Hospital volume, mitral repair rates, and mortality in mitral valve surgery in the elderly: An analysis of US hospitals treating Medicare fee-for-service patients

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ABSTRACT

Background: The volume-outcome relationship has been suggested as a quality metric in mitral valve surgery and would be particularly relevant in the elderly because of their greater burden of comorbidities and higher perioperative risk.

Methods and Results: The study included 1239 hospitals performing mitral valve surgery on Medicare beneficiaries from 2000 through 2009. Only 9% of hospitals performed more than 40 mitral operations per year, 29% performed 5 or less, and 51% performed 10 or less. Mitral repair rates were low; 22.7% of hospitals performed 1 or less, 65.1% performed 5 or less, and only 5.6% performed more than 20 mitral repairs per year in those aged 65 years or more. Repair rates increased with increasing volume of mitral operations per year: 5 or less, 30.5%; 6 to 10, 32.9%; 11 to 20, 34.9%; 21 to 40, 38.8%; and more than 40, 42.0% ($P = .0001$). Hospitals with lower volume had significantly higher adjusted operative mortality compared with hospitals performing more than 40 cases per year: 5 or less cases per year, odds ratio (OR) 1.58 (95% confidence interval [CI], 1.40-1.78); 6 to 10 cases per year, OR 1.29 (95% CI, 1.17-1.43); 11 to 20 cases per year, OR 1.17 (95% CI, 1.07-1.28); 21 to 40 cases per year, OR 1.15 (95% CI, 1.05-1.26). Hospitals with lower mitral repair rates had an increased likelihood of operative mortality relative to the top quartile: lowest quartile, OR 1.31 (95% CI, 1.20-1.44); second quartile, OR 1.18 (95% CI, 1.09-1.29); and third quartile, OR 1.14 (95% CI, 1.05-1.24). Long-term mortality beyond 6 months was also higher in low-volume hospitals: 5 or less cases year, hazard ratio (HR) 1.11 (95% CI, 1.06-1.18); 6 to 10 cases per year, OR 1.06 (95% CI, 1.02-1.10) compared with hospitals performing more than 40 cases per year.

Conclusions: Most hospitals perform few mitral valve operations on elderly patients. Greater volume of mitral procedures was associated with higher repair rates. Both greater volume of mitral procedures and increasing mitral repair rates were associated with decreased mortality. (J Thorac Cardiovasc Surg 2015;149:762-8)

Operative mortality and mitral repair rates				
	OR	95%LL	95%UL	p-value
Hosp annual MV volume ≤5*	1.58	1.40	1.78	0.0001
Hosp annual MV volume >5-10*	1.29	1.17	1.43	
Hosp annual MV volume >10-20*	1.17	1.07	1.28	
Hosp annual MV volume >20-40*	1.15	1.05	1.26	
* versus >40 / year				
Repair rate - 1st quartile**	1.31	1.20	1.44	0.0001
Repair rate - 2nd quartile**	1.18	1.09	1.29	
Repair rate - 3rd quartile**	1.14	1.05	1.24	
** versus top quartile				
	Repair rate (%)			
Hosp annual MV volume ≤5	30.5			
Hosp annual MV volume >5-10	32.9			
Hosp annual MV volume >10-20	34.9			
Hosp annual MV volume >20-40	38.8			
Hosp annual MV volume >40	42.0			

Odds ratios for adjusted operative mortality along with mitral valve repair rates.

Central Message

The majority of hospitals perform few mitral valve operations. Greater mitral procedural volume was associated with lower adjusted mortality, higher long-term survival, and higher repair rates. Lower hospital mitral repair rates were also independently predictive of higher mortality.

