0.9%)
Other Medical Complications	88,191 (3%)

SD = standard deviation; IQR = interquartile range; LVH = low volume hospital; HVH = high volume hospital; HSA = hospital service area.

1.20]) (Table 4). There was also a slightly elevated risk if patients had TJA at a different, non-local HVH (OR 1.02 [1.00, 1.05]). When compared to the option of TJA at a local HVH, there were significant increases in risk for orthopaedic complications at a local LVH (OR 1.38 [1.35, 1.42]) and non-local LVH (OR 1.53 [1.48, 1.58]). The risk of DVT/PE was significantly higher in patients who had surgery at a non-local HVH (OR 1.31 [1.23, 1.39]) but lower in patients who had surgery at either type of LVH.

Table 2
Risk of Complications in Scenario 1 (No High Volume Hospital Located Within Hospital Service Area).

Complication	All Patients Without an HVH Within Their HSA (n = 1,511,360) # (%)	HVH Outside of HSA vs LVH Within HSA Odds Ratio (95% CI)[a]	LVH Outside of HSA vs LVH Within HSA Odds Ratio (95% CI)[a]
Overall Complications[c]	144,578 (9.6%)	0.93 (0.92, 0.95)[b]	1.05 (1.04, 1.06)[b]
Infection	5142 (0.3%)	1.09 (1.02, 1.18)[b]	1.15 (1.08, 1.23)[b]
Orthopaedic Complication	71,874 (4.8%)	0.73 (0.71, 0.75)[b]	1.04 (1.02, 1.06)[b]
Cardiovascular and Cerebrovascular Complications	20,048 (1.3%)	1.02 (0.98, 1.06)	1.08 (1.05, 1.12)[b]
Pulmonary Embolism and Deep Venous Thrombosis	14,121 (0.9%)	2.87 (2.75, 2.99)[b]	1.20 (1.15, 1.26)[b]
Other Medical Complication	55,669 (3.7%)	0.99 (0.97, 1.02)	1.02 (1.00, 1.04)

Abbreviations: HVH = high volume hospital; LVH = low volume hospital; HSA = Hospital Service Area; CI = confidence interval.
[a] Adjusted for patient characteristics (age, gender, race, insurance type, comorbidities), community characteristics (education, poverty, population density), and surgical site (hip or knee).
[b] Indicates statistical significance.
[c] Indicates number of patients who experienced at least one complication; subcategories of complications do not sum to overall number/percentage due to some patients having more than one complication.

There were also significantly increased risks of infection-related complications in patients treated at non-local LVH (OR 1.52 [1.35, 1.71]) and non-local HVH (OR 1.21 [1.09, 1.35]).

Within this scenario, black patients were more likely to undergo surgery at a local LVH (OR 1.15 [1.14, 1.17]) rather than a local HVH. Patients with Medicaid were more likely to undergo surgery at either a local LVH (OR 1.28 [1.27, 1.30]) or an LVH outside of their HSA (OR 1.33 [1.30, 1.36]) than to have surgery at a local HVH.

Discussion

Regionalization of elective surgery has been considered as a strategy to improve quality and maximize value. However, these selective referral patterns may have undesirable consequences in restricting access to care, particularly in vulnerable populations [7,12,19]. In the current study, we have demonstrated that certain hospital utilization patterns are associated with lower complication risks. Utilizing a local HVH (if available) or traveling to a non-local HVH (if one is not available locally) is the ideal pattern of care given the increased risk of complications seen with all other patterns. However, patients from vulnerable groups (particularly Medicaid and black patients) are less likely to have access to these high volume institutions. These findings corroborate those from previous authors [7,12,19], but expand upon them by including a diverse group of patients across a spectrum of age and payer mix across 14 states. Lower complication rates indicate better quality of care and provide improved value to payers [23], but policies promoting regionalization should be carefully balanced against the risks of excluding vulnerable patients.

Existing patient-driven patterns in care delivery hold important lessons for proposed regionalization strategies. Our results indicate that patients from disadvantaged socioeconomic backgrounds are already less likely to utilize preferred hospitals for TJA. Future regionalization policies should include provisions to ensure that these vulnerable populations are not left behind, particularly because these patients are already known to be at increased risk for complications after TJA [24]. Investigations into existing health care disparities indicate that patient beliefs and attitudes towards TJA contribute greatly to underutilization [25–27]. Policy that overlooks, rather than addressing, these patient-centered characteristics is contrary to recent emphasis on shared decision-making [28] and may exacerbate disparities, as patients may utilize low volume centers (if available) [29] or may continue nonoperative treatment [9].

