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Relation of Mitral Valve Surgery Volume to Repair Rate, Durability, and Survival

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ABSTRACT

BACKGROUND Degenerative mitral valve repair rates remain highly variable, despite established benefits of repair over replacement. The contribution of surgeon-specific factors is poorly defined.

OBJECTIVES This study evaluated the influence of surgeon case volume on degenerative mitral valve repair rates and outcomes.

METHODS A mandatory New York State database was queried and 5,475 patients were identified with degenerative mitral disease who underwent mitral valve operations between 2002 and 2013. Mitral repair rates, mitral reoperations within 12 months of repair, and survival were analyzed using multivariable Cox modeling and restricted cubic spline function.

RESULTS Median annual surgeon volume of any mitral operations was 10 (range 1 to 230), with a mean repair rate of 55% (n = 20,797 of 38,128). In the subgroup of patients with degenerative disease, the mean repair rate was 67% (n = 3,660 of 5,475), with a range of 0% to 100%. Mean repair rates ranged from 48% (n = 179 of 370) for surgeons with total annual volumes of ≤10 mitral operations to 77% (n = 1,710 of 2,216) for surgeons with total annual volumes of >50 mitral operations ($p < 0.001$). Higher total annual surgeon volume was associated with increased repair rates of degenerative mitral valve disease (adjusted odds ratio [OR]: 1.13 for every additional 10 mitral operations; 95% confidence interval [CI]: 1.10 to 1.17; $p < 0.001$); a steady decrease in reoperation risk until 25 total mitral operations annually; and improved 1-year survival (adjusted hazard ratio: 0.95 for every additional 10 operations; 95% CI: 0.92 to 0.98; $p = 0.001$). For surgeons with a total annual volume of ≤25 mitral operations, repair rates were higher (63.8%; n = 180 of 282) if they operated in the same institution as a surgeon with total annual mitral volumes of >50 and degenerative mitral valve repair rates of >70%, compared with surgeons operating in the other institutions (51.3%; n = 580 of 1,130) (adjusted OR: 1.79; 95% CI: 1.24 to 2.60; $p < 0.001$).

CONCLUSIONS This study suggests that individual surgeon volume is a determinant of not only mitral repair rates, but also freedom from reoperation, and survival. The data from this study support the guideline's concept of reference referral to experienced mitral surgeons to improve outcomes in patients with degenerative mitral valve disease. (J Am Coll Cardiol 2017;69:2397–406) © 2017 The Authors. Published by Elsevier on behalf of the American College of Cardiology Foundation. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Mitral valve repair is favored over valve replacement for the treatment of severe mitral valve regurgitation in patients who have degenerative valve disease with mitral valve prolapse (1,2). Both U.S. and European guidelines strongly recommend valve repair whenever possible, and they also emphasize the importance of a durable and long-lasting repair, particularly when intervening

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ABBREVIATIONS AND ACRONYMS

CI = confidence interval

HR = hazard ratio

ICD-9-CM = International Classification of Diseases-Ninth Revision-Clinical Modification

OR = odds ratio

on an asymptomatic patient (1,2). Mitral valve replacement unfortunately remains relatively common in patients with degenerative valve disease, and studies have highlighted wide variation in mitral surgical volume and repair rates when looking at "all-comer" study groups (3–10). The influence of mitral surgical volume on perioperative mortality and repair rates is becoming established, but less is known regarding the impact of volume on 1-year survival and the need for early reoperation. Most large database reports have also included a broad range of causes of mitral valve disease.

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To understand the effect of case volume on clinical outcomes in patients likely to have isolated degenerative disease more clearly, we analyzed a cohort drawn from all patients undergoing mitral valve operations in New York State. We sought to determine the effect of surgeon-specific factors on repair rates, survival, and long-term freedom from repeat mitral valve surgery.