Author Perspective

Prior studies have found a relationship between volume and outcomes in cardiac surgery. We found that valve repair rates and mortality vary by hospital annual mitral procedure volume and that the majority of hospitals have a limited experience in treating elderly patients with mitral valve disease. We found a significant increase in mitral repair rates and a decrease in mortality as a function of hospital annual mitral procedure volume. Our findings support and extend prior reports suggesting that instituting specific volume thresholds for hospitals wishing to perform mitral valve surgery may lead to improved surgical outcomes.

See Editorial Commentary pages 769-70.

Supplemental material is available online.

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The management of elderly patients with mitral valve disease is complex. Options include medical management of heart failure symptoms and surgical intervention, consisting of either mitral repair or replacement. We recently found that outcomes after mitral surgery in the Medicare population are much better than previously reported; survival for those who underwent repair was similar to the age- and gender-matched US population.¹ Despite these favorable outcomes, mitral replacement is much more common in the elderly.² Hospitals vary dramatically in the number of mitral valve operations performed.

Previous studies have investigated the relationship between volume and outcome in mitral valve surgery.^{3,4} Using data from the Society of Thoracic Surgeons (STS) database, Gammie and colleagues³ analyzed data from

Abbreviations and Acronyms

BASF	= Beneficiary Annual Summary Files
CI	= confidence interval
CMS	= Centers for Medicare and Medicaid Services
HR	= hazard ratio
MEDPAR	= Medicare Provider Analysis and Review
NIS	= Nationwide Inpatient Sample
OR	= odds ratio
STS	= Society of Thoracic Surgeons

575 participating hospitals from 2000 to 2003 and found that a higher volume of mitral procedures was associated with lower adjusted operative mortality and increased repair rates.³ Because the mean age of the patient population included in that report was lower than 65 years, it is unclear if these findings can be extrapolated to older patients. In addition, far fewer hospitals participated in the STS at that time and it is possible that participating hospitals differed from nonparticipating hospitals. A more representative analysis of contemporary treatment in the elderly is needed to support this previously reported volume-outcome relationship.

Birkmeyer and colleagues⁴ used the Medicare database to examine the relationship between hospital volume and surgical mortality for a variety of procedures in the United States, including aortic and mitral valve replacement and found an inverse relationship. This methodology was limited by not taking into account the interhospital variability in the proportion of Medicare cases performed (ie, it was assumed that hospitals do not differ in the number of Medicare patients they see) as well as any variability of the proportion of Medicare cases performed at each hospital over time. Moreover, it did not include information on mitral repair, a procedure that has been used with increasing frequency in mitral valve surgery. The purpose of this investigation was to extend these previous efforts by providing a descriptive analysis of the association between hospital volume of mitral procedures, mitral valve repair rates, and mortality in the Medicare population.

METHODS**Data Sources**

The data files used for the present study included the Medicare Provider Analysis and Review (MEDPAR) files and corresponding Beneficiary Annual Summary Files (BASF) from 1999 to 2009. The MEDPAR files contain institutional claims for inpatient services covered under Part A. The BASF files contain information on patient demographics, eligibility, enrollment, summarized service utilization and payment, and chronic condition flags for eligible beneficiaries. The Vital Status file for February 2012 was used to calculate long-term survival.

The study was approved by the Institutional Review Board of Southern Illinois University, which waived the requirement for informed consent. In

addition, beneficiary confidentiality data was protected through a rigorous data use agreement with Centers for Medicare and Medicaid Services (CMS).

Patient Cohort

All Medicare beneficiaries aged 65 years or older who underwent mitral valve repair (International Classification of Diseases, Ninth Edition, Clinical Modification [ICD-9-CM] code 35.12) or replacement (35.23 or 35.24) from 2000 through 2009 were considered for inclusion. Figure 1 provides a flowchart outlining patient selection for the analysis. The ICD-9 codes used for the exclusions are provided in Table E1. Patients with significant concomitant procedures or other nonvalvular procedures were excluded to more directly assess the relationship between the volume of more straightforward mitral valve operations and outcomes. In addition, to ensure a more complete assessment of patient risk factors, patients were excluded if they did not have 12 months of Medicare Part A and Part B coverage in the year preceding their index admission, or if they had a period of enrollment under a Medicare managed plan at any point in the year before their index admission. Patients with emergency admission status were also excluded from the analysis.

