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By Jason W. Hammond, MD, William S. Queale, MD, MS, MHS, Tae Kyun Kim, MD, PhD, and Edward G. McFarland, MD

Investigation performed at the Division of Sports Medicine and Shoulder Surgery, Department of Orthopaedic Surgery, and the Department of Medicine, Johns Hopkins University, Baltimore, Maryland

Background: Previous studies have demonstrated that a high surgical volume for certain surgical procedures reduces morbidity and improves economic outcome; however, to our knowledge, no study has demonstrated a similar relationship between volume and outcome for total shoulder arthroplasty and hemiarthroplasty. The objective of this study was to determine whether increased surgeon experience was associated with improved clinical and economic outcomes for patients undergoing total shoulder arthroplasty or hemiarthroplasty.

Methods: We analyzed discharge data on patients treated between 1994 and 2000 from the Maryland Health Services Cost Review Commission, which has a statewide hospital discharge database of all patients in the state of Maryland. The database included all patients undergoing total shoulder arthroplasty and hemiarthroplasty. We assessed the relationship between surgeon volume (low, medium, and high) and the risk of complications, length of stay, and total charges. The statistics were adjusted for procedure, age, gender, race, marital status, comorbidity, diagnosis, insurance type, income, and hospital volume.

Results: For the 1868 discrete total shoulder arthroplasties and hemiarthroplasties done in the state of Maryland, the risk of at least one complication associated with the procedures done by the high-volume surgeon group was nearly half that associated with the procedures done by the low-volume surgeon group (adjusted odds ratio, 0.6; 95% confidence interval, 0.4 to 0.9). High-volume surgeons were three times more likely than were low-volume surgeons to have patients with a hospital stay of less than six days (odds ratio, 0.3; 95% confidence interval, 0.2 to 0.6). Although the average cost of hospitalization was $1000 less in the high-volume surgeon group compared with the low-volume surgeon group, this reduction did not reach significance after adjustment for multiple variables (odds ratio, 0.8; 95% confidence interval, 0.5 to 1.4).

Conclusions: This study indicates that the patients of surgeons with higher average annual caseloads of total shoulder arthroplasties and hemiarthroplasties have decreased complication rates and hospital lengths of stay compared with the patients of surgeons who perform fewer of these procedures. These analyses of hospital discharge data are limited because of a lack of prospective data, operative details, and patient outcomes data. However, this study emphasizes the importance of continued education for orthopaedic surgeons who perform shoulder arthroplasty.

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

Over the past two decades, total shoulder arthroplasty and hemiarthroplasty have been used to treat various conditions affecting the shoulder, including degenerative joint disease, inflammatory arthritis, rotator cuff arthropathy, and fractures of the proximal part of the humerus[1]. The effectiveness of these procedures in reducing pain and increasing joint mobility has led to their increasing use by orthopaedic surgeons.

This trend parallels an increase in total joint arthroplasty for all joints over the past decade. Between 1990 and 1997, the number of total hip replacements in the United States increased 34%, whereas the number of total knee replacements increased more than 106%[2]. Total shoulder arthroplasty and hemiarthroplasty increased 120% during this time-period.

With these increasing numbers, it is important to understand the clinical and cost outcomes associated with shoulder procedures. There is far less information in the liter-

TABLE I Clinical and Economic Outcomes of Shoulder Procedures by Provider Group

Outcomes	Surgeon Volume Groups			Hospital Volume Groups		
	Low	Medium	High	Low	Medium	High
Complication rate *(%)*	14.5	9.0	9.3	12.9	8.5	10.37
Mean length of stay *(days)*	4.2	2.9	2.8	3.8	2.8	3.2
Mean hospital charge	$11,262	$10,045	$10,271	$10,764	$9333	$11,195

ature on the prevalence of total shoulder arthroplasty and hemiarthroplasty than there is on the prevalence of other joint replacements. Recent data have suggested that more than three-quarters of orthopaedic surgeons who do a shoulder replacement typically perform only one or two of these procedures per year[3]. There have been few, if any, studies that have addressed the relationship between the number of shoulder procedures performed by surgeons and the outcomes, such as complications, length of hospital stay, and hospital charges.

