

ASSOCIATION BETWEEN HOSPITAL AND SURGEON PROCEDURE VOLUME AND THE OUTCOMES OF TOTAL KNEE REPLACEMENT

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Background: The annual volume of major cardiovascular and oncologic procedures performed in hospitals and by surgeons has been inversely associated with the rates of perioperative mortality and complications. The relationship between hospital and surgeon volume and perioperative outcomes following total knee replacement has received little study.

Methods: We analyzed claims data for Medicare patients who had elective primary total knee replacement between January 1 and August 31, 2000. Hospital and surgeon volumes were defined as the number of primary and revision total knee replacements performed in the hospital or by the surgeon in Medicare recipients in 2000. We examined the associations between the annual volumes of total knee replacement performed in the hospitals and by the surgeons and the rates of mortality and complications (infection, pulmonary embolus, myocardial infarction, or pneumonia) in the first ninety days postoperatively. The analyses were adjusted for age, gender, comorbid conditions, Medicaid eligibility (a marker of low income), and arthritis diagnosis. Analyses of hospital volume were adjusted for surgeon volume and vice versa.

Results: Twenty-five percent of the primary total knee replacements were done by surgeons who performed twelve of these procedures or fewer in the Medicare population annually, and 11% were done in hospitals with an annual volume of twenty-five of these procedures or fewer. Compared with the patients who had a primary total knee replacement in hospitals with an annual volume of twenty-five procedures or fewer, those managed in hospitals with an annual volume exceeding 200 procedures had a lower risk of pneumonia (odds ratio, 0.65; 99% confidence interval, 0.47 to 0.90) and any of the adverse outcomes examined (death, pneumonia, pulmonary embolus, acute myocardial infarction, or deep infection) (odds ratio, 0.74; 99% confidence interval, 0.60 to 0.90). Similarly, patients who had a primary total knee replacement done by surgeons who performed more than fifty such procedures in Medicare recipients annually had a lower risk of pneumonia (odds ratio, 0.72; 99% confidence interval, 0.54 to 0.95) and any adverse outcome (odds ratio, 0.81; 99% confidence interval, 0.68 to 0.98) compared with patients of surgeons with an annual volume of twelve procedures or fewer.

Conclusions: Patients managed at hospitals and by surgeons with greater volumes of total knee replacement have lower risks of perioperative adverse events following primary total knee replacement. Patients and clinicians should incorporate these findings into discussions about selecting a surgeon and a hospital for total knee replacement. These data should also be integrated into the policy debate about the advantages and drawbacks of regionalizing total joint replacement to high-volume centers.

Level of Evidence: Prognostic study, Level II-1 (retrospective study). See Instructions to Authors for a complete description of levels of evidence.

Total knee replacement, a remarkably effective treatment for advanced knee arthritis, is performed on more than 280,000 persons annually in the United States¹. More than 90% of the patients who undergo this procedure have relief of pain and improvement in function^{2,3}. The prostheses generally function well, with a revision rate of <10% after ten years and <20% after fifteen years⁴. Current research on total knee replacement has focused largely on improving the technology in order to optimize performance and minimize component wear and failure. Less attention has been given to improvement of the delivery of care in order to optimize patient outcomes with the currently available technology. One such strategy would be to steer surgical candidates toward hospitals and surgeons with particularly favorable results. Indeed, pilot projects to regionalize total knee and hip replacement to select centers are already underway in the United States Medicare program⁵.

While there is no widespread agreement about what constitutes a high-quality center, hospital procedure volume has been consistently associated inversely with perioperative mortality and complications across a range of cardiac, vascular, and oncologic surgeries^{6,7}. Patients managed by surgeons and at hospitals with a higher volume of total hip replacements have lower rates of perioperative mortality and complications following elective primary and revision total hip replacement in the United States Medicare population⁸.

A few studies have suggested that low-volume centers are associated with higher rates of mortality and complications following total knee replacement^{9,11}. However, interpretation of these investigations is constrained by important limitations such as the failure to adjust for relevant patient and hospital characteristics⁹, an inability to consider adverse events other than mortality⁹ or a lack of power to analyze such events¹¹, the failure to capture events occurring beyond the brief inpatient admission period^{10,11}, and the failure to account for the role of surgeon volume^{9,10}. The objective of this study was to examine the association between hospital and surgeon procedure volume on mortality and a range of complications in the ninety days following total knee replacement, adjusting for important patient and hospital characteristics.

