Defining the type of surgeon volume that influences the outcomes for open abdominal aortic aneurysm repair

J. Gregory Modrall, MD,[a,b] Eric B. Rosero, MD,[a,b] Jayer Chung, MD,[b] Frank R. Arko III, MD,[b] R. James Valentine, MD,[b] G. Patrick Clagett, MD,[b] and Carlos H. Timaran, MD,[a,b] *Dallas, Tex*

Objective: **Prior studies have reported improved clinical outcomes with higher surgeon volume, which is assumed to be a product of the surgeon's experience with the index operation. We hypothesized that composite surgeon volume is an important determinant of outcome. We tested this hypothesis by comparing the impact of operation-specific surgeon volume versus composite surgeon volume on surgical outcomes, using open abdominal aortic aneurysm (AAA) repair as the index operation.**

Methods: **The Nationwide Inpatient Sample was analyzed to identify patients undergoing open AAA repairs for 2000 to 2008. Surgeons were stratified into deciles based on annual volume of open AAA repairs ("operation-specific volume") and overall volume of open vascular operations ("composite volume"). Composite volume was defined by the sum of several open vascular operations: carotid endarterectomy, aortobifemoral bypass, femoral-popliteal bypass, and femoral-tibial bypass. Multiple logistic regression analyses were used to examine the relationship between surgeon volume and in-hospital mortality for open AAA repair, adjusting for both patient and hospital characteristics.**

Results: **Between 2000 and 2008, an estimated 111,533 (95% confidence interval [CI], 102,296-121,232) elective open AAA repairs were performed nationwide by 6,857 surgeons. The crude in-hospital mortality rate over the study period was 6.1% (95% CI, 5.6%-6.5%). The mean number of open AAA repairs performed annually was 2.4 operations per surgeon. The mean composite volume was 5.3 operations annually. As expected, in-hospital mortality for open AAA repair decreased with increasing volume of open AAA repairs performed by a surgeon. Mortality rates for the lowest and highest deciles of surgeon volume were 10.2% and 4.5%, respectively ($P < .0001$). A similar pattern was observed for composite surgeon volume, as the mortality rates for the lowest and highest deciles of composite volume were 9.8% and 4.8%, respectively ($P < .0001$). After adjusting for patient and hospital characteristics, increasing composite surgeon volume remained a significant predictor of lower in-hospital mortality for open AAA repair (odds ratio, 0.994; 95% CI, .992-.996; $P < .0001$), whereas increasing volume of AAA repairs per surgeon did not predict in-hospital deaths.**

Conclusions: **The current study suggests that composite surgeon volume—not operation-specific volume—is a key determinant of in-hospital mortality for open AAA repair. This finding needs to be considered for future credentialing of surgeons. (J Vasc Surg 2011;54:1599-604.)**

Over the past several years, increasing attention has been focused on surgeon volume as a variable that may influence operative morbidity and mortality. The improvements in clinical outcomes associated with increasing surgeon volume are believed to be a consequence of enhanced patient selection, technical expertise, and perioperative management that evolves from a robust operative experience. Volume-related improvements in outcome have been reported for cardiac, gastrointestinal, colorectal, and cancer operations.[1-6] In vascular surgery, increasing surgeon volume has been associated with improved outcomes for carotid endarterectomy, lower extremity bypass, and open abdominal aortic aneurysm (AAA) repair.[1,7-13]

It has been generally assumed that the effects of higher surgeon volume on outcomes are related directly to the surgeon's experience with the index operation. Recognizing the potential for transference of skill sets between operations, we challenged this assumption by hypothesizing that composite surgeon volume is an important determinant of outcomes. Using open AAA repair as the index operation to test this hypothesis, we compared the impact of operation-specific surgeon volume versus composite surgeon volume on operative mortality for open AAA repair.

METHODS

Database. The Nationwide Inpatient Sample (NIS) from the Healthcare Cost and Utilization Project (HCUP) was used to identify all open AAA repairs performed during the years 2000-2008. Details of the NIS are outlined at http://www.hcup-us.ahrq.gov/nisoverview.jsp and summarized in prior publications.[14-16] Data were included for the 28 states in which patient data are linked to specific surgeons in the NIS database via surgeon identifiers. The

From the Dallas Veterans Affairs Medical Center[a]; and the Division of Vascular and Endovascular Surgery, Department of Surgery, University of Texas Southwestern Medical School.[b]

Competition of interest: none.