The use of computerized administrative data sets has facilitated these outcome studies in other surgical specialties. Previous studies in the general surgery literature have demonstrated that a high hospital volume for certain surgical procedures proves to be of benefit to reduce morbidity and mortality and to improve economic outcome[4-7].

Similar relationships have been demonstrated for joint replacements of the lower extremity[8]. The patients of surgeons who performed a low volume of hip replacements (less than two cases per year) in the state of Washington tended to have a higher mortality rate, more infections, a higher rate of revision operations, and more serious complications during the index hospitalization than did patients of surgeons who performed a higher volume of procedures[9]. In primary total hip and total knee arthroplasty combined, the patients of surgeons with a low volume of primary cases (less than ten) had a significantly higher mortality rate (24%), higher average charges ($25,000), and increased average length of hospital stay (9.3 days) compared with the patients of surgeons with a higher volume in the same study period[10]. Studies of surgical volume of hemiarthroplasty for the treatment of hip fractures showed that the patients of surgeons who performed a low volume of arthroplasties (less than ten per year) had a substantially higher average length of stay and inhospital charges compared with the patients of surgeons who performed a medium or high volume of arthroplasties[11].

The relative infrequency of total shoulder arthroplasty and hemiarthroplasty compared with other surgical procedures has prevented a similar study of these issues. The purpose of this investigation, therefore, was to determine whether individual surgeon experience was associated with improved short-term clinical and cost outcomes for patients who underwent total shoulder arthroplasty and hemiarthroplasty in Maryland between 1994 and 2000. We hypothesized that the experience of the surgeon and the institution would be a factor influencing these measures of outcome.

Materials and Methods

Selection of the Study Cohort

The cohort included all patients who underwent a total shoulder arthroplasty or hemiarthroplasty in Maryland between January 1994 and December 2000, inclusive. Data were obtained from the Maryland Health Services Cost Review Commission hospital discharge database. The data set was restricted to inpatient admissions and included encrypted patient and surgeon identifiers, patient demographics, and hospital stay information. The hospital stay information that was available included charges, length of stay, and ICD-9 (International Classification of Diseases, Ninth Revision) diagnosis and procedure codes. All inpatient admissions for a total shoulder arthroplasty or hemiarthroplasty were identified, and at least one procedure was performed in fifty hospitals in the state of Maryland. The term "shoulder procedure" in this analysis was used to refer to total shoulder arthroplasty and hemiarthroplasty, ICD-9 procedure codes 81.80 and 81.81, respectively. In Maryland, hospitals have an incentive to report accurate information since the data are used to regulate hospital revenue. The Maryland Health Services Cost Review Commission reviews data fields with edit checks, and they are rejected if more than 10% of the cases contain errors.

Definitions of Variables

Surgeon volume and hospital volume were the main exposure variables in the study and were defined as the total number of procedures performed between 1994 and 2000 by a surgeon or hospital, respectively. Surgeons were included in the study if they had performed at least one shoulder procedure within the study period. The surgeons were categorized according to the total number of procedures performed, with one to five procedures considered low volume; six to thirty procedures, medium volume; and more than thirty procedures, high volume. Hospitals were included in the study if at least one shoulder procedure was performed at the institution within the study period. Hospital volume during the seven-year study period was categorized with one to forty-nine procedures considered low volume; fifty to 100 procedures, medium volume; and more than 100 procedures, high volume. Surgeon and hospital volume thresholds were chosen so that clinically sensible groupings could be made.

Covariates for this study included patient demographics, such as age, gender, and race, and payer status (Medicare, Medicaid, and commercial insurance). A comorbidity score

was calculated with use of the Charlson comorbidity index adapted for ICD-9-CM (International Classification of Diseases, Ninth Revision, Clinical Modification) administrative databases[12-14]. The score was based upon the comorbidities reported at the time of discharge for the index admission. The operative diagnosis was based upon the primary diagnosis code. The pertinent diagnoses assessed for this study were osteoarthritis, rheumatoid arthritis, and fractures of the humerus (see Appendix)[1,15]. Mean household income estimates for each zip code in the state of Maryland were obtained from the Precision Marketing Group within VNU Marketing Information Services (Upton, Massachusetts). These data were limited to residents of Maryland and were based on projections from the 1990 census data.

