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ORIGINAL ARTICLE

Evidence-based thresholds for the volume-value relationship in shoulder arthroplasty: outcomes and economies of scale

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Background: Whereas several studies suggest that high-volume surgeons and hospitals deliver superior patient outcomes with greater cost efficiency, no evidence-based thresholds separating high-volume surgeons and hospitals from those that are low or medium volume exist in shoulder arthroplasty. The objective of this study was to establish meaningful thresholds that take outcomes and cost into consideration for surgeons and hospitals performing shoulder arthroplasty.
Methods: Using 9546 patients undergoing primary shoulder arthroplasty for osteoarthritis from an administrative database, we created and applied 4 models using stratum-specific likelihood ratio (SSLR) analysis of a receiver operating characteristic (ROC) curve. We generated 4 sets of thresholds predictive of adverse outcomes, namely, increased length of stay (LOS) and increased cost for both surgeon and hospital volume.
Results: SSLR analysis of the 4 ROC curves by surgeon volume produced 3 volume categories. LOS and cost by annual shoulder arthroplasty surgeon volume produced the same strata: 0-4 (low), 5-14 (medium), and 15 or more (high). LOS and cost by annual shoulder arthroplasty hospital volume produced the same strata: 0-3 (low), 4-14 (medium), and 15 or more (high). LOS and cost decreased significantly ($P < .05$) in progressively higher volume categories.
Conclusions: Our study validates economies of scale in shoulder arthroplasty by demonstrating a direct relationship between volume and value through SSLR analysis of ROC curves for risk-based volume stratification using meaningful volume definitions for low-, medium-, and high-volume surgeons and hospitals. The described volume-value relationship offers patients, surgeons, hospitals, and other stakeholders meaningful thresholds for the optimal delivery of shoulder arthroplasty.
Level of evidence: Level II; Economic and Decision Analysis

Keywords: Shoulder; arthroplasty; volume; outcomes; cost; length of stay (LOS); receiver operating characteristic (ROC); threshold

Rising procedure volumes, wide geographic variation, and the primarily elective nature of many orthopedic interventions ideally suit orthopedic surgery for value-based health care.[6,8,14,15,26,30] Most experts agree that value can generally

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be defined as the ratio of the benefits from a health service to the cost of delivering that service.[6] As the search for optimizing value in health care systems continues, several studies have demonstrated that high-volume surgeons and hospitals achieve better outcomes for patients and at a lower cost of care.[7,8,11,13,28,30] Whereas the notion of "practice makes perfect" is intuitive in understanding why higher volume surgeons may produce superior outcomes, the concomitant decrease in cost can be attributed to the phenomenon well described in business management as "economies of scale."[4,18]

As the evidence continues to mount in favor of higher volume hospitals and surgeons, the mainstream media has become acutely aware of these variations.[1,3] However, no consensus exists as to what specific threshold differentiates high volume from medium and low.[31] Classically, the stratification of hospital and surgeon volume from a continuous variable into categories (eg, low, medium, high volume) has proved useful for ease of data interpretation and the implementation of interventions. Thus, volume-outcomes studies often have relied on establishing arbitrary cutoffs or splitting patients into quartiles for analysis without correlation to value of care.[5] The results of this limitation create the potential for information loss and the invention of volume categories that have limited rational basis and inconsistency between studies.[2,25] If arbitrary volume thresholds are established in the literature, this can negatively affect the structural policy metrics of quality, patient safety, and reimbursement. Already, several hospitals have mandated minimum volume standards for certain procedures that prevent trained surgeons from performing particular cases without a particular level of surgical repetitions.[20] Thus, determining appropriate volume-based thresholds that confer value is a necessary first step.[31]

Wilson et al recently resurrected a 1993 study by Pierce and Connell that first described the methodology termed stratum-specific likelihood ratio (SSLR) analysis, which uses receiver operating characteristic (ROC) curves to identify volume thresholds with differing risks between strata.[21,31] Although it was previously applied in risk stratification for heart transplants, the Wilson study was the first to describe the volume-outcomes relationship in the context of total knee arthroplasty by the SSLR technique to identify the volume thresholds where the risk of adverse events drops most precipitously.[23,31] As important as addressing the volume-outcomes relationship is, we also sought to introduce cost to the denominator to arrive at meaningful thresholds for a volume-value relationship in shoulder arthroplasty. Thus, value included both a patient outcome, in this case length of stay (LOS), and cost. The purpose of this study was to apply SSLR analysis of a ROC curve to determine the volume-value effect in shoulder arthroplasty, including (1) the volume thresholds most predictive of hospital LOS and costs for surgeons and hospitals and (2) the associations between SSLR-generated volume strata and the risk of extended hospital LOS and increased costs from both the surgeon's and hospital's perspective.

Table I Depiction of all 4 stratum-specific likelihood ratio threshold analysis models performed

Surgeon threshold analysis	Hospital threshold analysis
LOS vs. volume	LOS vs. volume
Cost vs. volume	Cost vs. volume

LOS, length of stay.

Methods

Four SSLR threshold analysis models were created for the scenarios depicted in Table I. We used Clinical Classification Software (CCS) and All Patient Refined Diagnosis Related Groups (APR-DRGs) codes to define shoulder arthroplasty procedures related to osteoarthritis. Volume for both surgeon and hospital analyses was analyzed on an annual basis.

Data sources and study population

We used the New York State Department of Health's Statewide Planning and Research Cooperative System (SPARCS) database, a comprehensive reporting system that collects patient-level detail on all discharges from nonfederal acute care hospitals in the state of New York. Our data set included patient-specific data from 2011 through 2015 because more detailed data that included expenses were not available until 2011.

The cohort for the 4 models including patients undergoing shoulder arthroplasty for osteoarthritis met the following CCS and APR-DRG code criteria: CCS diagnosis code 203, Osteoarthritis; CCS procedure code 154, Arthroplasty—not hip/knee; and APR-DRG code 315, Shoulder and upper arm procedures. There was no discernible method of distinguishing between anatomic total shoulder arthroplasty, reverse total shoulder arthroplasty, and shoulder hemiarthroplasty. The analyses included patients with surgery dates after January 1, 2011, up to December 31, 2015. A total of 9546 patients met the criteria.

We defined annual surgeon volume as the number of shoulder arthroplasties performed in that calendar year by unique attending and operating surgeon identifiers. Annual surgeon volume combines all case volume for a surgeon who operates at >1 hospital in the state of New York. Similarly, we defined annual hospital volume as the number of shoulder arthroplasties performed in that calendar year by the unique hospital identifier. LOS was available within the database and defined as the number of days during the patient's operative admission. Cost was available within the database and was derived from the Institutional Cost Report (ICR) and New York SPARCS data. The ICR is a uniform report completed by New York State facilities to report income, expenses, assets, liabilities, and statistics to the Department of Health. Estimates of inpatient costs were calculated using hospital discharge data from the New York SPARCS and ICR data. ICRs include data on cost for each facility as well as ratios of cost to charges (RCCs). RCCs are certified, calculated, and reported by facilities and are subject to external audit. Specifically, the reported cost was the total charged for the patient's operative admission by the individual hospital less the attributed RCC amount. Thus, the cost was specific to both the orthopedic procedure (ie, shoulder arthroplasty) and the hospital because