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Association Between Hospital and Surgeon Procedure Volume and Outcomes of Total Hip Replacement in the United States Medicare Population*

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Background: The mortality and complication rates of many surgical procedures are inversely related to hospital procedure volume. The objective of this study was to determine whether the volumes of primary and revision total hip replacements performed at hospitals and by surgeons are associated with rates of mortality and complications.

Methods: We analyzed claims data of Medicare recipients who underwent elective primary total hip replacement (58,521 procedures) or revision total hip replacement (12,956 procedures) between July 1995 and June 1996. We assessed the relationship between surgeon and hospital procedure volume and mortality, dislocation, deep infection, and pulmonary embolus in the first ninety days postoperatively. Analyses were adjusted for age, gender, arthritis diagnosis, comorbid conditions, and income. Analyses of hospital volume were adjusted for surgeon volume, and analyses of surgeon volume were adjusted for hospital volume.

Results: Twelve percent of all primary total hip replacements and 49% of all revisions were performed in centers in which ten or fewer of these procedures were carried out in the Medicare population annually. In addition, 52% of the primary total hip replacements and 77% of the revisions were performed by surgeons who carried out ten or fewer of these procedures annually. Patients treated with primary total hip replacement in hospitals in which more than 100 of the procedures were performed per year had a lower risk of death than those treated with primary replacement in hospitals in which ten or fewer procedures were performed per year (mortality rate, 0.7% compared with 1.3%; adjusted odds ratio, 0.58; 95% confidence interval, 0.38, 0.89). Patients treated with primary total hip replacement by surgeons who performed more than fifty of those procedures in Medicare beneficiaries per year had a lower risk of dislocation than those who were treated by surgeons who performed five or fewer of the procedures per year (dislocation rate, 1.5% compared with 4.2%; adjusted odds ratio, 0.49; 95% confidence interval, 0.34, 0.69). Patients who had revision total hip replacement done by surgeons who performed more than ten such procedures per year had a lower rate of mortality than patients who were treated by surgeons who performed three or fewer of the procedures per year (mortality rate, 1.5% compared with 3.1%; adjusted odds ratio, 0.65; 95% confidence interval, 0.44, 0.96).

Conclusions: Patients treated at hospitals and by surgeons with higher annual caseloads of primary and revision total hip replacement had lower rates of mortality and of selected complications. These analyses of Medicare claims are limited by a lack of key clinical information such as operative details and preoperative functional status.

Total hip replacement relieves pain and improves function in the great majority of patients with disabling hip arthritis who undergo the procedure[1]. Most reports of the results of total hip replacements are based on series from centers with a high annual volume of such procedures; the outcomes in low-volume centers have received little study.

Both greater hospital procedure volume[2] and greater surgeon (or operator) procedure volume[3-7] have been associated with lower rates of mortality and/or complications following several surgical procedures. The outcomes in hospitals in which a higher volume of patients with specific complex medical conditions have been treated[8-11] also have been better than those in hospitals in which fewer such patients have been treated.

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*The topic discussed in this article is also addressed in the Editorial and in a Letter to The Editor in this issue of *The Journal*.

TABLE I Baseline Characteristics of Medicare Beneficiaries Treated with Primary and Revision Total Hip Replacement from July 1995 through June 1996

Baseline Characteristics	Primary Arthroplasty (N = 58,521)	Revision Arthroplasty (N = 12,956)
Male*	21,041 (36.0%)	4876 (37.6%)
Caucasian*	55,081 (94.1%)	12,141 (93.7%)
>1 comorbidity*	8076 (13.8%)	2282 (17.6%)
>75 yr old*	23,148 (39.6%)	6153 (47.5%)
Mean age (and standard deviation) *(yr)*	74.3 ± 6.0	75.6 ± 6.5

*The values are given as the number of patients, with the percentage in parentheses.