Presented at the Thirty-ninth Annual Symposium of the Society for Clinical Vascular Surgery, Orlando, Fla, March 16-19, 2011.

Reprint requests: Dr J. Gregory Modrall, University of Arkansas for Medical Sciences, 4301 W. Markham Street, #520, Little Rock, AR 72205 (e-mail: gmodrall@uams.edu).

The editors and reviewers of this article have no relevant financial relationships to disclose per the JVS policy that requires reviewers to decline review of any manuscript for which they may have a competition of interest.

0741-5214/$36.00
Published by Elsevier Inc. on behalf of the Society for Vascular Surgery.
doi:10.1016/j.jvs.2011.05.103

NIS consists of a 20% stratified sampling of inpatient admissions to U.S. acute care hospitals, excluding federal hospitals, and represents more than 38 million discharges annually. The NIS databases include patient demographics, primary and secondary diagnoses based on International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) diagnosis and procedure codes, and clinical outcomes. The study was exempt from review by the institutional review board because the NIS is available to the public as aggregate data without personal identifiers.

Comorbidities were itemized and used to calculate a modified Charlson comorbidity index (CCI) for each patient, as described previously.[15,17,18] Hospitals were categorized as teaching or nonteaching hospitals based on an affiliation with any residency approved by the Accreditation Council for Graduate Medical Education or membership in the Council of Teaching Hospitals.[14] Designation as an urban or rural hospital was based on 2000 Census definitions (urban: population $\geq$50,000; rural: population $<$50,000).[14]

Surgeon volume. Operation-specific volume was defined as a surgeon's annual volume of nonruptured open AAA repairs per year. Nonruptured open AAAs were identified using ICD-9-CM procedure codes 38.34 and 38.44 after merging with ICD-9-CM diagnosis codes for aortic aneurysm (441.4 and 441.9). Composite volume was defined by the sum of several open vascular operations: carotid endarterectomy, aortobifemoral bypass, femoral-popliteal bypass, and femoral-tibial bypass (ICD-9-CM procedure codes 38.12, 39.25, and 39.29). Surgeons were identified using HCUP unique surgeon identification numbers. Thirty-two percent of patients undergoing open AAA repairs during the study period were excluded because their operations could not be attributed to a specific surgeon in the database, precluding an analysis of surgeon volume. Annual surgeon volume of open AAA and composite procedures was determined by calculating the total number of repairs performed by an individual surgeon divided by the number of years that the surgeon was surveyed. Surgeons were then ranked in order of increasing mean annual volumes. Surgeons were stratified into 10 equal groups (deciles) based on their average annual volume of open AAA repairs ("operation-specific volume") and composite volume of open vascular operations ("composite volume"), as defined above. The cutoff points for each decile of volume were established before outcomes were examined, assuring objective cutoff points. Based on open AAA volume, the lowest five deciles of surgeon volume were defined by an average volume of $<$one case per year. Deciles six and seven were defined by an average volume of one to two cases per year. The three highest deciles of volume were defined by average volumes of two to three, three to five, and $>$five open AAA repairs per year. Similarly, based on composite volume, the lowest five deciles of surgeon volume were characterized by an average volume of $<$one case per year. Deciles six and seven included surgeons who performed an average of one to two cases per year, and the three highest deciles of volume were defined by average volumes of two to four, four to 12, and $>$12 open operations (of the categories defined in Methods) per year.