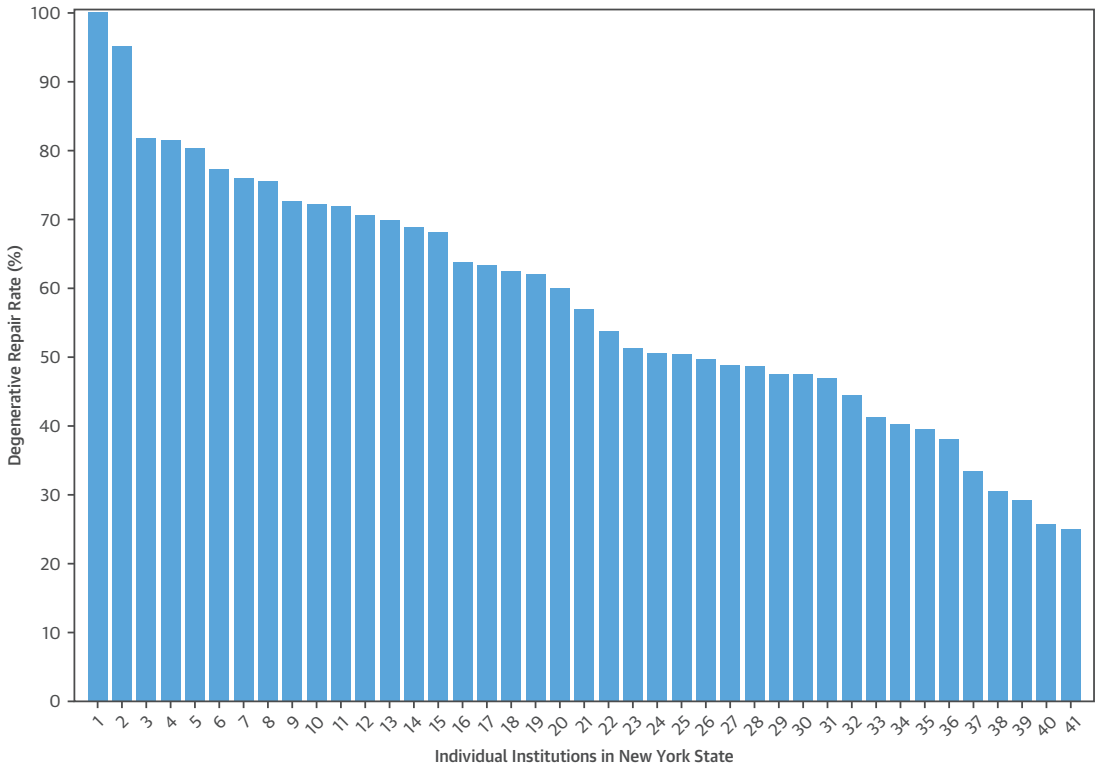
METHODS

PATIENTS. This study was an analysis of adult patients, 18 years of age or older, who underwent primary mitral valve operations in New York State between January 1, 2002 and December 31, 2013. Patients were identified using the Statewide Planning and Research Cooperative System, an all-payer, administrative database that prospectively collects data on every hospital discharge, ambulatory surgery, and emergency department visit in New York State, with longitudinal data available from 1995 to 2014. We reviewed all available pre-operative patient data to identify patients' baseline characteristics and followed up patients for at least 12 months post-operatively. Patients undergoing mitral valve replacement were identified using the International Classification of Diseases-Ninth Revision-Clinical Modification (ICD-9-CM) procedure codes 35.23 and 35.24; patients undergoing mitral valve repair were identified using ICD-9-CM codes 35.12 and 35.33. Through exclusion of other causes, we identified a subgroup of patients with presumed degenerative mitral valve disease. Exclusion criteria were other possible mitral valve causes, including any history of coronary artery disease, myocardial infarction, rheumatic valve disease, infective endocarditis, congenital heart disease, and cardiomyopathy. Patients who underwent concomitant surgery on the aortic valve, pulmonary valve, coronary arteries, or the left ventricle and patients with prior replacement or repair of any valve, prior coronary revascularization, prior heart transplantation, and prior ventricular assist device placement were also excluded. Additionally, we excluded patients with out-of-state residency to ensure complete follow-up using the Statewide Planning and Research Cooperative System. Patients who did not have identifiable surgeons were also excluded (Online Figure 1, Online Table 1 [ICD-9-CM codes]). Baseline comorbidities were identified using present-on-admission diagnosis codes from the index hospitalization and all diagnoses from hospitalizations before the index hospitalization (Online Table 2). We compared repair rates, long-term survival, and risk of post-repair reoperation in the subgroup of patients with degenerative disease according to total annual surgeon volume, which was defined as any mitral valve operation for any cause during the study period (see definitions). This study was approved by the Data Protection Review Board of the New York State Department of Health, as well as by the Program for Protection of Human Subjects at the Icahn School of Medicine at Mount Sinai in New York City. The approval included a waiver of informed consent.

DEFINITIONS. Total annual surgeon volume for the surgeon who performed the operation on each patient was calculated as the number of mitral valve operations for any causes (repair or replacement) performed by the patient's operating surgeon in the 365 days immediately before surgery, to reflect the recent experience of each surgeon at the time of surgery. Next, the experience of each surgeon across the entire study period was quantified as mean total annual surgeon volume. Degenerative mitral valve repair rate was calculated as the number of repairs divided by the total number of operations for degenerative mitral valve disease a surgeon performed. Surgeons were considered eligible for the study when they practiced for at least 365 days.

STUDY ENDPOINTS. The study endpoints were all-cause mortality, degenerative repair rates, and post-repair mitral valve reoperation. Reoperation was defined as any mitral valve operation, either replacement or repair, on subsequent admissions. Patients with no documented reoperation were censored on December 31, 2014. Deaths were identified using the full national Social Security Death Master File (current as of May 29, 2015) and by searching all hospital admissions and ambulatory or emergency department visits for patients' deaths. For 1-year mortality and reoperation, time to events was

FIGURE 1 Institutional Repair Rates for Degenerative Mitral Valve Operations Between 2002 and 2013 at All Institutions in New York State



Wide variation in degenerative mitral repair rates is observed among all 41 institutions reporting mitral valve operations in New York State.

censored at 1 year after surgery for patients who did not have events by then.