Prior studies of the association between the volume of total hip replacements performed at hospitals and by surgeons and the outcomes of those procedures have had notable methodological limitations. These have included failure of the investigators to examine both surgeon and hospital procedure volume[12-14] or to consider revision total hip replacement[12,13], relatively small samples[15,16], and inadequate adjustment for case mix[12,14]. Nonetheless, programs have been proposed to restrict total hip replacement in the Medicare population to higher-volume centers[17]. We examined associations between hospital and surgeon volume and mortality and complications occurring ninety days following primary and revision hip replacement. Our analyses accounted for clinical and sociodemographic factors and assessed the distinct contributions of hospital and surgeon volume to these outcomes.

Materials and Methods

Data Sources

We used claims data from July 1995 through June 1996 for the entire Medicare-beneficiary population to identify cases of primary and revision total hip replacement and selected outcomes. Hospital and outpatient facility claims contain diagnosis and procedure codes, classified according to the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM)[18]. Physician claims contain procedure codes utilizing the Current Procedural Terminology (CPT), Fourth Edition[19]. The Medicare Unique Physican Identification Number (UPIN) assigned to each surgeon permitted surgeon-level analyses. The 1995 American Hospitals Association Survey[20] provided data on selected hospital characteristics.

Sample

We identified all Medicare beneficiaries with codes, on surgeon or hospital claims, indicating that they had had elective primary or revision total hip replacement between July 1, 1995, and June 30, 1996, in a hospital in the United States. We excluded patients who were less than sixty-five years old and those with codes indicating infection of the hip, metastatic or bone cancer, conversion of hemiarthroplasty (or other hip surgery) to total hip replacement, or fracture of the hip or femur. For the analysis of revision total hip replacement, we excluded patients with fracture associated with cancer. We also excluded patients enrolled in a health maintenance organization, since capitated health maintenance organizations do not routinely submit claims to the Health Care Financing Administration. In addition, we excluded patients who were not enrolled in both parts of Medicare and those who were not residents of the United States, again because some of these claims could have been missing.

To examine the validity of our case identification algorithms, trained nurse abstractors reviewed the medical records of a random sample of 1031 (1.8%) of the primary procedures and 671 (5.2%) of the revision procedures identified in the Medicare claims in order to verify whether the procedure was indeed a primary (or revision) hip replacement. The positive predictive values of the algorithms for identification of the primary and revision total hip replacements were 0.99 and 0.92, respectively.

TABLE II Select Outcomes of Primary and Revision Total Hip Replacement in Medicare Beneficiaries Treated from July 1995 through June 1996

Outcome (≤90 Days Postop.)	Primary Arthroplasty* (N = 58,521)	Revision Arthroplasty* (N = 12,956)
Death	557 (0.95%)	319 (2.46%)
Dislocation	1834 (3.13%)	1077 (8.31%)
Deep infection	137 (0.23%)	124 (0.96%)
Pulmonary embolus	542 (0.93%)	101 (0.78%)

*The values are given as the number of patients, with the percentage in parentheses.

TABLE III Distribution, According to Hospital and Surgeon Procedure Volumes, of Primary Total Hip Replacements* Performed in Medicare Beneficiaries from July 1995 through June 1996

Hospital Volume	Surgeon Volume					
	1-5	6-10	11-25	26-50	>50	Total
1-10	7.3%	3.2%	1.0%	0.1%	0.0%	11.5%
11-25	9.1%	8.4%	6.5%	0.3%	0.1%	24.4%
26-50	7.0%	7.2%	11.2%	2.6%	0.3%	28.4%
51-100	3.8%	4.9%	8.9%	6.4%	1.7%	25.6%
>100	0.7%	0.9%	2.3%	2.2%	3.9%	10.1%
Total	27.9%	24.6%	29.9%	11.6%	6.0%	100%

*N = 57,488. The sample size is smaller than in Table I (n = 58,521) because data on surgeon volume were missing for about 2% of the cases.