Materials and Methods

Data Sources and Patient Sample

The present study used Medicare claims submitted by hospitals (Medicare Part A) and by surgeons (Medicare Part B) for services occurring between January 1 and August 31, 2000, throughout the United States. We did not analyze total knee replacements performed after August 31, to permit at least three months of follow-up for each patient. The claims contain unique identification numbers for hospitals, surgeons, and patients, permitting analysis of the effect of hospital and surgeon characteristics on patient outcomes. The claims also

TABLE I Baseline Characteristics of 80,904 Medicare Beneficiaries Treated with Primary Total Knee Replacement from January 1 Through August 31, 2000

Baseline Characteristics	No. (%) of Patients
Male	26,671 (33)
White	74,352 (92)
>1 comorbid condition	10,653 (13)
Age of >75 years	33,510 (41)
Diagnosis	
Osteoarthritis	76,351 (94)
Rheumatoid arthritis	3050 (4)
Other	1503 (2)
Medicaid eligible	6835 (8)

contain procedure and diagnosis codes, permitting identification of specific procedures and outcome events. Additional hospital characteristics were obtained from the *2000 Annual Hospital Survey* of the American Hospital Association¹².

Cases of primary total knee replacement were identified by searching for claims with International Classification of Diseases, Ninth Revision, Clinical Modification¹³ (ICD-9-CM) code 81.54 or Current Procedural Terminology¹⁴ (CPT) code 27447. We excluded patients with codes indicating pre-existing infection of the knee, metastatic cancer, or bone cancer. We also excluded patients enrolled in health maintenance organizations (because health maintenance organizations do not routinely file claims since their payment is capitated), those not enrolled in both parts of Medicare, those less than sixty-five years old, and those who were not residents of the United States. Finally, to increase homogeneity of the patient sample, we excluded patients who had a bilateral total knee replacement during the same hospitalization. Fifteen percent of the subjects were excluded altogether, primarily because of bilateral total knee replacement during the same hospitalization, as well as the unavailability of both hospital and surgeon claims.

Data Elements

Patient Outcomes

The five outcomes we studied were death, acute myocardial infarction, deep wound infection at the knee (requiring surgical débridement or removal of the prosthesis), pneumonia requiring hospitalization, and pulmonary embolus. We examined all such outcomes occurring within ninety days of admission for total knee replacement. Pulmonary embolus was defined by a hospital ICD-9-CM code of 415.1-415.19. Deep wound infection was defined as a hospital admission, with codes for the diagnosis of infection and for an appropriate surgical procedure such as removal of the implant or arthrotomy. Acute myocardial infarction and pneumonia were defined with use of ICD-9-CM codes from



TABLE II Select Outcomes of 80,904 Primary Total Knee Replacements in Medicare Beneficiaries Treated from January 1 Through August 31, 2000

Outcome (≤90 Days Postop.)	No. (%) of Patients
Death	508 (0.6)
Acute myocardial infarction	646 (0.8)
Deep infection	297 (0.4)
Pneumonia	1098 (1.4)
Pulmonary embolus	638 (0.8)

hospital claims, with algorithms developed and validated by the Agency for Healthcare Research and Quality¹.

Sociodemographic and Clinical Variables

Medicare claims and demographic files provided information regarding age, gender, race (white, black, or other/unknown), Medicaid eligibility (an indicator for low income), arthritis diagnosis (osteoarthritis, rheumatoid arthritis, osteonecrosis, or other), and comorbidity. The latter was calculated with an adaptation of the Charlson comorbidity index¹⁵. Acute conditions (e.g., pulmonary embolus, myocardial infarction, or pneumonia) were counted as complications if they were listed only on the index total knee replacement admission. If they were listed on a previous admission, they were considered comorbidities. Chronic conditions such as diabetes were counted as comorbidities whether they were noted on the index admission or an earlier admission.