The three primary outcomes for this study included (1) inhospital complications, (2) length of stay, and (3) average total hospital charges. Information on complications was obtained from secondary diagnoses and procedures as reported for each patient in the database. Complications considered in our study included diagnoses and procedures related to operative mishaps or infection and those that included complications in the definition (see Appendix). To diminish the effect of coding inaccuracies that are subject to wide interpretation, no attempt was made to evaluate ambiguous events such as recurrent shoulder dislocation or carpal tunnel syndrome, both of which could be considered a preoperative diagnosis or a postoperative complication[16]. Deyo et al.[12] reported that the presence of at least one complication coded during the index admission is associated with substantially increased length of stay and hospital charges. As a result, complications during the index hospitalization were dichotomized as one or more complications versus no complications. The mortality rate was not considered in this study, as only one patient died during the study period.

Data Analysis

The distribution of patient characteristics among provider groups was compared with use of analysis of variance for the continuous variables (age and comorbidity scores) and the chi-square statistic for categorical variables. Unadjusted and adjusted odds ratios were obtained with use of logistic regression for each of the dichotomous outcomes. Covariates were included in the final model if they made a significant contribution to the equation on the basis of the likelihood ratio test. Multiple cut-off points for selected exposure and outcome variables were analyzed to evaluate for consistency of the model. Significance for all analyses was set at $p \leq 0.05$. Data management and analysis were performed with use of Microsoft Access 2000 (Microsoft, Redmond, Washington) and Stata Statistical Software (release 7.0, 2001; Stata, College Station, Texas), respectively.

Results

Cohort Characteristics

The mean age for the cohort was 68.1 years. Of the 1868 patients, 31.8% were men, 8.6% were black, 53.3% were married, and 9.3% had a primary residence outside the state of Maryland.

TABLE II Univariate Analysis of Outcomes*

Exposure	Outcome†		
	Risk of Complications	Length of Stay	Total Hospital Charges
Surgeon volume (high versus low)	**0.6 (0.4-0.9)**	**0.2 (0.1-0.4)**	**0.5 (0.3-0.7)**
Hospital volume (high versus low)	0.8 (0.6-1.1)	**0.6 (0.5-0.9)**	0.8 (0.6-1.2)
Hemiarthroplasty (versus total shoulder arthroplasty)	1.2 (0.9-1.6)	**2.0 (1.5-2.7)**	**1.6 (1.1-2.2)**
Age of ≥65 yr	0.8 (0.6-1.1)	**2.2 (1.5-3.1)**	1.3 (0.9-1.8)
Female	**0.7 (0.5-0.9)**	**1.8 (1.3-2.6)**	0.9 (0.7-1.3)
Black	**2.2 (1.4-3.3)**	**1.6 (1.1-2.5)**	**2.4 (1.5-3.6)**
Married	0.8 (0.6-1.1)	**0.4 (0.3-0.6)**	**0.7 (0.5-0.9)**
Charlson comorbidity index of ≥1	1.1 (0.9-1.4)	**1.9 (1.6-2.3)**	**1.8 (1.4-2.1)**
History of osteoarthritis	**0.6 (0.4-0.8)**	**0.2 (0.1-0.3)**	**0.4 (0.3-0.6)**
History of fracture	0.9 (0.7-1.3)	**4.0 (2.9-5.4)**	**1.9 (1.4-2.5)**
History of rheumatoid arthritis	0.6 (0.2-1.4)	**0.3 (0.1-1.0)**	0.4 (0.1-1.2)
Medical assistance	0.7 (0.3-1.8)	**0.5 (0.2-1.0)**	0.5 (0.2-1.1)

*The values are given as odds ratios, with 95% confidence intervals in parentheses. Bold type indicates values that were significant ($p \leq 0.05$). †Outcomes are defined as the presence of one or more complications, a length of stay of more than six days, and a total hospital charge of ≥$15,000.