Sample Characteristics

The claims for a total of 76,627 patients contained codes indicating that a primary total hip replacement had been done. Of these procedures, 58,521 (76%) met our criteria for elective primary total hip replacement not associated with fracture. The claims for a total of 13,917 patients contained codes indicating that a revision total hip replacement had been done. Of these procedures, 12,956 (93%) met our criteria for elective revision total hip replacement. The patients who had a revision were slightly older and had more comorbid conditions than did those who had a primary hip replacement (Table I). Of the patients who had a primary total hip replacement, 55,002 (94%) had osteoarthritis (coded as an underlying joint disorder), 2115 (3.6%) had rheumatoid arthritis, and 3798 (6.5%) had avascular necrosis. (More than one diagnosis can be listed for a patient.)

Data Elements

Outcomes: Outcomes included death, dislocation, deep infection (requiring surgical débridement or removal of the prosthesis), and pulmonary embolus. We included all such outcomes that had occurred within ninety days after admission for the total hip replacement in order to maximize the likelihood that the event was causally related to the hip replacement. (The algorithms for identifying cases and outcomes in claims data are presented as an Appendix in the electronic versions of this paper.)

Covariates: Covariates obtained from the Medicare claims data included age, gender, race (coded as Caucasian or other), Medicaid eligibility (a surrogate for low income), arthritis diagnosis (osteoarthritis, rheumatoid arthritis, avascular necrosis, or other), and comorbidity index. The comorbidity index was calculated with an adaptation of the Charlson Comorbidity Index, which incorporates data on comorbid conditions documented in claims in the six months prior to and including the date of admission for total hip replacement[21,22].

Hospital and surgeon variables: Hospital and surgeon volume, calculated separately for primary and revision arthroplasty, was the number of procedures meeting our entry criteria that were performed at the institution or by the surgeon in the Medicare population between July 1, 1995, and June 30, 1996. We divided hospital and surgeon volume into clinically sensible categories. 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 and ownership status of the hospital (for-profit, nonprofit, or public). However, these factors were not found

TABLE IV Distribution, According to Hospital and Surgeon Procedure Volumes, of Revision Total Hip Replacements* Performed in Medicare Beneficiaries from July 1995 through June 1996

Hospital Volume	Surgeon Volume			
	1-3	4-10	>10	Total
1-5	22.1%	4.0%	0.3%	26.4%
6-10	11.8%	10.1%	0.7%	22.6%
11-25	9.4%	13.1%	8.3%	30.7%
26-50	1.5%	3.7%	7.0%	12.2%
>50	0.4%	1.1%	6.6%	8.0%
Total	45.3%	31.8%	22.9%	100%

*N = 12,724. The total sample size is smaller than in Table I (n = 12,956) because data on surgeon volume were missing for about 2% of the cases.

TABLE V Associations Between Hospital and Surgeon Procedure Volumes and Select Outcomes of Primary Total Hip Replacements in Medicare Beneficiaries Treated from July 1995 through June 1996