Data Variables

The index admission was defined as the first hospitalization documenting a mitral valve repair or replacement during the 10-year period from 2000 through 2009. Demographic and comorbidity data were obtained from the MEDPAR file, using ICD-9-CM diagnostic codes from both the index admission and any hospitalizations during the 12-month period before the index admission. Operative mortality was defined as hospital or 30-day mortality, whichever was longer, in accordance with the standard STS definition. Long-term mortality was calculated from the Vital Status file for February 2012. Hospital annual volume of mitral procedures was calculated as the average number of mitral valve operations per year, that is, the total number of mitral valve operations paid for by Medicare over the 10-year study period, divided by the number of years that the hospital reported performing mitral valve operations. Thus, if a hospital had claims only in 6 of the 10 years, the total number of claims would be divided by 6. After examining the distribution of annual mitral valve volumes across hospitals, we identified clinically and statistically relevant categories of annual volumes. Similarly, the hospital annual volume of mitral repairs was defined as the average number of mitral valve repairs per year. The average annual mitral repair rates for each hospital were categorized into quartiles of the distribution across the hospitals.

Statistical Analysis

Categorical patient characteristics were compared across the volume groups using the χ^2 test, including observed mitral repair rates. A Cochran-Armitage trend test was used to assess the influence of the volume of mitral procedures on mitral repair rates. In order to account for clustering of patients within hospitals, hierarchical logistic regression was used to model operative mortality. Adjusted odds ratios (ORs) are presented, accounting for the clustering of patients within hospitals, the hospital characteristics of annual volume of mitral valve procedures and mitral valve repair rates, as well as the baseline patient and surgery characteristics. Similarly, Cox proportional hazards models, specifying hospital as a random effect to account for patients being nested within hospitals, were used to examine the impact of patient and hospital characteristics on long-term mortality beyond 6 months. After inspecting mortality curves, we chose to look at the impact of these factors on long-term mortality after the initial 6-month period after surgery because there is a high mortality phase immediately after surgery followed by a fairly constant hazard of death thereafter. Adjusted hazard ratios (HRs) reflecting the relative increase/decrease in the likelihood of death over the follow-up period from more than 6 months to 10 years are presented. All analyses were performed using SAS v 9.3 (SAS Institute Inc, Cary, NC).

FIGURE 1. Flowchart of patient selection. *ICD-9-CM*, International Classification of Diseases, Ninth Edition, Clinical Modification; *ESRD*, end-stage renal disease; *VAD*, ventricular assist device.

TABLE 1. Distribution of annual hospital volumes of Medicare mitral procedure (n = 1239)

All mitral procedures			Mitral repairs		
Range	No. of hospitals	%	Range	No. of hospitals	%
			0	36	2.9
≤5	354	28.6	1	245	19.8
6-10	276	22.3	2-5	525	42.4
11-20	313	25.3	6-10	233	18.8
21-40	188	15.2	11-20	130	10.5
>40	108	8.7	>20	70	5.6

RESULTS

Distribution of Mitral Valve Operations

This study included all US hospitals using the Medicare fee-for-service system that performed any mitral operations on Medicare patients during the study period. A total of 1239 hospitals were included in the study. The number of mitral valve operations performed on Medicare patients at most of the hospitals was low (Table 1). More than one quarter (28.6%) of the hospitals performed 5 mitral operations or less per year and 50.9% of the hospitals performed 10 or less mitral valve operations per year. In contrast, only