STATISTICAL ANALYSIS. Continuous variables were reported as means with SDs. Categorical variables were expressed as proportions. Differences in baseline characteristics and comorbidities among patients treated by surgeons with different volumes were assessed using analysis of variance for normally distributed continuous variables and Pearson's chi-square test for categorical variables. To describe the difference in patients' baseline demographics and comorbidities according to total annual surgeon volume, 4 groups with arbitrary cutoffs were created: ≤10; 11 to 24; 25 to 50; and ≥51 mitral valve procedures/year.

Survival after mitral valve repair or replacement and post-repair reoperation were assessed by fitting multivariable Cox proportional hazard models with a robust sandwich variance estimator to control for clustering of patients operated on by the same surgeons and adjusting for covariates and total annual surgeon volume treated as a continuous variable. Baseline characteristics (age, sex, race or ethnicity, type of admission, year of mitral surgery, hypertension, diabetes, peripheral vascular diseases, cerebrovascular disease, chronic heart failure, atrial fibrillation, chronic obstructive pulmonary disease, chronic kidney disease, liver disease, malignant disease, coagulation, platelet disorders, and pulmonary hypertension) were included in the model as covariates. For the primary endpoint analysis of survival, a separate model with procedure type (repair or replacement) was also created. This model included the baseline covariates listed in the preceding text and procedure type. The probability of mitral valve repair was assessed by fitting multivariable logistic regression models with generalized estimating equations to control for clustering of patients operated on by the same surgeons, where repair procedure was a dependent variable and the baseline characteristics listed earlier were included as

TABLE 1 Demographics of Patients With Degenerative Mitral Valve Disease Stratified by Surgeon Volume Groups

	≤10 Operations/Yr (n = 370)	11–24 Operations/Yr (n = 1,042)	25–50 Operations/Yr (n = 1,847)	≥51 Operations/Yr (n = 2,216)	p Value
Demographics					
Age, yrs	59.3 ± 13.9	59.0 ± 14.3	60.3 ± 14.0	58.8 ± 14.2	0.005
Male	177 (47.8)	505 (48.5)	875 (47.4)	1128 (50.9)	0.14
Race					<0.001
White (non-Hispanic)	227 (61.4)	649 (62.3)	1,263 (68.4)	1,636 (73.8)	
African American (non-Hispanic)	44 (11.9)	119 (11.4)	173 (9.4)	126 (5.7)	
Hispanic	18 (4.9)	75 (7.2)	163 (8.8)	80 (3.6)	
Other/unknown	81 (21.9)	199 (19.1)	248 (13.4)	374 (16.9)	
Urgent admission	98 (26.5)	231 (22.2)	309 (16.7)	345 (15.6)	<0.001
Comorbidities					
Hypertension	182 (49.2)	549 (52.7)	973 (52.7)	1,015 (45.8)	<0.001
Diabetes mellitus	37 (10.0)	105 (10.1)	168 (9.1)	138 (6.2)	<0.001
Peripheral vascular disease	<10 (<2.7)*	12 (1.2)	15 (0.8)	15 (0.7)	0.10
Cerebrovascular disease	12 (3.2)	42 (4.0)	67 (3.6)	50 (2.3)	0.02
Congestive heart failure	159 (43.0)	440 (42.2)	698 (37.8)	595 (26.9)	<0.001
Atrial fibrillation	141 (38.1)	356 (34.2)	654 (35.4)	716 (32.3)	0.07
Chronic obstructive pulmonary disease	52 (14.1)	159 (15.3)	289 (15.7)	236 (10.7)	<0.001
Chronic kidney disease	25 (6.8)	52 (5.0)	106 (5.7)	50 (2.3)	<0.001
Liver disease	<10 (<2.7)*	49 (4.7)	48 (2.6)	55 (2.5)	0.003
Cancer	37 (10.0)	79 (7.6)	180 (9.8)	221 (10.0)	0.15
Coagulation/platelet disorders	14 (3.8)	60 (5.8)	84 (4.6)	114 (5.1)	0.35
Pulmonary hypertension	<10 (<2.7)*	24 (2.3)	34 (1.8)	36 (1.6)	0.61
Mitral repair (repair rate)	179 (48.4)	581 (55.8)	1,190 (64.4)	1,710 (77.2)	<0.001

Values are mean ± SD or n (%). *Small cell sizes (number <10) are suppressed according to our data use agreement with the Statewide Planning and Research Cooperative System.