	Hospital			Surgeon		
Outcome	Annual Volume of Primary Hip Replacements	Rate of Outcome	Adjusted Odds Ratio* (95% Confidence Interval)	Annual Volume of Primary Hip Replacements	Rate of Outcome	Adjusted Odds Ratio* (95% Confidence Interval)
Mortality	1-10	1.3%	1.0	1-5	1.1%	1.0
	11-25	1.0%	0.82 (0.62, 1.07)	6-10	1.0%	0.98 (0.78, 1.23)
	26-50	0.9%	0.72 (0.54, 0.95)	11-25	0.9%	0.97 (0.77, 1.22)
	51-100	0.9%	0.68 (0.51, 0.92)	26-50	0.8%	1.10 (0.95, 1.54)
	>100	0.7%	0.58 (0.38, 0.89)	>50	0.7%	0.95 (0.56, 1.62)
Dislocation	1-10	4.4%	1.0	1-5	4.2%	1.0
	11-25	3.8%	0.96 (0.82, 1.17)	6-10	3.4%	0.85 (0.76, 0.96)
	26-50	2.9%	0.79 (0.67, 0.93)	11-25	2.6%	0.68 (0.59, 0.78)
	51-100	2.5%	0.72 (0.60, 0.87)	26-50	2.4%	0.68 (0.54, 0.86)
	>100	2.2%	0.77 (0.58, 1.03)	>50	1.5%	0.49 (0.34, 0.69
Deep infection	1-10	0.4%	1.0	1-5	0.3%	1.0
	11-25	0.3%	0.84 (0.52, 1.37)	6-10	0.3%	0.90 (0.59, 1.37)
	26-50	0.2%	0.56 (0.33, 0.96)	11-25	0.2%	0.80 (0.51, 1.26)
	51-100	0.2%	0.74 (0.42, 1.32)	26-50	0.1%	0.64 (0.30, 1.36)
	>100	0.1%	0.52 (0.22, 1.22)	>50	0.1%	0.28 (0.07, 1.11)
Pulmonary embolus	1-10	1.1%	1.0	1-5	1.0%	1.0
	11-25	1.0%	0.86 (0.64, 1.15)	6-10	1.0%	0.98 (0.78, 1.23)
	26-50	1.0%	0.89 (0.66, 1.21)	11-25	0.9%	0.91 (0.72, 1.14)
	51-100	0.8%	0.83 (0.60, 1.14)	26-50	0.7%	0.75 (0.51, 1.08)
	>100	0.8%	0.79 (0.51, 1.23)	>50	0.7%	0.73 (0.44, 1.21)

*Each odds ratio is adjusted for gender, age, comorbidity, Medicaid eligibility, and arthritis diagnosis. In addition, the odds ratios for hospital volume are adjusted for surgeon volume, and the odds ratios for surgeon volume are adjusted for hospital volume.

to have any influence and thus were not included in the final models.

Analyses

For each outcome, we constructed two sets of multivariate models, one examining the association between outcomes and hospital-volume strata and the other examining the association between outcomes and surgeon-volume strata. The hospital-volume models were adjusted for surgeon volume, and the surgeon-volume models were adjusted for hospital volume. In each model, we adjusted for age, gender, comorbidity index, specific arthritis diagnosis, and Medicaid eligibility indicator. The strength of the association between volume and outcome was expressed with an adjusted odds ratio, and the test for linear trend was performed with an ordinal variable representing the volume stratum.

We examined more explicitly the simultaneous effects of both hospital and surgeon volume on dislocation following primary total hip replacement. We ran additional logistic regression models of the surgeon effect within each hospital-volume stratum. We carried out these analyses in hospitals in which at least twenty-five primary total hip replacements were performed per year. The analyses could not be carried out in hospitals with smaller caseloads because high-volume surgeons generally do not operate in lower-volume centers. These models were adjusted for the same set of covariates as described above. All analyses were performed with SAS software[23]. Generalized estimating equations[24] were used to adjust for clustering within hospitals in all models.

Results

Five hundred and fifty-seven (1.0%) of the patients who underwent primary total hip replacement died within ninety days after surgery, and 1834 (3.1%) had a dislocation (Table II). Infection was uncommon, developing in only 137 (0.2%) of the patients. Rates of mortality, dislocation, and infection were higher after the revisions than they were after the primary hip replacements.

Six thousand seven hundred and seventy-five (12%) of the primary total hip replacements and 6381 (49%) of the revisions were performed in centers in which ten or fewer of these procedures were carried out in the Medicare population during July 1995 through June 1996. Similarly, 30,176 (52%) of the primary total hip replacements and 9809 (77%) of the revisions were performed by surgeons who carried out ten or fewer of these procedures annually in the Medicare population (Tables III and IV). These procedures were rarely carried out by high-volume surgeons in low-volume centers, but occa-

sionally they were carried out by low-volume surgeons in high-volume centers (Tables III and IV).