Hospital and Surgeon Variables

Hospital and surgeon volume were calculated as the number of primary and revision total knee replacements in the Medicare population that were performed at the institution or by the surgeon during the calendar year 2000.

We also examined the influence on outcome of the number of years since the surgeon graduated from medical school, an urban compared with a rural location of the hospital, the

ratio of nurses to discharges, and the teaching status and the ownership status of the hospital (for-profit, nonprofit, or public).

Analyses

The primary outcome variables were dichotomous indicators of whether the patient experienced the outcomes of interest within ninety days after total knee replacement. We examined each of the five outcomes (death, myocardial infarction, hospitalization for pneumonia, pulmonary embolus, and deep infection) separately. We also examined aggregations of outcomes, including *any* medical event (myocardial infarction, hospitalized pneumonia, or pulmonary embolus), and *any* event (the medical events, deep infection, or death). The principal predictor variables were the hospital and surgeon volume indicators. We assessed associations between volume and these outcomes in multiple logistic regression analyses. Covariates in each model included age (a categorical variable composed of five-year strata), gender, Charlson comorbidity index (more than one versus no or one comorbid condition), Medicaid eligibility (yes versus no), and arthritis diagnosis (osteoarthritis, rheumatoid arthritis, or other).

We examined associations between volume and outcome in two ways, addressing two a priori hypothesized types of associations between volume and outcome. First, we conducted tests for trend, using an ordinal volume indicator to assess for trends in logistic regression analyses. These analyses tested whether the risks of complications declined steadily, in a linear fashion. Then, we calculated adjusted odds ratios (with 99% confidence intervals) for the outcome within each volume stratum compared with the lowest volume stratum as the reference category. These analyses permitted us to inspect the odds ratios visually for threshold effects—that is, when the risk of the complication appears to decrease abruptly at a specific volume cut-off.

In all of these multivariate analyses, we used ordinal volume variables to adjust the hospital volume analyses for surgeon volume and vice versa. We adjusted variances of parameter estimates for clustering of patients within hospitals by using generalized estimating equations (Proc Genmod; SAS

TABLE III Distribution, According to Hospital and Surgeon Procedure Volumes, of 78,745 Primary Total Knee Replacements Performed in Medicare Beneficiaries from January 1 Through August 31, 2000*

Annual Hospital Volume	Annual Surgeon Volume				Total
	1-12	13-25	26-50	>50	
1-25	6.3%	3.6%	1.0%	0.2%	11.0%
26-100	11.9%	14.0%	11.6%	3.4%	40.9%
101-200	4.7%	6.8%	9.1%	8.0%	28.6%
>200	2.1%	3.6%	3.9%	10.1%	19.6%
Total	24.9%	27.9%	25.5%	21.7%	100.0%

*The sample size is smaller than that in Table I (n = 80,904) because data on surgeon volume were missing for about 2% of the cases.

TABLE IV Associations Between Hospital and Surgeon Annual Procedure Volume and Select Adverse Events Occurring Within Ninety Days Postoperatively Among 80,904 Medicare Beneficiaries Who Had a Primary Total Knee Replacement Between January 1 and August 31, 2000