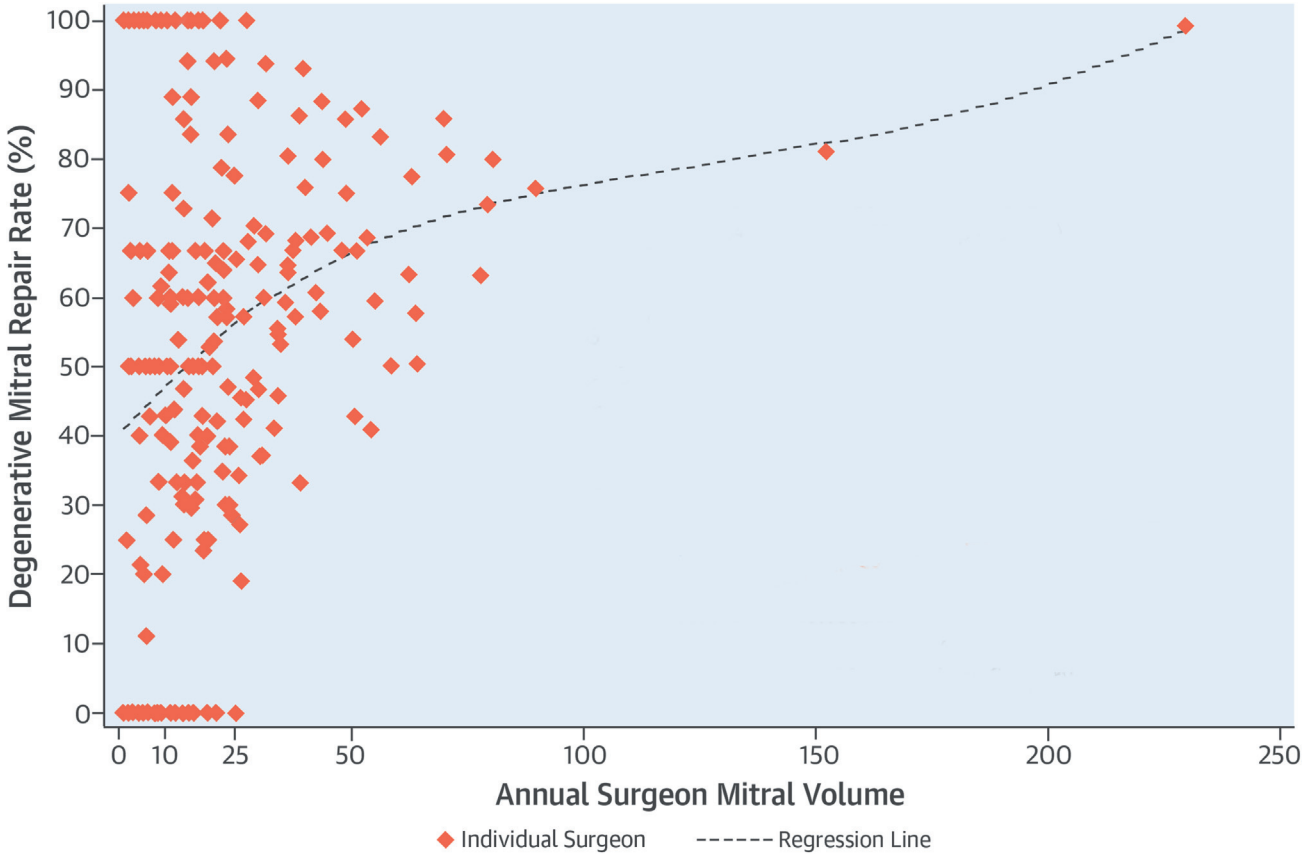
independent variables. Risk-adjusted probabilities of mitral valve repair with corresponding 95% confidence intervals (CIs) were plotted at each total annual surgeon volume.

Total annual surgeon volume was first included into each model as a continuous variable, and the linear association between volume and each outcome was tested using restricted cubic spline functions with 3 knots at total annual surgeon volumes of 10, 25, and 50 operations/year (11,12). Linearity was assessed by linear hypothesis testing, and Akaike information criteria were used for the best model selection. The volume association with outcomes was shown either as an adjusted hazard ratio (HR) for survival and reoperations or as an adjusted odds ratio (OR) with its 95% CI for assessing probability of repair. The association between total annual surgeon volume and post-repair reoperation was nonlinear. By using a multivariable Cox regression model with restricted cubic spline function, the HR of reoperation within 1 year after repair was plotted against total annual surgeon volume (11). The observed change point of the slope of the HR curve was used as a cutoff value. The same Cox regression model, with surgeon volume as a categorical variable, was created, and the adjusted HR by 2 groups was reported. The association between total annual surgeon volume and survival or probability of repair was linear: adjusted HR for survival and adjusted OR for repair were calculated by 10-case volume increments and also by the arbitrary cutoffs defined earlier. Cumulative incidence function curves of post-repair reoperation were constructed using risk competing analysis. The proportional hazards assumption was valid in all Cox models. All tests were 2-tailed, and an alpha level of 0.05 was considered statistically significant. All statistical analyses were performed using SAS software version 9.4 (SAS Institute, Cary, North Carolina).