Volume and Outcomes of Primary Total Hip Replacement

Multivariate logistic regression analyses showed hospital volume to be significantly associated with ninety-day rates of mortality and dislocation (p value for trend < 0.01 for each outcome) (Table V). Patients who had primary total hip replacement in hospitals in which more than 100 of those procedures were performed in Medicare beneficiaries per year had a lower rate of mortality than those who had primary replacement in hospitals in which ten or fewer procedures were performed per year (mortality rate, 0.7% compared with 1.3%; adjusted odds ratio, 0.58; 95% confidence interval, 0.38, 0.89). Greater hospital volume was also associated with a lower rate of deep infection, but the trend did not reach significance (p value for trend = 0.09). The adjusted odds ratio of each adverse outcome diminished steadily across the volume categories, without a specific threshold volume at which outcomes changed from better to worse.

After adjustment for hospital volume, higher surgeon volume was independently associated with a lower rate of dislocation following primary total hip replacement (p value for trend = 0.0001) (Table V). Compared with patients operated on by surgeons who performed five or fewer procedures in the Medicare population per year, those operated on by surgeons who performed more than fifty procedures had a lower rate of dislocation (dislocation rate, 1.5% compared with 4.2%; adjusted odds ratio, 0.49; 95% confidence interval, 0.34, 0.69). Greater surgeon volume had less striking associations with deep infection and pulmonary embolus (p value for trend = 0.03 for infection and 0.06 for pulmonary embolus).

The association between surgeon volume and risk of dislocation following primary total hip replacement was assessed separately within each of the three largest hospital-volume categories (Table VI). In hospitals in which twenty-six to fifty procedures were performed per year and in those in which fifty-one to 100 procedures were performed per year, the risk of dislocation diminished steadily with greater surgeon volume (p value for trend < 0.01 for each). However, in the highest-volume hospitals (more than 100 cases per year), surgeon volume had no effect on dislocation rate (p value for trend = 0.55).

Volume and Outcomes of Revision Total Hip Replacement

The associations between hospital volume and outcomes of revision hip arthroplasty (Table VII) were less striking than the associations observed for primary total hip replacement. A greater hospital volume of revisions was associated with a lower rate of dislocation (p value for trend = 0.005). Multivariate logistic regression analysis showed that patients operated on in hospitals in which more than fifty revisions were performed in Medicare recipients per year had a lower rate of dislocation than patients operated on in hospitals in which five or fewer such operations were performed (dislocation rate, 4.2% compared with 9.8%; adjusted odds ratio, 0.45; 95% confidence interval, 0.30, 0.66).

TABLE VI Risk of Dislocation Associated with Surgeon Volume of Primary Total Hip Replacement in Medicare Beneficiaries Treated from July 1995 through June 1996, Stratified by Hospital Volume*

Hospital Volume	Surgeon Volume	Dislocation	
		Rate	Adjusted Odds Ratio† (95% Confidence Interval)
26-50	1-5	3.7%	1.0
	6-10	3.0%	0.83 (0.66, 1.05)
	11-25	2.5%	0.69 (0.54, 0.89)
	26-50	2.9%	0.84 (0.53, 1.31)
	>50	1.3%	0.34 (0.10, 1.13)
51-100	1-5	3.2%	1.0
	6-10	3.4%	1.1 (0.81, 1.45)
	11-25	2.2%	0.70 (0.52, 0.95)
	26-50	2.1%	0.65 (0.46, 0.92)
	>50	1.1%	0.33 (0.19, 0.59)
>100	1-5	2.5%	1.0
	6-10	2.5%	1.2 (0.57, 2.45)
	11-25	2.6%	1.2 (0.61, 2.20)
	26-50	2.6%	1.2 (0.68, 2.20)
	>50	1.7%	0.95 (0.51, 1.77)

*The results were restricted to hospitals in which more than twenty-five elective primary total hip replacements were performed in Medicare beneficiaries from July 1995 through June 1996. †Each odds ratio is adjusted for gender, age, comorbidity, Medicaid eligibility, and arthritis diagnosis.