TABLE 2. Baseline characteristics by hospital volume

Characteristics	Overall % (n = 125,079)	% ≤5 (n = 4897)	% >5-10 (n = 11,765)	% >10-20 (n = 27,618)	% >20-40 (n = 33,318)	% >40 (n = 47,481)	P value
Patient characteristics							
Age ≥75 y	55.6	51.4	54.1	55.6	56.6	55.8	.0001
Female	53.2	56.7	55.1	53.7	52.9	52.4	.0001
Hypertension	53.7	52.8	52.9	52.4	53.9	54.5	.0001
Diabetes	20.7	21.7	20.2	20.6	20.8	20.6	.2791
PVD	3.9	3.6	3.6	3.9	3.8	4.1	.0615
Stroke	9.7	9.7	9.5	9.8	9.6	9.9	.7135
Heart failure	63.8	65.9	64.0	62.9	64.2	63.7	.0002
CAD	59.1	57.0	59.0	58.7	59.6	59.1	.0066
COPD	20.7	22.9	23.0	20.8	20.2	20.2	.0001
Respiratory failure	12.8	16.9	14.8	13.9	12.8	11.4	.0001
Renal failure	11.0	24.6	24.1	23.6	24.2	22.5	.0001
Atrial fibrillation	46.8	44.3	45.0	45.0	46.8	48.5	.0001
Anemia	17.0	18.3	17.3	16.7	16.8	17.0	.0606
History of MI	19.8	19.0	19.6	19.8	20.1	19.7	.3432
Previous cardiac surgery	3.7	2.7	2.9	3.5	3.8	4.1	.0001
Surgery characteristics							
Urgent admission	58.0	58.6	55.4	56.4	58.3	59.2	.0001
Mitral valve repair	38.3	30.5	32.9	34.9	38.8	42.0	.0001
CABG	46.8	46.8	48.4	48.3	47.8	44.9	.0001
Other valve surgery	24.5	17.9	18.5	23.1	25.2	27.0	.0001

PVD, Peripheral vascular disease; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; MI, myocardial infarction; CABG, coronary artery bypass graft.

8.7% of the hospitals performed more than 40 mitral operations per year.

The annual hospital rate of mitral repairs ranged from 0% to 100%. The median annual hospital repair rate was 32.9% (interquartile range [IQR], 21.8% to 44.4%). The 10th and 90th percentiles were 12% and 54%, respectively. Furthermore, the distribution of mitral repair volumes among the hospitals revealed that almost one quarter of the hospitals (22.7%) performed only 1 or no mitral repairs per year and that most hospitals (65.1%) performed 5 or fewer mitral repairs per year. Only 5.6% of the hospitals performed more than 20 mitral repairs per year on Medicare patients.

Patient Characteristics

The study population included a total of 125,079 patients; 47,897 (38.3%) underwent mitral valve repair and 77,182 (61.7%) underwent mitral valve replacement. The median age was 75 years. The baseline characteristics for the overall cohort of patients undergoing mitral valve surgery as well as by hospital volume are presented in Table 2. Higher-volume hospitals treated patients with a higher incidence of atrial fibrillation, a higher proportion of patients who required concomitant other valve surgery, and a higher percentage of reoperations (Table 2). Mitral repair rates increased significantly with increasing hospital annual volume of mitral procedures ($P = .0001$), from 30.5% for hospitals performing 5 or fewer mitral operations per year to 42.0% for hospitals performing more than 40 mitral operations per year.

Hospital Mortality

The overall hospital mortality rate was 10.7%. The results of the hierarchical logistic regression model for adjusted operative mortality are presented in Table 3. In this model, each hospital mitral volume category was used as a separate covariate. Similarly, mitral repair rates were divided into quartiles and each quartile was examined as an independent covariate. Because preoperative profiles differed among patients presenting to different volume centers, adjusted operative mortality was calculated to account for these differences. After adjustment for baseline characteristics and hospital repair rates (quartiles), the lower-volume hospitals all exhibited increased likelihood of operative mortality relative to those hospitals performing more than 40 cases per year: 5 or less cases per year, OR 1.58 (95% confidence interval [CI], 1.40-1.78); 6 to 10 cases per year, OR 1.29 (95% CI, 1.17-1.43); 11 to 20 cases per year, OR 1.17 (95% CI, 1.07-1.28); 21 to 40 cases per year, OR 1.15 (95% CI, 1.05-1.26).