RESULTS

STUDY POPULATION. A total of 5,475 adults with degenerative mitral valve disease, 18 years of age or older, who underwent primary mitral valve operations performed by cardiac surgeons in New York State from January 1, 2002 to December 31, 2013, were identified: 3,660 (66.8%) patients underwent mitral valve repair, and 1,815 patients (33.2%) underwent mitral valve replacement. Median follow-up time was 6.8 years (range 0 to 13.4 years).

CENTRAL ILLUSTRATION **Current Status of Degenerative Mitral Valve Repair in New York State**



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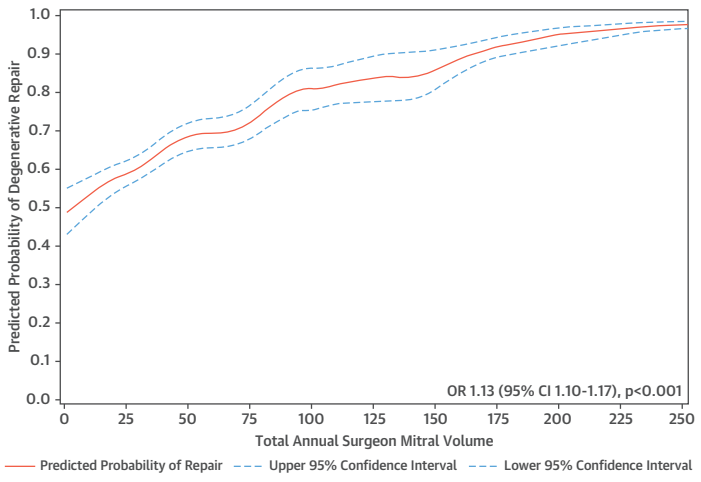
Key findings: 1) the median annual surgeon mitral volume is 10 operations; 2) wide variability of repair rates is observed among surgeons; 3) higher volume is associated with higher repair rates and better outcomes; 4) reoperation after repair is less common for patients operated on by surgeons with ≥25 mitral valve operations a year; and 5) low-volume surgeons (<25 operations/year) in institutions where high-volume, high-repair-rate surgeons (>50 operations/year and >70% repair rate) are present have improved repair rates.

A total of 313 surgeons from 41 institutions met the study eligibility criteria. Surgeons in New York State performed a median of 10 mitral valve operations/year (range 1 to 230). The repair rate for primary mitral valve procedures for any causes was 55% (n = 20,797 of 38,128); the median annual institutional mitral valve volume was 59 mitral valve operations, ranging from a minimum of 6 to a maximum of 310 operations. Repair rates for primary mitral valve operations for any cause at all 41 institutions varied from 15% to 83%, and repair rates for degenerative mitral valve operations varied from 25% to 100% (Figure 1). Of 313 surgeons, 231 operated on at least 1 patient in the cohort with degenerative disease who was included in further analysis.

In the cohort of 5,475 patients with degenerative disease, surgeons with a total annual surgeon volume <25 operations carried out 25% of operations (n = 1,412). These patients were significantly more likely to present as urgent admissions (27% vs. 16%; $p < 0.001$), and they were more likely to have major comorbidities, such as congestive heart failure (43% vs. 27%; $p < 0.001$), chronic kidney disease (7% vs. 2%; $p < 0.001$), or chronic airway disease (14% vs. 11%; $p < 0.001$) than were patients operated on by surgeons with higher total annual surgeon volumes (Table 1).

MITRAL VALVE REPAIR RATE. We observed a significant association between lower total annual

FIGURE 2 Predicted Probability of Mitral Repair for Degenerative Operations According to Total Annual Surgeon Mitral Valve Volume



After adjustment for pre-operative risk factors, degenerative repair probability is significantly associated with total annual mitral valve surgeon volume. CI = confidence interval; OR = odds ratio.

surgeon volume and lower mitral valve repair rates in the cohort with degenerative disease. The overall mitral valve repair rate in the degenerative disease cohort was 66.8% (n = 3,660 of 5,475). The observed degenerative disease repair rate according to mean total annual surgeon volume is shown in the **Central Illustration**. After multivariable adjustment, total annual surgeon volume was independently associated with the probability of mitral valve repair; the chance of repair increased by 13% for every 10-case increment in total annual surgeon volume (adjusted OR: 1.13/10-case increment; 95% CI: 1.10 to 1.17; p < 0.001) (**Figure 2**). Compared with patients operated on by surgeons with a total annual surgeon volume of ≤10 operations, patients operated on by surgeons with a total annual surgeon volume of >50 operations were >3 times as likely to undergo mitral valve repair (adjusted OR: 3.18; 95% CI: 2.02 to 5.00; p < 0.001) (**Table 2**).