TABLE VII Associations Between Hospital and Surgeon Procedure Volumes and Select Outcomes of Revision Total Hip Replacement in Medicare Beneficiaries Treated from July 1995 through June 1996

	Hospital			Surgeon		
Outcome	Annual Volume of Revision Hip Replacements	Rate of Outcome	Adjusted Odds Ratio* (95% Confidence Interval)	Annual Volume of Revision Hip Replacements	Rate of Outcome	Adjusted Odds Ratio* (95% Confidence Interval)
Mortality	1-5	3.5%	1.0	1-3	3.1%	1.0
	6-10	2.6%	0.85 (0.62, 1.15)	4-10	2.2%	0.78 (0.59, 1.03)
	11-25	2.1%	0.74 (0.54, 1.00)	>10	1.5%	0.65 (0.44, 0.96)
	26-50	1.5%	0.67 (0.40, 1.11)			
	>50	1.8%	0.85 (0.43, 1.67)			
Dislocation	1-5	9.8%	1.0	1-3	9.1%	1.0
	6-10	8.6%	0.90 (0.75, 1.08)	4-10	8.7%	1.04 (0.89, 1.21)
	11-25	8.4%	0.90 (0.75, 1.09)	>10	6.1%	0.84 (0.67, 1.06)
	26-50	7.0%	0.75 (0.56, 1.02)			
	>50	4.2%	0.45 (0.30, 0.66)			
Deep infection	1-5	0.9%	1.0	1-3	1.0%	1.0
	6-10	1.1%	1.31 (0.78, 2.21)	4-10	1.0%	0.97 (0.61, 1.55)
	11-25	1.0%	1.39 (0.84, 2.31)	>10	0.7%	0.64 (0.33, 1.24)
	26-50	0.9%	1.36 (0.64, 2.92)			
	>50	0.5%	0.78 (0.29, 2.10)			
Pulmonary embolus	1-5	0.7%	1.0	1-3	0.7%	1.0
	6-10	1.1%	1.63 (0.94, 2.81)	4-10	1.0%	1.44 (0.89, 2.34)
	11-25	0.7%	1.01 (0.54, 1.90)	>10	0.6%	1.00 (0.53, 1.90)
	26-50	0.5%	0.67 (0.29, 1.57)			
	>50	0.7%	0.91 (0.40, 2.06)			

*Each odds ratio is adjusted for gender, age, comorbidity, Medicaid eligibility, and arthritis diagnosis. In addition, the odds ratios for hospital volume are adjusted for surgeon volume, and the odds ratios for surgeon volume are adjusted for hospital volume.

A greater surgeon volume of revision total hip replacements was associated with a lower mortality rate (p value for trend = 0.02). Patients who had revision hip replacement by surgeons who performed more than ten revisions in Medicare recipients per year had a lower mortality rate than patients operated on by surgeons who performed three or fewer revisions per year (mortality rate, 1.5% compared with 3.1%; adjusted odds ratio, 0.65; 95% confidence interval, 0.44, 0.96) (Table VII). As was the case for primary arthroplasties, there were no discrete volume thresholds at which the outcomes of revision hip replacement changed; the volume effect was incremental across volume strata.

Discussion

We used Medicare claims data to examine the effects of hospital and surgeon procedure volumes on mortality and complications within ninety days following primary and revision total hip replacements in Medicare recipients. After adjustment for surgeon volume as well as age, gender, comorbidity, arthritis diagnosis, and a proxy for low income, higher hospital volume was significantly associated with lower rates of mortality and dislocation after primary total hip replacement (p value for trend < 0.01 for each outcome). Higher surgeon volume was significantly associated with a lower rate of dislocation (p value for trend = 0.0001) and, less strongly, with a lower rate of deep hip infection (p = 0.03). The findings for revision total hip replacement are less precise because of a smaller sample size, but they are generally comparable with those for primary total hip replacement. An important exception is that surgeon volume, but not hospital volume, was associated with mortality following revision hip replacement (p value for trend = 0.02).