TABLE III Multivariate Analysis of Outcomes*

Exposure	Outcome†		
	Risk of Complications	Length of Stay	Total Hospital Charges
Surgeon volume (high versus low)	**0.6 (0.4-0.9)**	**0.3 (0.2-0.6)**	0.8 (0.5-1.3)
Hospital volume (high versus low)			
Hemiarthroplasty (versus total shoulder arthroplasty)		**2.3 (1.4-3.7)**	**1.8 (1.1-2.9)**
Age of ≥65 yr		**2.2 (1.3-3.8)**	**1.9 (1.1-3.2)**
Female gender	**0.5 (0.3-0.8)**		
Black	**2.0 (1.1-3.6)**	**2.5 (1.3-4.7)**	**3.4 (1.8-6.2)**
Married	**0.6 (0.4-0.9)**	**0.4 (0.3-0.7)**	**0.6 (0.4-0.9)**
Charlson comorbidity index of ≥1		**1.8 (1.4-2.4)**	**1.4 (1.1-2.0)**
History of osteoarthritis			
History of fracture			
History of rheumatoid arthritis			
Medical assistance			**0.2 (0.1-0.5)**

*The values are given as odds ratios, with 95% confidence intervals in parentheses. Bold type indicates values that were significant ($p \leq 0.05$). All variables were adjusted for all other variables in the final model. †Outcomes are defined as the presence of one or more complications, a length of stay of more than six days, and a total hospital charge of ≥$15,000.

Surgical Volume

Between 1994 and 2000, 1868 discrete total shoulder arthroplasties and hemiarthroplasties were performed in the state of Maryland. This was an increase of 106% over the ten-year period prior to the study period (907 procedures were performed from 1984 to 1993). Overall, the number of shoulder procedures increased from 233 procedures per year between 1994 and 1996 to 292 procedures per year between 1997 and 2000.

A total of 377 surgeons who were affiliated with fifty of the fifty-eight hospitals in Maryland and had performed at least one shoulder procedure between 1994 and 2000 were identified. There were 297 low-volume surgeons (594 procedures), seventy-one medium-volume surgeons (799 procedures), and nine high-volume surgeons (475 procedures). There were thirty-eight low-volume hospitals (731 procedures), seven medium-volume hospitals (539 procedures), and five high-volume hospitals (598 procedures) (see Appendix). Over the seven-year period, low-volume surgeons performed an average of 0.29 procedure per year, whereas middle and high-volume surgeons performed an average of 1.6 and 7.54 procedures, per year, respectively. The surgeons with the highest volume performed a disproportionately large number of all shoulder procedures. Although high-volume surgeons represented 2.4% of the surgeons, they did 25% of the procedures. In contrast, low-volume surgeons represented almost 80% of the surgeons but did only 32% of the procedures. High-volume surgeons had significantly fewer female patients and a significantly higher percentage of patients who were white and married than did low-volume surgeons ($p \leq 0.05$).

When the data for total shoulder arthroplasty and hemiarthroplasty were combined, the percentage of the procedures that were total shoulder arthroplasties was directly proportional to the volume of procedures that the surgeon performed (26.5% for low-volume, 39.9% for medium-volume, and 63.6% for high-volume surgeons), whereas the percentage of the procedures that were hemiarthroplasties was inversely proportional (73.5% for low-volume, 60.1% for medium-volume, and 36.4% for high-volume surgeons). Hospital volume demonstrated the same proportionality. The data showed that the highest-volume surgeons performed significantly fewer shoulder procedures on patients with a fracture of the humerus (20%) than did lower-volume surgeons (47.5%) ($p \leq 0.05$). The surgeons with the highest volume performed more shoulder replacement procedures on patients with osteoarthritis than did low-volume surgeons. The comorbidity index was not significantly different among surgeon groups.

Patient Outcomes

Descriptive data on the clinical and economic outcomes and the results of univariate analysis of the outcomes are summarized in Tables I and II, respectively. The complication rates associated with the high-volume surgeons were 5% less than those associated with the low-volume surgeons. After adjustment for procedure, age, gender, race, marital status, comorbidity, diagnosis, insurance status, income, and hospital volume, the risk of a complication associated with the high-volume surgeon group was nearly half that associated with the low-volume surgeon group (odds ratio, 0.6; 95% confidence interval, 0.4 to 0.9) (Table III). Multivariate analysis demonstrated that female patients and patients who were

married had a decreased risk of complications.