Statistical analysis. The primary endpoint of the study was in-hospital mortality for nonruptured open AAA repair. Continuous data were reported as means with standard deviation (SD) for normally distributed data and medians (with interquartile range) for non-normally distributed data. Categorical data were analyzed using χ^2, Fisher exact, and the Cochran-Armitage trend tests, as appropriate. Weighted analyses using the PROC SURVEYFREQ SAS procedure were performed to estimate the number of nonruptured open AAA repairs during the study period. As the analysis of interest was the effect of surgeon's volume on the primary outcome, all the other analyses were performed using the unweighted data. Multiple logistic regression analyses were used to examine the association between surgeon volume and in-hospital mortality for open AAA repair, adjusting for both patient and hospital characteristics, using the patient as the unit of analysis, with volume measured at the surgeon level. The final multivariable models adjusted for patient age, gender, race, elective repair, comorbidity index, expected principal source of payment, and hospital teaching status and location. All analyses were two-tailed, and the threshold for significance was .05. Statistical analysis was performed using SAS, version 9.2 (SAS Institute, Inc, Cary, NC).

RESULTS

Between 2000 and 2008, there were 22,988 discharges for nonruptured open AAA repairs performed by 6,857 surgeons, representing a nationwide estimate of 111,533 (95% confidence interval [CI], 102,296-121,232) open AAA repairs. The crude in-hospital mortality rate during the study period was 6.1% (95% CI, 5.6%-6.5%). The increasing use of endovascular aortic aneurysm repair during the study period may have influenced the outcomes for open AAA repair, so the longitudinal trend in mortality rate for open AAA repair was examined. No significant difference in mortality rate over time was identified ($P = .15$ by Cochran-Armitage trend test). Among those patients who survived to discharge, the majority were discharged home (82.0%), although 18.1% required home health care assistance. The remaining patients were discharged to short-term hospitals (1.1%) or skill nursing or intermediate care facilities (16.8%). The disposition could not be ascertained for a minority of patients (0.1%).

The baseline demographics and comorbidities of patients undergoing open AAA during the study period are outlined in Table I. The patient population was predominately male and Caucasian with a mean age of 67 ± 18 years. The majority (52.9%) of open AAA repairs were performed at teaching hospitals. Urban hospitals were the most common site for open AAA repairs (93.8%).

The mean number of open AAA repairs performed annually was 2.4 operations per surgeon (SD 3.2, median 1.0, interquartile range 1.0-2.5, mode 1.0 operations). Similarly, the mean composite volume was 5.3 operations annually per surgeon (SD 12.7, median 1.0, interquartile range 1.0-3.0, mode 1.0 operations). As expected, in-hospital mortality for open AAA repair decreased significantly with increasing volume of open AAA repairs performed by a surgeon (Fig 1; $P < .0001$). The mortality rate for open AAA repairs performed by surgeons in the lowest

Table I. Patient demographics and comorbidities

Characteristic	*Number of patients (%)*	P *value*[a]
Gender		$P < .0001$
Male	17,064 (74.2)	
Female	5922 (25.8)	
Age (years)		$P < .0001$
0-44	1363 (5.9)	
45-64	4579 (19.9)	
65-84	16,288 (70.9)	
≥85	758 (3.3)	
Race		$P < .0001$
White	16,720 (88.5)	
African-American	905 (4.8)	
Hispanic	779 (4.1)	
Other	483 (2.5)	
Unknown race	4101 (17.1)	
Primary expected payer		$P < .0001$
Medicare/Medicaid	4299 (65.4)	
Private insurance	2094 (31.9)	
Self-pay/other	183 (2.7)	
Congestive heart failure	973 (4.2)	
Hypertension	13,053 (56.8)	
Peripheral arterial disease	8156 (35.5)	
Diabetes	2229 (9.7)	
Chronic pulmonary disease	7918 (34.4)	
Chronic renal failure	1262 (5.5)	
Myocardial infarction	2774 (12.1)	
Cerebrovascular disease	1060 (4.6)	
Obesity	820 (3.6)	
Charlson comorbidity index score		$P < .0001$
0	984 (4.3)	
1	8901 (38.7)	
2	8103 (35.2)	
≥3	5000 (21.8)	
Hospital type		$P < .0001$
Teaching	12,157 (52.9)	
Nonteaching	10,831 (47.1)	
Hospital location		$P < .0001$
Urban	21,575 (93.8)	
Rural	1413 (6.2)	

[a] χ^2 for equal proportions.

decile of volume (10.2%) was nearly twofold higher than the mortality rate obtained by surgeons in the highest decile of volume (4.5%). Interestingly, a similar relationship was seen between composite surgeon volume and in-hospital mortality (Fig 2; $P < .0001$). Again, surgeons in the lowest decile of annual volume experienced a nearly twofold higher mortality rate for open AAA repair than surgeons in the highest decile of annual volume (9.8% vs 4.8%; $P < .0001$).