The analyses failed to reveal discrete volume thresholds that distinguished favorable from poor outcomes, but rather they showed a steady trend across all volume strata toward better outcomes associated with higher volume. The effect of surgeon volume was strongest in hospitals with 100 or fewer cases per year; in the largest centers, with more than 100 cases annually, surgeon volume had little effect on outcomes.

We recognized that there are two reasonable approaches to estimating the annual volume of revision hip replacements performed by a surgeon or in a hospital. One is calculating the number of revisions performed in Medicare beneficiaries by the surgeon or in the hospital during the year. The other is calculating the total volume of hip procedures (both primary and revision replacements) performed by the surgeon or in the hospital during the year. These two variables (revision volume and total volume) were highly correlated (Pearson r = 0.65). If

volume is presented as the total number of primary and revision arthroplasties, the distribution of revisions naturally shifts, with a higher proportion done in high-volume centers. The associations between volume and outcome were similar with use of either measure. We presented the results of the analyses based on the volume of revision procedures, as this is a more precise measure of experience with these procedures.

Despite the superior outcomes in high-volume centers, 6775 (12%) of the primary total hip replacements and 6381 (49%) of the revisions were performed in hospitals in which ten or fewer of the respective procedures were carried out in the Medicare population per year. Similarly, 30,176 (52%) of the primary total hip replacements and 9809 (77%) of the revisions were performed by surgeons who did ten or fewer of these procedures in the Medicare population annually. It is likely that if more procedures were performed in high-volume centers or by high-volume surgeons, there would be fewer deaths and complications[2].

Our results are consistent with those of studies of coronary artery bypass surgery[25,26], coronary angioplasty[5,7,27,28], carotid endarterectomy[4], abdominal aortic resection[29], cancer surgery[30], complex gastrointestinal surgery[31,32], liver transplantation[33], cataract surgery[34], total knee replacement[14,16,35,36], and medical care for a range of conditions including infection by human immunodeficiency virus[9], myocardial infarction[10], and systemic lupus erythematosus[11]. In each of these studies, a higher hospital and/or surgeon volume was associated with better outcomes. The mechanisms mediating the effects of hospital and surgeon volume on outcome have not been established and constitute an important research priority.

An important potential limitation of our analyses is that key factors such as the complexity of the surgery (particularly the revisions) and preoperative and postoperative psychological and physical functional status and pain are not captured in claims data. Exclusion of Medicare patients who belonged to a health maintenance organization may have limited generalizability slightly, but it is unlikely that it introduced bias.

Our findings offer some support for recommendations to concentrate total hip replacements in high-volume referral centers[17] in order to reduce avoidable mortality and morbidity[2]. However, efforts to regionalize these procedures should take into account several factors. First, the absolute risk of death following total hip replacement remains low (<2% following primary total hip replacement), even in the lowest-volume centers. Some patients would accept greater risk in order to receive care at a nearby hospital rather than a referral center[37]. The trade-off between the comfort of having surgery at a community center and the better outcomes in referral centers should be examined explicitly. Second, the effects of procedure volume on pain relief, functional improvement, and durability of the implant should be examined to provide a more complete picture of the influence of volume on outcome. Moreover, volume is likely a proxy for a range of hospital, surgeon, and patient-related characteristics and for the processes of care that influence outcome. Research is needed to identify the aspects of the processes of care and the care setting that provide better outcomes. It would be preferable to urge all centers to adapt these features than to simply close low-volume centers. Finally, regionalization may be difficult in areas where some patients might be unable to travel to the referral center. Given the associations between volume and outcome documented in our study, these additional research directions merit high priority.

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Appendix

eA The algorithms for identifying cases and outcomes in claims data are available with the electronic versions of this article, on our web site at www.jbjs.org (go to the article citation and click on "Supplementary Material") and on our quarterly CD-ROM (call our subscription department, at 781-449-9780, to order the CD-ROM). ■

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