TABLE 2 Adjusted OR of Mitral Valve Repair According to Surgeon Volume Groups, p < 0.001

Volume Category (Operations/Yr)	Adjusted OR (95% CI)	Observed Repair Rate, %
≤10	Reference	48.4
11–24	1.22 (0.89–1.70)	55.8
25–50	1.77 (1.26–2.49)	64.4
≥51	3.18 (2.02–5.00)	77.2

CI = confidence interval; OR = odds ratio.

We observed a possible influence of a high-volume and high-repair surgeon on low-volume surgeons in the same institution. Among the 1,412 patients with degenerative mitral valve disease who were operated on by surgeons with a total annual surgeon volume <25, 20% (n = 282) underwent mitral valve surgery at centers where there was also an individual surgeon carrying out >50 mitral valve operations annually with a >70% degenerative disease repair rate. The repair rate of the 49 surgeons who performed <25 operations annually at such centers was 63.8%, compared with 51.3% at the remaining centers (adjusted OR: 1.79; 95% CI: 1.24 to 2.60; p = 0.002).

REOPERATION AFTER MITRAL REPAIR. We observed a significant association between low surgeon volume and increased risk of mitral valve reoperation within 12 months of follow-up after mitral valve repair (p = 0.04). This relationship was nonlinear, and the curve of the HR of reoperation changed its slope at a total annual surgeon volume of 25 operations (**Figure 3**). On the basis of these data, patients were stratified into 2 volume groups (<25 operations/year and ≥25 operations/year). The cumulative incidence of reoperation at 12 months was 1.3% (95% CI: 1.0% to 1.8%) for patients operated on by a surgeon with a total annual surgeon volume of ≥25 operations compared with 3.6% (95% CI: 2.4% to 5.0%) for patients operated on by a surgeon with total annual surgeon volume of <25 operations (adjusted HR: 0.45; 95% CI: 0.26 to 0.76; p = 0.003) (**Figure 4**). The significant difference in reoperation rates persisted to 12 years (9.5%; 95% CI: 6.9% to 12.6% vs. 6.2%; 95% CI: 5.0% to 7.7%; p < 0.001) (Online Figure 2).

SURVIVAL. We observed an association between higher total annual surgeon volume and improved survival after mitral valve operations controlling for pre-operative risk factors. Total annual surgeon volume was independently associated with improved 1-year survival in the degenerative disease cohort (adjusted HR: 0.95/10-case increment; 95% CI: 0.92 to 0.98; p = 0.001). The actuarial survival after 1 year of repair or replacement of patients with degenerative mitral valve disease operated on by surgeons performing >50 operations a year was 97.8% (95% CI: 97.1 to 98.4) compared with 94.1% (95% CI: 91.1 to 96.0) for patients operated on by surgeons performing ≤10 operations a year (**Table 3**). To evaluate whether and how the effect of surgeon volume was confounded by repair rates, we added repair versus replacement to the previous model. Mitral repair

(vs. replacement) was significantly associated with better survival (adjusted HR: 0.80; 95% CI: 0.68-0.94; p = 0.006), but total annual surgeon volume still remained a significant independent predictor, despite some attenuated effects (adjusted HR: 0.96/10-case increment; 95% CI: 0.95 to 0.98; p < 0.001), a finding implying that better patient survival by higher-volume surgeons was explained not simply by their higher repair rate alone, but also by the effect of their higher volumes. In those patients who underwent mitral valve repair, total annual surgeon volume was an independent predictor of late death (adjusted HR: 0.96/10-case increment; 95% CI: 0.94 to 0.98; p < 0.001).