Aside from surgeon volume, univariate analyses identified several patient and hospital characteristics that were associated with higher mortality rates after open AAA repair (Table II). To identify independent risk factors for in-hospital mortality, the 11 significant variables from univariate analysis were entered into a stepwise logistic regression model: age, gender, chronic renal failure, congestive heart failure, diabetes mellitus, obesity, CCI, elective repair, teaching status of hospital, primary expected payer, and surgeon volume. Surgeon volume was accounted for by

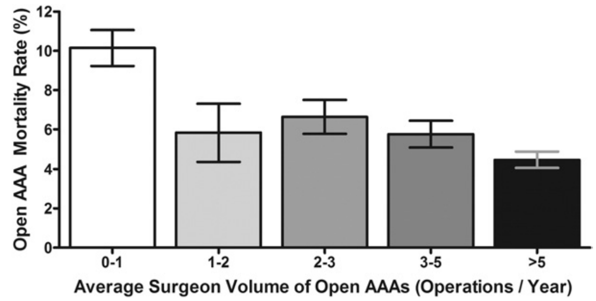

Fig 1. Surgeon volume of open abdominal aortic aneurysms (*AAAs*) and the effect on mortality rate for open AAA repair. The mortality rate (with 95% confidence intervals) for open AAA repair was plotted for the deciles of annual volume of open AAA repairs performed per surgeon. The lowest five deciles of surgeon volume were plotted together since these groups shared an average volume of less than one open AAA repair per year. Deciles six and seven were plotted together since these groups shared an average volume of one to two cases per year. The three highest deciles of volume were defined by average volumes of two to three, three to five, and >five open AAA repairs per year. A significant relationship was noted between surgeon volume of open AAAs and mortality rate for open AAA repair ($P < .0001$; Cochran-Armitage trend test).

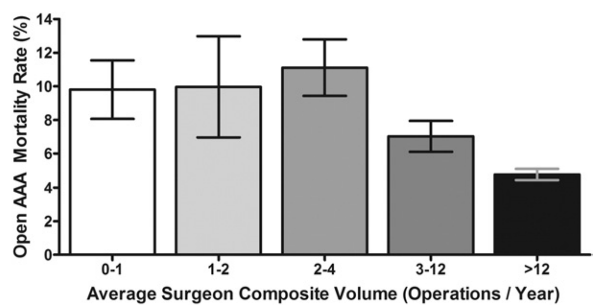

Fig 2. Composite surgeon volume and the effect on mortality rate for open abdominal aortic aneurysm (*AAA*) repair. The mortality rate (with 95% confidence intervals) for open AAA repair was plotted for the deciles of composite surgeon volume. The lowest five deciles of surgeon volume were plotted together since these groups shared an average volume of less than one case per year. Deciles six and seven were plotted together since these groups shared an average volume of one to two cases per year. The three highest deciles of volume were defined by average volumes of two to four, four to 12, and >12 open vascular operations (of the types defined in Methods) per year. A significant relationship was noted between composite surgeon volume and mortality rate for open AAA repair ($P < .0001$; Cochran-Armitage trend test).

performing two different multivariate analyses. One model included operation-specific surgeon volume of open AAAs, and the second model included composite surgeon volume in place of open AAA volume. In both models, surgeon volume was analyzed as a continuous variable. Interestingly, increasing volume of AAA repairs per surgeon was not a significant predictor of in-hospital mortality on multivariate analysis (data not shown), whereas increasing composite surgeon volume remained a significant predictor of