Outcome	Hospital			
	Annual Procedure Volume	Percentage of Patients with Outcome	Adjusted Odds Ratio* (99% Confidence Interval)	P Value for Trend
Death	1-25	0.92	1.00	0.189
	26-100	0.58	0.67 (0.47, 0.95)	
	101-200	0.62	0.73 (0.49, 1.08)	
	>200	0.58	0.69 (0.45, 1.05)	
Acute myocardial infarction	1-25	0.95	1.00	0.454
	26-100	0.78	0.86 (0.62, 1.21)	
	101-200	0.84	0.96 (0.66, 1.37)	
	>200	0.70	0.79 (0.52, 1.20)	
Pulmonary embolus	1-25	0.88	1.00	0.372
	26-100	0.81	0.95 (0.67, 1.33)	
	101-200	0.75	0.86 (0.58, 1.28)	
	>200	0.75	0.88 (0.57, 1.36)	
Pneumonia	1-25	1.93	1.00	<0.001
	26-100	1.46	0.80 (0.62, 1.03)	
	101-200	1.18	0.71 (0.53, 0.96)	
	>200	1.06	0.65 (0.47, 0.90)	
Deep infection	1-25	0.55	1.00	0.075
	26-100	0.39	0.80 (0.50, 1.28)	
	101-200	0.36	0.84 (0.49, 1.43)	
	>200	0.23	0.61 (0.33, 1.16)	
Pneumonia, pulmonary embolus, or acute myocardial infarction	1-25	3.5	1.00	0.004
	26-100	2.8	0.85 (0.71, 1.02)	
	101-200	2.6	0.82 (0.67, 1.01)	
	>200	2.4	0.75 (0.60, 0.94)	
Pneumonia, pulmonary embolus, acute myocardial infarction, infection, or death	1-25	4.6	1.00	<0.001
	26-100	3.6	0.83 (0.71, 0.98)	
	101-200	3.4	0.82 (0.68, 0.99)	
	>200	3.0	0.74 (0.60, 0.90)	

*Odds ratios are adjusted for gender, age, comorbidity, Medicaid eligibility, and arthritis diagnosis. Also, odds ratios for hospital volume are adjusted for surgeon volume, and odds ratios for surgeon volume are adjusted for hospital volume.

Institute, Cary, North Carolina). To account for multiple end points in the tests for trend, we used 0.01 as the critical p value for significance (0.05 divided by five distinct clinical outcomes). We used 99% confidence intervals to characterize the precision of the estimates of odds ratios.

Results

Patient Characteristics

A total of 80,904 patients who met our entry criteria underwent primary total knee replacement between January 1 and August 31, 2000 (Table I).

Patient Outcomes

In the first ninety days following primary total knee replacement, 0.6% of the patients died, 0.8% had an acute myocardial infarction, 0.8% had a pulmonary embolus, 0.4% had a deep wound infection, and 1.4% were hospitalized for pneumonia (Table II).

Hospital and Surgeon Volume

Eleven percent of the primary total knee replacements were performed in hospitals in which twenty-five of these procedures or fewer were carried out annually in the Medicare population (Table III); one-fifth were performed in hospitals with

TABLE IV (continued)

Surgeon			
Annual Procedure Volume	Percentage of Patients with Outcome	Adjusted Odds Ratio* (99% Confidence Interval)	P Value for Trend
1-12	0.67	1.00	0.782
13-25	0.65	1.00 (0.72-1.38)	
26-50	0.60	0.94 (0.67-1.33)	
>50	0.58	0.97 (0.66-1.43)	
1-12	0.80	1.00	0.426
13-25	0.87	1.11 (0.83-1.47)	
26-50	0.81	1.03 (0.76-1.40)	
>50	0.69	0.90 (0.64-1.28)	
1-12	0.76	1.00	0.688
13-25	0.84	1.14 (0.85-1.53)	
26-50	0.79	1.10 (0.81-1.50)	
>50	0.74	1.06 (0.73-1.54)	
1-12	1.68	1.00	0.002
13-25	1.41	0.87 (0.70-1.08)	
26-50	1.26	0.82 (0.64-1.04)	
>50	1.02	0.72 (0.54-0.95)	
1-12	0.55	1.00	0.006
13-25	0.32	0.61 (0.41-0.91)	
26-50	0.29	0.57 (0.37-0.89)	
>50	0.29	0.62 (0.37-1.06)	
1-12	3.1	1.00	0.023
13-25	2.9	0.98 (0.84-1.15)	
26-50	2.7	0.92 (0.78-1.09)	
>50	2.3	0.84 (0.68-1.03)	
1-12	4.0	1.00	0.003
13-25	3.6	0.93 (0.81-1.07)	
26-50	3.4	0.88 (0.76-1.02)	
>50	2.9	0.81 (0.68-0.98)	

an annual volume exceeding 200 such cases per year. One-quarter of the primary total knee replacements were done by surgeons who performed twelve total knee replacements or fewer annually in Medicare patients, and 22% were performed by surgeons with an annual volume of more than fifty Medicare patients.