Policies to improve quality and value of TJA delivery should be market-specific, paying particular attention to strategic utilization of existing resources within each community [9]. While selective referral to HVH may be suitable in areas where LVH are sparsely utilized, communities without a nearby HVH may be better served by implementing pathways that maximize adherence to [30] and standardization of [31] process-of-care measures within the local LVH. When patients travel for care, the risks of undergoing surgery at hospitals far from the patient's residence should be further investigated to determine prudent regionalization strategy. In the interim, a combination of policies that encourage appropriate use of selective referral, address barriers in access to care, and incorporate process improvement measures is needed to provide optimal value to patients, providers, and other stakeholders.

Despite its findings and their potential implications, our study carries limitations. We are limited to reporting of in-hospital complications. Additional data after discharge would provide further insight into the influence of hospital utilization on outcomes after TJA. This limitation has likely resulted in a relatively conservative underestimate of complications after TJA. Additionally, our use of administrative data relies on consistent and accurate entry of complication codes. Inconsistent reporting would have an uncertain effect on our findings regarding the risks associated with hospital utilization patterns. However, our analysis adds to the literature by demonstrating the negative effects of less desirable regionalization patterns, rather than implying these consequences [12,19]. Our analysis is also prone to variations in practice at each institution. The elevated risk of DVT/PE seen at HVH may be partially explained by surveillance bias: more aggressive diagnostic testing may be used at HVH, particularly if patients travel long distances after discharge. Elevated rates of DVT diagnosis at institutions with routine screening have been demonstrated in trauma centers [32]. For example, our institution previously conducted routine postoperative ultrasounds, which led to the diagnosis and coding of many clinically insignificant thromboses. In data used for this investigation, there is a disproportionate frequency of DVT/PE (19.9%) at our institution relative to our surgical volume (1.9% of the total study cohort). Sensitivity analysis with removal of our institution shows a substantial change in the odds ratios for DVT/PE from 2.87 (CI: 2.75, 2.99) to 1.46 (CI: 1.39, 1.54) in patients who travel to an HVH compared to those who have surgery at a local LVH. There is still an elevated risk of DVT/PE, but this may be attributable to increased travel time to our referral center.

Another potential limitation is the use of the location of a hospital within the patient's HSA as the definition of a local facility. This designation has been previously used in assessing small area variations in surgical resource availability [33], but may not be the most appropriate way to determine the feasibility of accessing a facility. Using HSAs also provides greater specificity to the analysis compared to larger hospital referral regions, which have been applied to previous orthopaedic health services research [34–37].

Our approach allows us to evaluate the implications of future regionalization policies through the lens of the hospitals potentially available

Table 3
Characteristics Influencing Patterns of Hospital Selection for TJA.