Table II. In-hospital mortality rates by risk factor

Parameter	*Mortality rate (%)*	P *value*[a]
Gender		$P < .0001$
Male	5.5	
Female	7.9	
Age (years)		$P < .0001$
1-44	4.7	
45-64	4.0	
65-84	6.5	
≥85	13.4	
Charlson comorbidity index score		$P < .0001$
0	4.1	
1	5.1	
2	5.4	
≥3	9.5	
Chronic lung disease		$P = .70$
Absent	6.2	
Present	6.0	
Chronic renal failure		$P < .0001$
Absent	5.7	
Present	13.3	
Congestive heart failure		$P < .0001$
Absent	5.8	
Present	13.8	
Diabetes mellitus		$P = .0008$
Absent	6.3	
Present	4.5	
Obesity		$P = .007$
Absent	6.2	
Present	3.9	
Elective operation		$P < .0001$
No	11.2	
Yes	4.4	
Hospital type		$P = .008$
Teaching	5.7	
Nonteaching	6.5	
Hospital location		$P = .13$
Urban	5.2	
Rural	6.2	
Primary expected payer		$P < .0001$
Medicare/Medicaid	7.3	
Private insurance	4.0	
Self-pay/other	8.5	

[a]*P* values by χ^2.

Table III. Independent predictors of in-hospital mortality

Predictor	*Odds ratio*[a] *(95% confidence interval)*	P *value*
Composite surgeon volume	0.994 (0.992-0.996)	$P < .0001$
Age (per year increase)	1.03 (1.03-1.04)	$P < .0001$
Female gender	1.41 (1.24-1.60)	$P < .0001$
Elective repair	0.39 (0.35-0.44)	$P < .0001$
Charlson comorbidity index	1.11 (1.06-1.18)	$P < .0001$
Chronic renal failure	1.63 (1.30-2.03)	$P < .0001$
Congestive heart failure	1.87 (1.51-2.33)	$P < .0001$
Diabetes mellitus	0.59 (0.46-0.74)	$P < .0001$
Nonteaching hospital	1.28 (1.14-1.44)	$P < .0001$

[a]Odds ratio of in-hospital mortality after open AAA repair.

lower in-hospital mortality for open AAA repair (odds ratio, 0.994; 95% CI, .992-.996; $P < .0001$; Table III). In addition to composite surgeon volume, multivariate analysis identified eight additional independent predictors of in-hospital mortality for open AAA repair: age, gender, elective repair, congestive heart failure, diabetes mellitus, chronic renal failure, CCI, and teaching status of the hospital (Table III). Among these variables, increasing composite surgeon volume, elective operations, and diabetes were associated with decreased mortality, while the remaining variables increased operative mortality for open AAA repair. Obesity and primary expected payer were not significant predictors of in-hospital mortality on multivariate analysis.

DISCUSSION

Several reports over the past 2 decades have described an association between increasing surgeon volume and improved outcomes for various operations across a wide array of specialties, including vascular surgery.[1-5,7-10,13] It has been generally assumed that a robust experience with the index operation itself ("operation-specific surgeon volume") is required to optimize outcomes for that operation. Recognizing that skill sets derived from one operation may be transferred to other operations, we questioned whether a surgeon's overall volume of open vascular operations ("composite surgeon volume") would confer any improvement in outcomes for an index vascular operation, such as open AAA repair. Indeed, the current study found that composite surgeon volume was an independent predictor of in-hospital mortality for open AAA repair. In contrast, we found that a surgeon's annual volume of open AAA repairs per se was not a predictor of in-hospital mortality for that operation after controlling for patient and hospital characteristics. Taken together, these data suggest that composite volume is the more important variable in determining outcomes of open AAA repair.

In the current era of vascular surgery, there are two general types of technical skill sets that must be acquired and maintained by vascular surgeons—traditional "open" vascular surgical skills and endovascular skills. Our data suggest that open skills may be less operation-specific than traditionally believed. It may be more important to be a skilled "open" vascular surgeon with a robust experience, including a wide array of open vascular operations, than it is to be an expert aortic surgeon. This conclusion is supported by our observation that mortality was more strongly linked to composite surgical volume than AAA volume.