Association Between Procedure Volume and Outcome of Primary Total Knee Replacement

The mortality rate for patients who had a primary total knee replacement in hospitals in which more than twenty-five total

knee replacements were carried out annually in the Medicare population was about 30% lower than that for patients who had the procedure in hospitals in which between one and twenty-five total knee replacements were performed in the Medicare population per year (Table IV). The test for linear trend in mortality across volume strata was not significant, as the risk did not diminish continuously but rather exhibited a threshold effect. The risks of myocardial infarction and pulmonary embolus were also higher among patients who had the procedure in lower-volume hospitals, but these trends also did not achieve significance.

The pneumonia risk among patients who had the procedure in the highest-volume hospitals (1.06%) was lower than that among patients in the lowest-volume hospitals (1.93%) (adjusted odds ratio, 0.65; 99% confidence interval, 0.47 to 0.90). The risk of pneumonia declined steadily over increasingly higher-volume strata (p value for trend <0.001). The risk of deep infection also declined steadily with hospital volume (p value for trend = 0.08). Patients who had the procedure in hospitals with a higher volume had lower risks for any medical complication (myocardial infarction, pneumonia, or pulmonary embolus; p value for trend = 0.004) and for any complication (p value for trend <0.001). For both of these composite end points, patients who had the procedure in the highest-volume hospitals had about 25% lower rates of adverse outcomes than did patients in the lowest-volume centers. For any complication, the odds ratio was 0.74 (99% confidence interval, 0.60 to 0.90).

Surgeon volume was not associated with the risk of mortality, acute myocardial infarction, or pulmonary embolus following primary total knee replacement in analyses adjusted for hospital volume and other patient covariates (Table IV). However, the risk of pneumonia diminished steadily across higher-volume strata for surgeons (p value for trend = 0.002). The risk of pneumonia was 1.02% among patients who had the operation done by a surgeon who performed more than fifty total knee replacements in the Medicare population per year compared with 1.68% among patients of surgeons who performed twelve such procedures or fewer per year (adjusted odds ratio, 0.72; 99% confidence interval, 0.54 to 0.95). There was a significant trend for lower infection rates among patients of higher-volume surgeons ($p = 0.006$). Patients managed by surgeons who performed more than fifty procedures per year also had a 40% lower rate of deep wound infection than did patients managed by the lowest-volume surgeons (odds ratio, 0.62; 99% confidence interval, 0.37 to 1.06). Patients managed by the highest-volume surgeons had a lower rate of any medical complication than did those managed by the lowest-volume surgeons (2.9% compared with 4.0%; odds ratio, 0.81; 99% confidence interval, 0.68 to 0.98; p value for trend = 0.003).

Other Hospital and Surgeon Factors

There were no consistent associations between the outcomes examined and the hospital's teaching status, ownership status, rural or urban location, the ratio of nurses to discharges, or to the years since the surgeon had graduated from medical school.

Discussion

We used Medicare claims data to examine the association between hospital and surgeon procedure volume of total knee replacement and the perioperative outcomes of these procedures among Medicare recipients undergoing elective primary total knee replacement in 2000. We found that centers with an annual volume of 200 procedures or greater in the Medicare population perform just 20% of all primary total

knee replacements. Thus, while most of what we know about total knee replacement is reported by high-volume centers, relatively few knee replacements are performed in such centers in the United States. Our data also demonstrate that total knee replacement is a relatively low-risk surgical procedure in terms of the ninety-day rates of death, acute myocardial infarction, pneumonia prompting hospitalization, pulmonary embolus, and deep wound infection.

Our analyses of volume and outcome show that patients receiving primary total knee replacement in higher-volume hospitals generally have lower rates of mortality, pneumonia, and deep knee infection than do patients managed in lower-volume hospitals. For some complications, such as pneumonia, the risk declined steadily across volume strata. For other rates, such as mortality, there appeared to be a threshold effect: the patients managed in hospitals in which twenty-five or fewer primary total knee replacements were performed per year in the Medicare population had a higher rate of mortality, whereas patients managed in hospitals in which more than twenty-five procedures were performed per year had a reduced rate. Similarly, patients of surgeons who performed more than twelve procedures per year had a significantly lower rate of deep wound infection following primary total knee replacement than did patients of surgeons who performed twelve procedures or fewer per year ($p = 0.006$).