	Scenario 1: No HVH Within HSA				Scenario 2: HVH Within HSA					
	HVH Outside of HSA vs LVH Within HSA		LVH Outside of HSA vs LVH Within HSA		LVH Within HSA vs HVH Within HSA		HVH Outside of HSA vs HVH Within HSA		LVH Outside of HSA vs HVH Within HSA	
	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value	OR (95% CI)	P value
Patient characteristics										
Age										
50–75 vs. <50	0.82 (0.82, 0.83)	<0.001	0.89 (0.88, 0.89)	<0.001	1.01 (1.00, 1.03)	0.005	0.91 (0.90, 0.92)	<0.001	0.93 (0.92, 0.95)	<0.001
>75 vs. <50	0.71 (0.71, 0.72)	<0.001	0.81 (0.80, 0.82)	<0.001	1.00 (0.99, 1.01)	0.968	0.83 (0.82, 0.84)	<0.001	0.88 (0.87, 0.90)	<0.001
Female, n (%)	0.94 (0.94, 0.94)	<0.001	0.95 (0.95, 0.96)	<0.001	1.00 (1.00, 1.01)	0.151	0.93 (0.92, 0.93)	<0.001	0.97 (0.96, 0.97)	<0.001
Race, n (%)										
Black vs. White	0.90 (0.89, 0.91)	<0.001	0.96 (0.95, 0.97)	<0.001	1.15 (1.14, 1.17)	<0.001	0.87 (0.85, 0.88)	<0.001	1.05 (1.04, 1.07)	<0.001
Other vs. White	0.95 (0.95, 0.96)	<0.001	0.96 (0.95, 0.96)	<0.001	1.05 (1.04, 1.06)	<0.001	0.84 (0.83, 0.84)	<0.001	1.04 (1.03, 1.04)	<0.001
Insurance type, n (%)										
Medicare vs. Private	0.80 (0.79, 0.80)	<0.001	0.89 (0.88, 0.89)	<0.001	1.01 (1.00, 1.02)	<0.001	0.94 (0.93, 0.95)	<0.001	0.91 (0.91, 0.92)	<0.001
Medicaid vs. Private	0.77 (0.75, 0.78)	<0.001	1.00 (0.99, 1.01)	0.876	1.28 (1.27, 1.30)	<0.001	0.94 (0.92, 0.96)	<0.001	1.33 (1.30, 1.36)	<0.001
Other vs. Private	0.88 (0.87, 0.89)	<0.001	1.10 (1.09, 1.12)	<0.001	1.17 (1.15, 1.18)	<0.001	0.98 (0.97, 1.00)	0.045	1.24 (1.22, 1.26)	<0.001
Elixhauser comorbidities, n (%)										
Chronic pulmonary disease	0.96 (0.95, 0.96)	<0.001	0.95 (0.95, 0.96)	<0.001	0.98 (0.97, 0.99)	<0.001	0.96 (0.95, 0.97)	<0.001	0.97 (0.96, 0.98)	<0.001
Diabetes w/o chronic complications	0.97 (0.96, 0.97)	<0.001	0.98 (0.97, 0.98)	<0.001	1.00 (1.00, 1.01)	0.288	0.96 (0.95, 0.97)	<0.001	0.99 (0.98, 1.00)	0.190
Hypertension	1.11 (1.10, 1.11)	<0.001	1.00 (1.00, 1.00)	0.793	0.92 (0.92, 0.93)	<0.001	0.99 (0.98, 0.99)	<0.001	0.94 (0.93, 0.95)	<0.001
Hypothyroidism	1.12 (1.11, 1.12)	<0.001	1.00 (0.99, 1.00)	0.493	0.92 (0.91, 0.92)	<0.001	1.02 (1.01, 1.03)	<0.001	0.92 (0.91, 0.93)	<0.001
Rheumatoid arthritis/collagen vascular diseases	1.07 (1.05, 1.08)	<0.001	1.02 (1.01, 1.03)	0.002	0.94 (0.93, 0.96)	<0.001	0.99 (0.98, 1.01)	0.529	0.93 (0.91, 0.95)	<0.001
Congestive heart failure	0.90 (0.89, 0.91)	<0.001	0.95 (0.94, 0.96)	<0.001	1.06 (1.04, 1.07)	<0.001	0.92 (0.90, 0.93)	<0.001	1.01 (0.99, 1.03)	0.395
Depression	1.23 (1.22, 1.25)	<0.001	0.97 (0.96, 0.98)	<0.001	0.84 (0.83, 0.85)	<0.001	1.00 (0.99, 1.01)	0.931	0.85 (0.83, 0.86)	<0.001
Valvular disease	1.21 (1.19, 1.22)	<0.001	1.00 (0.99, 1.01)	0.568	0.87 (0.86, 0.88)	<0.001	1.12 (1.10, 1.13)	<0.001	0.91 (0.90, 0.93)	<0.001
Community characteristics										
Education (%)										
25th–50th vs. 0–25th percentile	0.97 (0.96, 0.98)	<0.001	0.88 (0.87, 0.88)	<0.001	0.92 (0.92, 0.93)	<0.001	0.86 (0.85, 0.86)	<0.001	0.87 (0.86, 0.88)	<0.001
50th–75th vs. 0–25th percentile	1.01 (1.00, 1.02)	0.016	0.89 (0.88, 0.89)	<0.001	0.86 (0.85, 0.87)	<0.001	0.85 (0.84, 0.86)	<0.001	0.89 (0.88, 0.90)	<0.001
75th–100th vs. 0–25th percentile	1.15 (1.14, 1.15)	<0.001	0.89 (0.88, 0.90)	<0.001	0.84 (0.83, 0.85)	<0.001	0.78 (0.77, 0.79)	<0.001	0.80 (0.79, 0.81)	<0.001
Poverty (%)										
25th–50th vs. 0–25th percentile	0.87 (0.87, 0.88)	<0.001	0.93 (0.92, 0.93)	<0.001	0.92 (0.92, 0.93)	<0.001	1.03 (1.02, 1.03)	<0.001	0.97 (0.96, 0.98)	<0.001
50th–75th vs. 0–25th percentile	0.86 (0.85, 0.86)	<0.001	0.88 (0.88, 0.89)	<0.001	1.00 (0.99, 1.01)	0.548	0.93 (0.92, 0.94)	<0.001	0.87 (0.86, 0.88)	<0.001
75th–100th vs. 0–25th percentile	0.86 (0.86, 0.87)	<0.001	0.87 (0.87, 0.88)	<0.001	1.06 (1.05, 1.07)	<0.001	0.84 (0.83, 0.85)	<0.001	0.87 (0.86, 0.88)	<0.001
Population density (**persons per sq mile**)										
25th–50th vs. 0–25th percentile	0.78 (0.78, 0.79)	<0.001	0.81 (0.80, 0.81)	<0.001	1.01 (1.00, 1.02)	0.086	1.14 (1.13, 1.15)	<0.001	0.91 (0.90, 0.92)	<0.001
50th–75th vs. 0–25th percentile	0.86 (0.85, 0.86)	<0.001	0.93 (0.92, 0.94)	<0.001	1.20 (1.19, 1.21)	<0.001	1.11 (1.10, 1.12)	<0.001	1.00 (0.99, 1.01)	0.649
75th–100th vs. 0–25th percentile	1.09 (1.09, 1.10)	<0.001	1.10 (1.09, 1.11)	<0.001	1.53 (1.52, 1.55)	<0.001	1.21 (1.19, 1.22)	<0.001	1.23 (1.22, 1.25)	<0.001