The findings of this study have direct implications for credentialing of vascular surgeons. In recent years, many hospitals have gravitated toward criterion-based credentialing of surgeons in granting hospital privileges for certain operative procedures. This approach has been necessitated by the contentious nature of privileging for procedures for which there is overlap between multiple specialties. In some institutions, minimum case numbers of certain operations are used as a criterion for privileging. Our data suggest that such operation-specific numbers cannot be justified in absence of specific data to document improvements in outcome with a minimum level of experience. A notable example of a procedure for which a threshold number of cases is supported by literature is carotid artery angioplasty and stenting, where data from the lead-in phase of a clinical trial documented a critical "learning curve" that impacted clinical outcomes.[19] Aside from such examples, though, the routine use of specific case numbers for certain operations does not appear to be justifiable based on our data. It must be noted, though, that this study did not examine the relationship between surgeon volume and outcomes for endovascular operations, so it is not known whether this conclusion may be extrapolated to endovascular therapies.

A striking observation from this study is the relatively low volume of operations performed per surgeon in the NIS database. The average number of open AAA repairs per surgeon was 2.3 operations annually, and the average composite volume was 5.3 operations per surgeon per year. We interpret these modest numbers as evidence that many of these operations were performed by surgeons from other specialties, such as cardiac or general surgeons, who perform an occasional vascular operation. This supposition is consistent with the number of surgeons who performed those operations (6,857), which far exceeds the number of certified vascular surgeons in the United States (approximately 2,000). Certainly, most vascular surgeons would not consider performing more than five open AAAs per year to be a "high volume" experience, but it is clear from these data that vascular surgeons constitute a minority among those who are performing open AAA repairs. Regardless of training background, the current data could be construed as an important admonition that performing few open vascular operations each year is associated with worse outcomes, compared with surgeons who perform higher numbers of open vascular operations. In essence, these data may provide a circumstantial argument against practicing vascular surgery as a secondary specialty, recognizing that surgeon specialty per se is not specified in the NIS database. These data could also be used to argue for regionalization of vascular care to funnel certain index vascular operations, such as AAAs, to those surgeons with sufficient ongoing experience to provide superior clinical outcomes.

The current study appears to contradict prior studies on the relationship between surgeon volume and outcomes for open AAA repair.[1,7,10-13] Several factors may account for the discrepancy between the current and prior studies. First, the current study covered a study period from 2000 to 2008. During this time period, endovascular aneurysm repair has become first-line therapy for most AAAs The resulting decline in frequency of open AAA repairs may have impacted the surgeon volume-outcome relationship for this operation. The current study also employed extensive risk adjustment specific to open AAA repair in its multivariate analysis. Finally, the current study examined both composite and operation-specific surgeon volumes, which extended the observations of prior studies.

The current did not address the role of hospital volume in determining outcomes for open AAA repair. With increasing surgeon volume, hospital systems may evolve and improve concurrently, which may impact surgical outcomes. Indeed, both Birkmeyer[1] and McPhee[13] found that increasing hospital volume was associated with decreased in-hospital mortality for open AAA repair. However, both investigators found that surgeon volume was the more important variable in influencing outcomes. Birkmeyer found that only 15% of the effect of surgeon volume could be attributed to hospital volume effects.[1] McPhee also found that high surgeon volume conferred a greater mortality reduction than did high institution volume.[13]

The findings of the current study provide new insight into the type of surgeon volume that is relevant to outcomes in vascular surgery, but there are limitations to the study that must be acknowledged. First, the extent to which these findings may be generalized to other operations in vascular surgery is not known. We examined the outcomes for open AAA repair, so it is not known whether the current findings apply to all open vascular operations, certain subsets of vascular operations, or only apply to open AAA repair. The current study did not address the issue of surgeon volume and outcomes for endovascular therapies, so it is not known whether these findings are applicable to endovascular procedures. In addition, the current study was unable to assess the relative contributions of training background or cumulative prior experience with the index case to the outcomes obtained for open AAA repair. Furthermore, there are potential limitations to the NIS database that must be recognized. One-third of patients could not be attributed to a specific surgeon and were excluded from the study population. The impact of these exclusions on the results of the study is unknown. In spite of this limitation, the size of the remaining cohort afforded a unique opportunity to examine the relationship between surgeon volume and outcomes for open AAA repair. Administrative databases such as the NIS have been criticized by some authors who allege that the utility of these databases are limited by allegations of inaccurate coding, undercoding of comorbidities, and nonstandardized mortality endpoints.[20,21] Although we cannot dispute these contentions, the observation that composite volume was more closely associated with improved outcomes for open AAA remains an interesting finding that warrants further study.