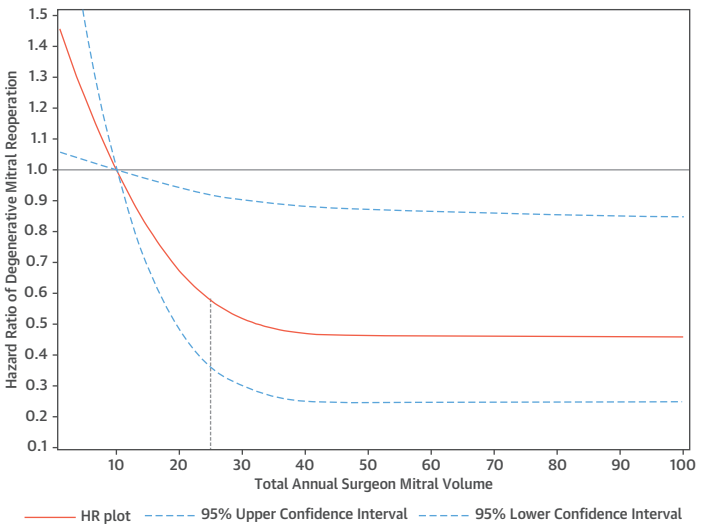
DISCUSSION

This New York State-wide multicenter analysis suggests that individual surgeons' mitral valve case volume has a significant impact on early- and long-term patients' outcomes after mitral valve surgery. We observed incremental benefits in terms of repair rates, survival, and reoperation with increasing surgeon volume. Thus our data provide additional strong support to the calls for systematically focusing experience in mitral valve surgery (13-17). Encouraging targeted referral, with the goal of concentrating surgical volume, should help to address the wide variation in mitral valve repair rates described in the United States and elsewhere (3-10), a variation that persists despite the significant benefits of mitral valve repair over replacement (1,2). We found that a total annual surgeon volume of <25 operations was associated not only with lower mitral valve repair rates, but also with increased 1-year mortality and mitral valve reoperation rates, and that improvements in repair rates, survival, and freedom from reoperation continued with increasing surgeon case volumes. The median number of mitral valve operations performed annually by individual surgeons in the United States was 5, according to an analysis of The Society of Thoracic Surgeons database (3); similarly, in New York State, most surgeons actually performed <1 mitral operation/month. Our data indicate that there may be several factors contributing to poorer outcomes in patients operated on by the lower-volume surgeons in this analysis.

We observed significant differences in the characteristics of patients across surgeons' case volume groups. For example, the prevalence of congestive heart failure was significantly higher in patients operated on by surgeons with lower annual case volumes, compared with surgeons with higher annual case volumes. The proportion of patients undergoing urgent surgery was also significantly higher for lower-volume surgeons. This leads to a double jeopardy, where sicker patients are adversely affected by the lower repair rates and poorer outcomes seen with lower-volume surgeons, and it underscores the need to refer the highest-risk patients to high-volume surgeons.

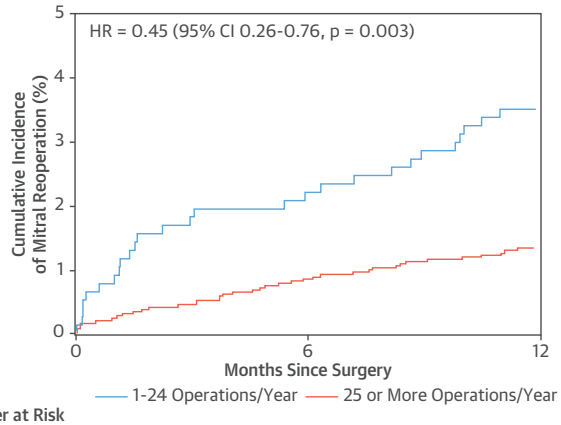
Importantly, we observed improved mitral valve repair rates and survival in the patients of the lower-volume surgeons if they operated at institutions where there was a surgeon performing >50 total mitral operations annually with a >70% degenerative repair rate. One potential explanation for this finding is the direct benefit of reviewing and operating on patients who require a technically complex repair strategy with a more experienced surgeon and surgical team. A second reason for this finding may be that centers where mitral valve surgeons perform a higher number of mitral valve repairs are more likely to have cardiology, imaging, and critical care teams optimally equipped to evaluate and manage these patients. The demonstrated ability of experienced centers to field multidisciplinary teams experienced in the guideline-based assessment and management of complex heart valve disease is the main rationale for managing such patients in heart valve referral centers (1,2). New and low-volume

FIGURE 3 Adjusted HR of Mitral Reoperation After Repair Within 1 Year, Plotted According to Total Annual Surgeon Mitral Valve Volume



Adjusted hazard ratio (HR) of mitral reoperation after repair within 1 year was plotted against total annual surgeon mitral volume, with 10 mitral operations/year as a reference. The curve of the hazard ratio of reoperation changed its slope at a total annual surgeon volume of 25 operations. CI = confidence interval.

FIGURE 4 Cumulative Incidence of Mitral Valve Reoperation After Repair Within 1 Year by 2 Volume Groups



Patients operated on by higher-volume surgeons (≥25 operations/year) had lower risk of reoperation at 1 year than patients operated on by lower-volume surgeons (1 to 24 operations/year). Abbreviations as in Figure 3.

surgeons may be mentored and technically supported, thus allowing them to perform degenerative mitral valve repair while successfully transforming to high-volume surgeons. Even among high-volume surgeons, there was an observed variability of degenerative disease repair rates, ranging from 19% to nearly 100%. This finding reflects that surgeon volume is not the only factor for better outcomes, and it emphasizes the need for more transparency of surgeon-related factors and outcomes of degenerative mitral valve surgery for patients and referring cardiologists.