Abbreviations: HVH = high volume hospital; LVH = low volume hospital; HSA = Hospital Service Area; CI = confidence interval.

to patients. For patients considering TJA and have a local HVH available, undergoing surgery at the local HVH is ideal given the increased risk of complications seen with all other patterns of care. Traveling to an HVH is advised for those patients without one in their HSA. However, patients from vulnerable groups are less likely to have access to these optimal patterns. Future regionalization policies must balance the volume-related benefits against the risks of excluding vulnerable patients.

Table 4
Risk of Complications in Scenario 2 (High Volume Hospital Located Within Hospital Service Area).

Complication	All Patients With an HVH Within Their HSA (n = 1,048,088) # (%)	LVH Within HSA vs HVH Within HSA Odds Ratio (95% CI)[a]	LVH Outside of HSA vs HVH Within HSA Odds Ratio (95% CI)[a]	HVH Outside of HSA vs HVH Within HSA Odds Ratio (95% CI)[a]
Overall Complications[c]	80,955 (7.7%)	1.18 (1.16, 1.20)[b]	1.28 (1.24, 1.31)[b]	1.02 (1.00, 1.05)[b]
Infection	2894 (0.3%)	1.23 (1.12, 1.36)[b]	1.52 (1.35, 1.71)[b]	1.21 (1.09, 1.35)[b]
Orthopaedic Complication	37,887 (3.6%)	1.38 (1.35, 1.42)[b]	1.53 (1.48, 1.58)[b]	1.08 (1.05, 1.12)[b]
Cardiovascular and Cerebrovascular Complications	12,059 (1.2%)	1.02 (0.97, 1.07)	1.07 (1.01, 1.14)[b]	1.02 (0.97, 1.08)
Pulmonary Embolism and Deep Venous Thrombosis	7832 (0.7%)	0.85 (0.80, 0.90)[b]	0.90 (0.83, 0.98)[b]	1.31 (1.23, 1.39)[b]
Other Medical Complication	32,494 (3.1%)	1.02 (0.99, 1.05)	1.06 (1.02, 1.10)[b]	0.89 (0.86, 0.92)[b]

Abbreviations: HVH = high volume hospital; LVH = low volume hospital; HSA = Hospital Service Area; CI = confidence interval.
[a] Adjusted for patient factors (age, gender, race, insurance type, comorbidities), community factors (education, poverty, population density), and surgical site (hip or knee).
[b] Indicates statistical significance.
[c] Indicates number of patients who experienced at least one complication; subcategories of complications do not sum to overall number/percentage due to some patients having more than one complication.

Appendix A. Categorization of in-hospital complications.

Orthopaedic Complications	Cardiovascular and Thromboembolic Complications	Pulmonary Embolism and Deep Venous Thrombosis	Infectious Complications	Other Complications
Fractures (Hip: ICD9 820, 821.0, 821.1; Knee ICD9 821.2, 821.3, 822, 823, 827) Dislocations (Hip: ICD9 718.2, 718.3, 835; Knee: 718.2, 718.3, 836) Other complications of procedure (ICD9 998) Complications of medical care (ICD9 999) Mechanical complication of internal orthopedic device (ICD9 996.4)	Acute myocardial infarction (ICD9 410.0–410.91) Cardiac complications (ICD9 997.1) Cerebrovascualar events (ICD9 434.01, 434.11, 434.91, 997.02) Peripheral vascular complications (ICD9 997.2)	Pulmonary embolism (ICD9 415.1–415.19) Deep venous thrombosis (ICD9 451.1–451.9, 453.0, 453.2–453.9),	Infection and inflammatory reaction due to internal prosthetic device implant and graft (996.60, 996.66, 996.67, 996.69) Postoperative Wound Infection (998.3, 998.6, 998.5, and 998.83)	Complications affecting specified body systems (ICD9 997; excluding 997.1 and 997.2).

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