Hospital and surgeon procedure volumes exerted somewhat different effects on outcomes. Mortality was found to be associated with hospital volume but not with surgeon volume, whereas pneumonia and deep infection were found to be associated independently with both surgeon and hospital volume. These observations suggest that the rate of mortality may reflect hospital factors such as the quality and intensity of anesthesia care, nursing, and other services. Deep infection and pneumonia, on the other hand, may arise both from hospital factors and from processes largely under the surgeon's control, such as the surgical technique and the duration of the procedure. The specific mechanisms that link volume and outcomes should be examined in further research. It is of note that we recently documented that hospital characteristics did not explain much of the association between hospital volume and complications of total hip replacement¹⁶, leading us to conclude that practice may indeed make perfect in this clinical setting.

Most of our findings are consistent with those reported in the literature on associations between procedure volume and outcomes. Higher hospital and surgeon volumes have been associated with lower rates of mortality and select complications in many studies, typically involving cardiac or oncologic procedures^{6,7,17}. Several studies on total hip replacement also have shown inverse associations between hospital and surgeon volume and perioperative mortality and complications^{8,9,18-21}. However, there have been few prior studies of the association between volume and the outcome of total knee replacement. Taylor et al.⁹ identified an inverse association between hospital volume and mortality. Those authors did not consider end points other than mortality, nor did they

distinguish the roles of hospital volume and surgeon volume. Norton et al.¹⁰ examined the association between hospital volume and select complications in Medicare recipients. That study considered a range of in-hospital complications, but it did not examine complications occurring after the acute admission or the role of surgeon volume. Hervey et al.¹¹ recently reported analyses of a population-based sample of 50,874 primary total knee replacement recipients and 4646 patients who had undergone revision total knee replacement. They found that patients managed in higher-volume centers or by higher-volume surgeons had lower rates of mortality during the acute inpatient admission. The majority of perioperative events occur after discharge²². Furthermore, length of stay is lower in high-volume hospitals¹¹; thus, restricting outcomes to those occurring during the acute admission not only reduces power but may also bias results toward lower event rates in high-volume centers. That study also lacked the power to detect modest risks of complications such as infection and deep-vein thrombosis or pulmonary thromboembolism. Finally, the smaller sample size in the study by Hervey et al.¹¹ required that their low-volume centers include hospitals in which up to eighty-five procedures were performed annually (about fifty-seven were done in Medicare recipients, given that 67% of the total knee replacements were performed in the Medicare population¹), whereas our lowest-volume centers had an annual volume of twenty-five procedures or fewer in the Medicare population.

Our study overcomes several of the methodological limitations of prior work. We adjusted for a wide range of potential confounders, including age, gender, Medicaid eligibility, comorbidity, and underlying arthritis diagnosis. We distinguished the independent effects of hospital and surgeon volume by including terms for both within each model. In addition, we accounted for clustering of observations within hospitals. Finally, we included all outcomes occurring within ninety days of discharge.

The study also has important limitations. It was conducted exclusively in Medicare beneficiaries and cannot necessarily be generalized to younger recipients of total knee replacements. Medicare claims data do not have information on a range of clinical characteristics associated with outcome, such as preoperative functional status^{23,24}. While Medicare claims data do permit the construction of a comorbidity index, we acknowledge that the index may not adjust for comorbidity as successfully as medical record-based data. Similarly, Medicare claims data have limited socioeconomic information. Thus, there may be residual confounding by comorbidity, socioeconomic status, and other variables measured imprecisely in claims. Despite the large sample size, the outcomes are relatively rare and thus statistical power was limited. Several odds ratios showed that the magnitude of the associations was impressive, yet the 99% confidence intervals crossed 1.0 (Table IV). Thus, these findings should be confirmed. The data also do not provide the outcomes of greatest interest to patients—that is, pain relief and improvement in functional status.