Patients of low-volume surgeons stayed in the hospital an average of 1.4 days longer than did patients of high-volume surgeons. After adjustment, high-volume surgeons were three times more likely than were low-volume surgeons to have patients with a hospital stay of less than six days (odds ratio, 0.3; 95% confidence interval, 0.2 to 0.6) (Table III).

Although the average cost of hospitalization was $1000 less for the high-volume surgeon group compared with the low-volume surgeon group, this reduction did not reach significance after adjustment for multiple variables (odds ratio, 0.8; 95% confidence interval, 0.5 to 1.3). Patients with a higher number of comorbid conditions and those who were black had significantly higher hospital costs, whereas those who were married had significantly lower hospital costs.

Discussion

In this study, a significant pattern of association was found between increased surgeon volume and improved outcomes. The patients of the surgeons who performed an average of less than two shoulder arthroplasties during the entire seven-year study period fared worse in most of the outcomes evaluated. The patients of the highest-volume surgeons had the fewest complications and the shortest length of stay both before and after adjustment of the data for procedure, age, gender, race, marital status, comorbidities, diagnosis, type of insurance, and hospital volume.

Far fewer total shoulder arthroplasties are performed nationwide compared with other total joint replacements, and, therefore, surgeons may have less experience with the procedure[1]. Luft et al.[17,18] argued that better outcomes are a direct result of greater experience with a procedure. Another possible explanation for the finding that the patients of low-volume surgeons have more complications is that low-volume surgeons treat patients who have more comorbidities. However, this was not the case since the results of this study were unchanged after they were adjusted for the severity of the comorbidites with use of a commonly utilized comorbidity index. A third explanation for these results is that patients are referred to surgeons who have better outcomes[18]. In this manner, these surgeons increase their caseload and become high-volume surgeons.

Individual surgeon experience rather than hospital factors was significantly associated with improved complication rates and shorter hospital stay. This finding suggests that improved outcomes for shoulder procedures are less dependent on familiarity with treatment procedures by support staff, ancillary services, or medical consultants. These hospital services, standards, and protocols did not appear to influence the outcomes as much as the experience of the individual surgeon did. This is likely because the support care for these procedures is relatively limited and these patients usually do not require intense monitoring. Another factor that may have influenced these results is the definition of a complication as shown in the Appendix. Most of the complications as defined in this paper are associated with patient or surgical factors and would be recorded regardless of how well the hospital services treated a particular patient.

Surgical volume was shown in the analysis to be predictive of a shorter length of stay for both shoulder procedures. Familiarity with the injury, rehabilitation protocols, and discharge plans already in place are possible reasons for the decreased duration of hospital stay associated with patients of high-volume surgeons. However, this does not explain why length of stay was not significantly affected by hospital volume. It is possible that the patients of a highly experienced surgeon had a shorter recovery time because there were fewer complications or because an experienced surgeon is apt to discharge patients sooner. These factors may negate any influence of hospital standards, protocols, or services, thus causing hospital volume not to significantly affect length of stay. Although length of stay was reduced for patients of high-volume surgeons, a concurrent reduction in total charges for this group did not reach significance. As seen in the multivariate analysis, this finding is most likely due to the fact that high-volume surgeons see patients who have an increased rate of comorbidities.

In the univariate analysis, patients undergoing hemiarthroplasty were shown to have two times the risk of a longer length of stay and one and one-half times the risk of increased hospital charges. This association is most likely due to the nature of the injuries that require a hemiarthroplasty compared with those that need a total shoulder arthroplasty. In particular, hemiarthroplasty is the procedure of choice for the treatment of many fractures of the proximal part of the humerus[1], which are typically complicated by a higher rate of comorbidity. Although low-volume surgeons treated more fractures than did high-volume surgeons, this factor was not an independent predictor for increased length of stay and total hospital charges in the multivariate analysis.

Patients with one comorbidity or more had significantly increased hospital charges. This finding could be due to the increased number of tests, consultations, ancillary services, and procedures done for these individuals. Although these patients had increased total hospital charges, the length of stay remained consistent with that of the healthier patients. Female patients and married individuals were shown to have lower rates of complications. Marital status was also shown to be significantly associated with a shorter length of stay and lower total charges. Additional studies need to be carried out to clarify the issues, but it is possible that a good support system at home reduces delays in discharge.