CONCLUSION

The current study suggests that composite surgeon volume—not operation-specific volume—is a key determinant of in-hospital mortality for open AAA repair. These data suggest that composite case numbers may be a more valid criterion than operation-specific case numbers in credentialing. Whether this finding may be generalized to other open and endovascular procedures remains to be clarified.

AUTHOR CONTRIBUTIONS

Conception and design: JM, CT
Analysis and interpretation: JM, RV, ER, GC, CT, FA, JC
Data collection: JM, CT
Writing the article: JM, RV, GC, CT, FA, JC

Critical revision of the article: JM, RV, ER, GC, CT
Final approval of the article: JM, RV, ER, GC, CT, JC, FA
Statistical analysis: JM, ER, CT
Obtained funding: Not applicable
Overall responsibility: JM

REFERENCES

1. Birkmeyer JD, Stukel TA, Siewers AE, Goodney PP, Wennberg DE, Lucas FL. Surgeon volume and operative mortality in the United States. N Engl J Med 2003;349:2117-27.
2. van Gijn W, Gooiker GA, Wouters MW, Post PN, Tollenaar RA, van de Velde CJ. Volume and outcome in colorectal cancer surgery. Eur J Surg Onc 2010;36 (Suppl 1):S55-63.
3. Park HS, Roman SA, Sosa JA. Outcomes from 3144 adrenalectomies in the United States: which matters more, surgeon volume or specialty? Arch Surg 2009;144:1060-7.
4. Eppsteiner RW, Csikesz NG, McPhee JT, Tseng JF, Shah SA. Surgeon volume impacts hospital mortality for pancreatic resection. Ann Surg 2009;249:635-40.
5. Nathan H, Cameron JL, Choti MA, Schulick RD, Pawlik TM. The volume-outcomes effect in hepato-pancreato-biliary surgery: hospital versus surgeon contributions and specificity of the relationship. J Am Coll Surg 2009;208:528-38.
6. Hannan EL, Radzyner M, Rubin D, Dougherty J, Brennan MF. The influence of hospital and surgeon volume on in-hospital mortality for colectomy, gastrectomy, and lung lobectomy in patients with cancer. Surgery 2002;131:6-15.
7. Dardik A, Lin JW, Gordon TA, Williams GM, Perler BA. Results of elective abdominal aortic aneurysm repair in the 1990s: a population-based analysis of 2335 cases. J Vasc Surg 1999;30:985-95.
8. Hannan EL, Popp AJ, Tranmer B, Fuestel P, Waldman J, Shah D. Relationship between provider volume and mortality for carotid endarterectomies in New York state. Stroke 1998;29:2292-7.
9. Cowan JA Jr, Dimick JB, Thompson BG, Stanley JC, Upchurch GR Jr. Surgeon volume as an indicator of outcomes after carotid endarterectomy: an effect independent of specialty practice and hospital volume. J Am Coll Surg 2002;195:814-21.
10. Dimick JB, Cowan JA Jr, Stanley JC, Henke PK, Pronovost PJ, Upchurch GR Jr. Surgeon specialty and provider volumes are related to outcome of intact abdominal aortic aneurysm repair in the United States. J Vasc Surg 2003;38:739-44.
11. Marlow NE, Barraclough B, Collier NA, Dickinson IC, Fawcett J, Graham JC, et al. Effect of hospital and surgeon volume on patient outcomes following treatment of abdominal aortic aneurysms: a systematic review. Eur J Vasc Endovasc Surg 2010;40:572-9.
12. Cho JS, Kim JY, Rhee RY, Gupta N, Marone LK, Dillavou ED, et al. Contemporary results of open repair of ruptured abdominal aortoiliac aneurysms: effect of surgeon volume on mortality. J Vasc Surg 2008; 48:10-7.
13. McPhee JT, Robinson WP III, Eslami MH, Arous EJ, Messina LM, Schanzer A. Surgeon case volume, not institution case volume, is the primary determinant of in-hospital mortality after elective open abdominal aortic aneurysm repair. J Vasc Surg 2011;53:591-9.
14. Healthcare Cost and Utilization Project. Overview of the National Inpatient Sample of the Healthcare Cost and Utilization Project. Available at: http://www.hcup-us.ahrq.gov/nisoverview.jsp. Accessed September 1, 2010.
15. Modrall JG, Rosero EB, Smith ST, Arko FR III, Valentine RJ, Clagett GP, et al. Operative mortality for renal artery bypass in the United States: results from the National Inpatient Sample. J Vasc Surg 2008; 48:317-22.
16. Modrall JG, Rosero EB, Smith ST, Arko FA III, Valentine RJ, Clagett GP, et al. Effect of hospital volume on in-hospital mortality for renal artery bypass. Vasc Endovasc Surg 2009;43:339-45.
17. Deyo RA, Cherkin DC, Ciol MA. Adapting a clinical comorbidity index for use with ICD-9-CM administrative databases. J Clin Epidemiol 1992;45:613-9.
18. Charlson ME, Pompei P, Ales KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chronic Dis 1987;40:373-83.
19. Hobson RW 2nd, Howard VJ, Roubin GS, Ferguson RD, Brott TG, Howard G, et al. Credentialing of surgeons as interventionalists for carotid artery stenting: experience from the lead-in phase of CREST. J Vasc Surg 2004;40:952-7.
20. Shahian DM, Silverstein T, Lovett AF, Wolf RE, Normand SL. Comparison of clinical and administrative data sources for hospital coronary artery bypass graft surgery report cards. Circulation 2007; 115:1518-28.
21. Iezzoni LI, Foley SM, Daley J, Hughes J, Fisher ES, Heeren T. Comorbidities, complications, and coding bias. Does the number of diagnosis codes matter in predicting in-hospital mortality? JAMA 1992; 267:2197-203.