Our findings inform but do not resolve the debate as to whether procedures such as total knee replacement should be regionalized to high-volume centers. The difference in mortality after primary total knee replacement between the centers with the highest volume (>200 procedures per year) and those with the lowest volume (one to twenty-five procedures per year) is 0.34%. Thus, about 300 patients would have to be shifted from low-volume to high-volume centers to avert one perioperative death. It is possible that some of these patients would simply decline surgery rather than go to the high-volume center. On the other hand, given the growing frequency of total knee replacement, our data suggest that an increasing number of patients could avoid perioperative death if care were regionalized and if indeed regionalization had the effect suggested by these cross-sectional data. In fact, we do not know whether patients who shift from low to high-volume centers decrease their risk to the extent suggested by our data. There may be disadvantages associated with having surgery in a distant and unfamiliar center that attenuate these risk differences. Furthermore, the associations between hospital volume and pain relief, functional status, and prosthesis survival—crucial outcomes of total knee replacement—are largely unknown and require further investigation. One study has shown that patients in higher-volume centers were more likely to have an improvement in functional status following total knee replacement²⁵. On the other hand, we showed recently that hospital and surgeon volumes were not associated with pain or functional status following total hip replacement²⁶.

We suggest that it is not possible to make a definitive policy recommendation regarding regionalization given the data available at present. More data are needed on the medium-term and long-term outcomes of total joint replacement in high and low-volume centers, and such studies should be given a high priority. For now, we suggest that the findings of this and similar studies be brought into the physician-patient discussion about treatment options. It would be reasonable, given the evidence available, for clinicians to discuss explicitly with patients the trade-offs involved in electing surgery in a high-volume compared with a low-volume center. Once informed of the relevant data, patients should be supported in making these decisions on the basis of their own preferences. ■