No difference was found between black and white patients with respect to complications; however, despite adjustment for known confounding factors, such as a diagnosis of a proximal humeral fracture, insurance status, and income, black patients were shown to have an increased length of stay and higher hospital charges. It is most likely that these differences were due to incomplete data with regard to the economic and overall health status of our study population. Another possible explanation for the increased hospital stay may have been the variations in destination after discharge or

other intangible social issues complicating discharge planning. A larger data set with more complete information about income and social status would clarify these issues.

This database was chosen because it was highly regulated and was all-inclusive for all hospitals in the state. Previous studies on shoulder procedures have used data from the Health Care Financing Administration Medicare database (MEDPAR) or data from the National Hospital Discharge Survey from the National Center for Health Statistics[19-24]. Medicare data encompasses patients over the age of sixty-five years. The average age of patients who have a total shoulder arthroplasty is the lowest among those for all major joint replacements[25]. This suggests that Medicare data alone would not be sufficient to study all shoulder procedures in the state of Maryland. The National Hospital Discharge Survey was a national survey derived from a random sampling of data from various hospitals throughout the country. This database also was not optimum because the random sampling of discharge data was not as comprehensive as that of the Maryland database.

Computerized administrative data sets have limitations. The Maryland Health Services Cost Review Commission database did not allow us to follow prospective outcomes, and no details of the surgery itself were available. This database did not allow us to determine whether a given patient was readmitted a second time for a revision procedure or for a procedure on the contralateral shoulder, since each patient had an encrypted unique patient identifier. Each case was treated as a unique patient, and this could have an effect on the analysis. Additional studies are needed to determine the long-term results and the percentage of patients requiring a revision or bilateral shoulder procedure. Furthermore, this database did not allow an analysis of the rates of specific surgical complications, and this study did not measure functional outcomes, pain relief, or patient satisfaction.

The accuracy of any database that utilizes CPT (current procedural terminology) coding has been questioned by some authors[14,16,26-32]. Most studies have demonstrated that demographic information on patients is typically accurate but that coding of comorbidities and complications is subject to substantial variations between coders, physicians, and other health personnel[14,16,26-32]. This variability is due in part to the indistinct nature of clinical codes, the variable threshold for reporting certain symptoms as indicative of a specific disease, lack of gradation of the severity of a condition in the codes, coding performed by coding clerks who are not medically trained, and difficulty in interpreting physicians' notes with regard to disease states[26,29,30,32].

A study performed at our institute reviewed medical records to determine whether complications of thyroidectomy that were identified in the Maryland Health Services Cost Review Commission database, which was the same one used in our study, were the same as those in the hospital chart[4]. The authors found a positive predictive value of 82% and a negative predictive value of 98% for the database. We did not perform a similar review for our study since it would not reflect the possible ranges of variability of reporting by other hospitals contributing to the data set. One study has suggested that coding errors were higher in small hospitals than in large hospitals[16].

The present study does not define acceptable minimum outcomes for shoulder replacements nor does it define what is "good enough." There may be no need to forgo the convenience and comfort of a low-volume community center under these guidelines. As with other total joint replacements, the need for immediate, local care may be paramount over other considerations. Katz et al.[33] suggested that information on pain relief, functional improvement, and the durability of the implant should be correlated with volume to provide an overall assessment of the feasibility of regionalization. Further study is needed to evaluate how the quality of total shoulder arthroplasty and hemiarthroplasty can be improved both in low-volume and high-volume centers.

Appendix

eA Tables showing the ICD-9 diagnostic codes, complications listed by ICD-9-CM diagnostic codes, and the characteristics of the provider groups 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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Jason W. Hammond, MD
William S. Queale, MD, MS, MHS
Tae Kyun Kim, MD, PhD
Edward G. McFarland, MD
Division of Sports Medicine and Shoulder Surgery, Department of Orthopaedic Surgery, Johns Hopkins University, 10753 Falls Road, Suite 215, Lutherville, MD 21093. E-mail address for E.G. McFarland: emcfarl@jhmi.edu

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