The role of volume thresholds in designating referral centers and surgeons has not been established. A volume threshold of 25 mitral valve repairs/year for surgeons performing mitral surgery was originally proposed in a consensus statement on best practices in the United Kingdom, at a time when no data on volume-outcome relationships for mitral valve surgery were available (13). In the United States, large health care purchasers, payers, and professional organizations have already established minimum volume standards for several surgical procedures, but mitral valve surgery is not among these (18). Our data suggest that focusing surgeon experience may help to facilitate improvements in mitral valve repair rates and long-term outcomes. Until then, consensus guideline standards (which require a high likelihood of a durable repair for patients undergoing surgery for degenerative mitral valve disease) (1,2) may best be served by concentrating referrals among surgeons performing ≥25 mitral valve operations annually.

Considering that there was an incremental improvement in survival and probability of repair with increasing volume over 25 operations, one could make the argument that a minimum volume target of 50, or even more, operations would be optimal. Developing more very high-volume surgeons experienced in mitral valve repair would likely be particularly beneficial for patients with complex, but repairable mitral valve disease and for asymptomatic patients whose repair feasibility would optimally approach 100% (19).

The main strength of this study is the ability to analyze freedom from reoperation and mortality rates in a large, multicenter, contemporary cohort of patients undergoing surgery for degenerative disease by using a statewide mandatory database.

TABLE 3 Adjusted HR of 1-Yr Mortality of Patients With Degenerative Mitral Valve Disease According to Surgeon Volume Groups, $p < 0.001$

Volume Category (Operations/Yr)	Adjusted HR (95% CI)	1-Yr Survival (95% CI)
≤10	Reference	94.1% (91.1-96.0)
11-24	0.72 (0.42-1.22)	95.8% (94.4-96.8)
25-50	0.52 (0.31-0.85)	97.0% (96.1-97.7)
≥51	0.46 (0.28-0.76)	97.8% (97.1-98.4)

CI = confidence interval; HR = hazard ratio.

STUDY LIMITATIONS. For this analysis, we used an administrative dataset subject to well-recognized limitations that can affect the reliability of information obtained from it. Data may be entered by nonclinicians and are subject to inaccurate coding of patients' diagnoses and procedures. Additionally, ICD-9-CM codes do not perfectly distinguish degenerative from ischemic mitral valve disease, nor do they provide detailed information on symptom status, severity of mitral valve disease, ventricular function, pulmonary hypertension, or severity of comorbidities (e.g., coronary disease). Because preoperative echocardiographic data or surgical reports were not available, our creation of a subgroup of patients with degenerative disease relied on an exclusionary process. We believe we were able to validate a method of identifying patients with degenerative disease with high specificity, but this was at the expense of sensitivity. For example, we excluded certain patients with degenerative mitral valve disease and concomitant coronary disease from our analysis to minimize the inclusion of patients with ischemic mitral regurgitation in our degenerative

disease group. We also excluded nearly 10% of patients who lived out of New York State. Although the use of a statewide, rather than a single-center, database improved our ability to detect reoperations, we could not identify patients with residual or recurrent mitral regurgitation, patients who underwent valve replacement for immediate failure of repair during the same operation, or patients who subsequently migrated out of state, thus potentially causing us to underestimate the rate of repair failure. We excluded 2.5% of operations performed by surgeons where we were unable to calculate their annual surgical volumes; this could potentially contribute to underestimating the effect of volume on repair rates and long-term outcomes. Each surgeon's cumulative experience was not analyzed because cumulative volume could not be accurately calculated for surgeons who started their practice before the study period or out of New York State. Finally, we were unable to adjust for referral bias, which may cause us to overestimate the number of mitral valves amenable to repair seen by low-volume surgeons, as well as the impact of more complex repairs seen by higher-volume surgeons.

CONCLUSIONS

In this 12-year analysis of patients operated on for mitral valve disease in New York State, surgeons performing <25 mitral valve operations/year were significantly more likely to replace, rather than repair, mitral valves in patients with degenerative disease than were surgeons performing ≥25 mitral valve operations/year. Additionally, patients operated on by the lower-volume surgeons had significantly worse survival and were significantly more likely to undergo reoperation in long-term follow-up than patients operated on by higher-volume surgeons. Incremental benefits, in terms of repair rates, reoperation, and survival, continued with increasing surgeon volume, up to the highest-volume surgeons in the study cohort. The presence of a high-volume surgeon was associated with better repair rates achieved by low-volume surgeons operating at the same institution. Our data support concentrating surgeons' experience in mitral valve surgery and the concept of centers of excellence in mitral valve repair.

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PERSPECTIVES

COMPETENCY IN PRACTICE-BASED LEARNING: Based on observations in the state of New York, a minimum surgeon annual volume of 25 mitral operations is a reasonable target to improve clinical outcomes in patients with degenerative mitral valve disease.

TRANSLATIONAL OUTLOOK: Prospectively acquired national data in patients undergoing mitral surgery for degenerative disease is needed to further define estimates of minimum surgeon volume targets to improve repair rates and clinical outcomes.

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KEY WORDS mitral valve repair, mitral valve replacement, surgical volume

APPENDIX For supplemental tables and figures, please see the online version of this paper.