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References

1. **Agency for Healthcare Research and Quality.** *HCUPnet, Healthcare Cost and Utilization Project.* Rockville, MD: Agency for Healthcare Research and Quality; 2002. www.ahrq.gov
2. **Callahan CM, Drake BG, Heck DA, Dittus RS.** Patient outcomes following tricompartmental total knee replacement. A meta-analysis. *JAMA.* 1994; 271:1349-57.
3. **Hawker G, Wright J, Coyte P, Paul J, Dittus R, Croxford R, Katz B, Bombardier C, Heck D, Freund D.** Health-related quality of life after knee replacement. *J Bone Joint Surg Am.* 1998;80:163-73.
4. **Rand JA, Trousdale RT, Ilstrup DM, Harmsen WS.** Factors affecting the durability of primary total knee prostheses. *J Bone Joint Surg Am.* 2003; 85:259-65.
5. **Centers for Medicare and Medicaid Services.** Fact sheet: Medicare partnerships for quality cardiovascular services and quality total joint replacement services. 2003. www.cms.hhs.gov/researchers/demos/qpfadem.asp.
6. **Dudley RA, Johansen KL, Brand R, Rennie DJ, Milstein A.** Selective referral to high-volume hospitals: estimating potentially avoidable deaths. *JAMA.* 2000;283:1159-66.
7. **Halm EA, Lee C, Chassin MR.** Is volume related to outcome in health care? A systematic review and methodologic critique of the literature. *Ann Intern Med.* 2002;137:511-20. Summary for patients in: *Ann Intern Med.* 2002;137:152.
8. **Katz JN, Losina E, Barrett J, Phillips CB, Mahomed NN, Lew RA, Guadagnoli E, Harris WH, Poss R, Baron JA.** Association between hospital and surgeon procedure volume and outcomes of total hip replacement in the United States Medicare population. *J Bone Joint Surg Am.* 2001;83:1622-9.
9. **Taylor HD, Dennis DA, Crane HS.** Relationship between mortality rates and hospital patient volume for Medicare patients undergoing major orthopaedic surgery of the hip, knee, spine, and femur. *J Arthroplasty.* 1997;12:235-42.
10. **Norton EC, Garfinkel SA, McQuay LJ, Heck DA, Wright JG, Dittus R, Lubitz RM.** The effect of hospital volume on the in-hospital complication rate in knee replacement patients. *Health Serv Res.* 1998;33(5 Pt 1):1191-210.
11. **Hervey SL, Purves HR, Guller U, Toth AP, Vail TP, Pietrobon R.** Provider volume of total knee arthroplasties and patient outcomes in the HCUP-Nationwide Inpatient Sample. *J Bone Joint Surg Am.* 2003;85:1775-83.
12. **American Hospital Association.** *Annual hospital survey.* Chicago: American Hospital Association; 2000.
13. **National Center for Health Statistics.** *International classification of diseases, ninth revision, clinical modification.* Hyattsville, MD: National Center for Health Statistics; 2000.
14. **Kirschner CG, Kopacz J, Reyes D, American Medical Association.** *CPT: Current procedural terminology 2001.* Chicago: American Medical Association; 2000.
15. **Romano PS, Roos LL, Jollis JG.** Adapting a clinical comorbidity index for use with ICD-9-CM administrative data: differing perspectives. *J Clin Epidemiol.* 1993;46:1075-9,1081-90.
16. **Solomon DH, Losina E, Baron JA, Fossel AH, Guadagnoli E, Lingard EA, Miner A, Phillips CB, Katz JN.** Contribution of hospital characteristics to the volume-outcome relationship: dislocation and infection following total hip replacement surgery. *Arthritis Rheum.* 2002;46:2436-44.
17. **Birkmeyer JD, Siewers AE, Finlayson EV, Stukel TA, Lucas FL, Batista I, Welch HG, Wennberg DE.** Hospital volume and surgical mortality in the United States. *N Engl J Med.* 2002;346:1128-37.
18. **Kreder HJ, Deyo RA, Koepsell T, Swiontkowski MF, Kreuter W.** Relationship between the volume of total hip replacements performed by providers and the rates of postoperative complications in the State of Washington. *J Bone Joint Surg Am.* 1997;79:485-94.
19. **Kreder HJ, Williams JI, Jaglal S, Hu R, Axcell T, Stephen D.** Are complication rates for elective primary total hip arthroplasty in Ontario related to surgeon and hospital volumes? A preliminary investigation. *Can J Surg.* 1998;41:431-7.
20. **Lavernia CJ, Guzman JF.** Relationship of surgical volume to short-term mortality, morbidity, and hospital charges in arthroplasty. *J Arthroplasty.* 1995;10:133-40.
21. **Luft HS, Bunker JP, Enthoven AC.** Should operations be regionalized? The empirical relation between surgical volume and mortality. *N Engl J Med.* 1979;301:1364-9.
22. **Phillips CB, Barrett JA, Losina E, Mahomed NN, Lingard EA, Guadagnoli E, Baron JA, Harris WH, Poss R, Katz JN.** Incidence rates of dislocation, pulmonary embolism, and deep infection during the first six months after elective total hip replacement. *J Bone Joint Surg Am.* 2003;85:20-6.
23. **Fortin PR, Penrod JR, Clarke AE, St-Pierre Y, Joseph L, Belisle P, Liang MH, Ferland D, Phillips CB, Mahomed N, Tanzer M, Sledge C, Fossel AH, Katz JN.** Timing of total joint replacement affects clinical outcomes among patients with osteoarthritis of the hip or knee. *Arthritis Rheum.* 2002;46:3327-30.
24. **Fortin PR, Clarke AE, Joseph L, Liang MH, Tanzer M, Ferland D, Phillips C, Partridge AJ, Belisle P, Fossel AH, Mahomed N, Sledge CB, Katz JN.** Outcomes of total hip and knee replacement: preoperative functional status predicts outcomes at six months after surgery. *Arthritis Rheum.* 1999;42:1722-8.
25. **Heck DA, Robinson RL, Partridge CM, Lubitz RM, Freund DA.** Patient outcomes after knee replacement. *Clin Orthop.* 1998;356:93-110.
26. **Katz JN, Phillips CB, Baron JA, Fossel AH, Mahomed NN, Barrett J, Lingard EA, Harris WH, Poss R, Lew RA, Guadagnoli E, Wright EA, Losina E.** Association of hospital and surgeon volume of total hip replacement with functional status and satisfaction three years following surgery. *Arthritis Rheum.* 2003; 48:560-8.