Submitted Mar 19, 2011; accepted May 17, 2011.

INVITED COMMENTARY

Timothy F. Kresowik, MD, *Iowa City, Iowa*

There have been numerous publications on the relationship between volume and outcome for various complex surgical procedures. The concept that more experience leads to better outcomes certainly has face validity. What has been more problematic is how to quantify this relationship in a way that could be and/or should be used to guide credentialing or certification. Although most publications do show a statistically significant positive relationship between volume of procedures performed and better outcomes, the linear correlation is weak. Setting arbitrary minimum thresholds is potentially associated with a perverse incentive to try to meet the target number by doing more unnecessary procedures.

In addition, the finding of a statistically significant difference does not mean the difference is clinically significant. For example, if the mortality rate for surgeons with a volume of less than five cases per year was 6% and the mortality rate was 5% for surgeons who do more than 30 cases per year, most of us would not consider the 1% difference in mortality enough to justify a credentialing threshold.

The report by Modrall et al has similar findings and limitations as most of the other publications about the procedure volume outcome relationship. Although clearly at the extremes of low and high volumes there is a significant difference in mortality for open abdominal aortic aneurysm (AAA) repair, they did not demonstrate a clear stepwise decrement in mortality with either increasing AAA or composite volume (Figs 1 and 2). Their individual case volumes are also strikingly low with the finding that more than 50% of the surgeons in the database did one or less open AAA repairs per year and one or less "composite" open vascular procedures per year. This finding may be more indicative of the considerable limitations of the NIS database because of the 20% sampling strategy and the fact that one-third of the cases could not be associated with an individual surgeon than a representative of the real world of vascular procedures.

Nonetheless, the important "take-home" message of this report is the finding that composite vascular volume is a better predictor of better outcomes than open AAA repair volume alone. One would think that the aforementioned limitations of the database would not invalidate this finding. I would agree with the authors' conclusion that this suggests that overall experience with related types of procedures may be a better criteria for credentialing than a procedure-specific focus.