When hospitals were divided into 4 quartiles according to their annual repair rates, the hospitals with the lowest annual repair rates also had an increased likelihood of operative mortality relative to those in the top quartile: lowest quartile, OR 1.31 (95% CI, 1.20-1.44); second quartile, OR 1.18 (95% CI, 1.09-1.29); and third quartile, OR 1.14 (95% CI, 1.05-1.24). The median repair rates and the range for each quartile were as follows: first quartile, median 14%, range 0% to 22%; second quartile, median 28%, range 22% to 33%; third quartile, median 38%, range 33% to 44%; fourth quartile, median 52%, range 44% to 100%.

TABLE 3. Operative mortality

Characteristics	Odds ratio	95% Lower limit	95% Upper limit	P value
Age ≥ 75 y	1.60	1.53	1.66	.0001
Female	1.28	1.23	1.33	.0001
Hypertension	0.69	0.66	0.72	.0001
Diabetes	1.06	1.02	1.11	.0092
PVD	1.33	1.22	1.45	.0001
Stroke	1.66	1.57	1.75	.0001
Heart failure	1.33	1.27	1.39	.0001
CAD	0.83	0.79	0.87	.0001
COPD	1.12	1.07	1.17	.0001
Respiratory failure	2.49	2.39	2.61	.0001
Renal failure	1.78	1.69	1.88	.0001
Atrial fibrillation	0.76	0.73	0.79	.0001
Anemia	0.94	0.90	0.99	.0189
History of MI	1.44	1.38	1.51	.0001
Previous cardiac surgery	1.03	0.92	1.14	.6557
Urgent admission	1.76	1.68	1.85	.0001
CABG	1.37	1.31	1.44	.0001
Other valve surgery	1.61	1.55	1.68	.0001
Hospital annual volume of mitral valve procedures				
$\leq 5^*$	1.58	1.40	1.78	
6-10*	1.29	1.17	1.43	.0001
11-20*	1.17	1.07	1.28	
21-40*	1.15	1.05	1.26	
Repair rate				
First quartile**	1.31	1.20	1.44	
Second quartile**	1.18	1.09	1.29	.0001
Third quartile**	1.14	1.05	1.24	

PVD, Peripheral vascular disease; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; MI, myocardial infarction; CABG, coronary artery bypass graft. *Versus >40 per year. **Versus top quartile.

Important surgical characteristics that were associated with increased operative mortality included urgent admission status and concomitant coronary artery bypass graft (CABG) or other valve surgery. Important patient baseline characteristics that were predictive of increased operative mortality included respiratory failure, stroke, renal failure, history of previous myocardial infarction and age 75 years or more.

Long-Term Mortality

The overall long-term mortality rates were 20.1% at 1 year, 29.0% at 3 years, 39.0% at 5 years, and 66.4% at 10 years. The 6-month mortality rates for the volume groups were 21.5% for patients in the hospitals with the lowest volume (≤ 5 cases per year), 19.3% for those in the hospitals with 6 to 10 cases per year, 17.7% for those in the hospitals with 11 to 20 cases per year, 17.5% for those in the hospitals with 21 to 40 cases per year, and 15.4% for those in hospitals with more than 40 cases per year. After adjustment for baseline characteristics and hospital repair rates (quartiles), patients in the lower-volume hospitals exhibited greater long-term mortality beyond 6 months relative to those

TABLE 4. Long-term mortality

Characteristics	Hazard ratio	95% Lower limit	95% Upper limit	P value
Age ≥ 75 y	1.54	1.51	1.57	.0001
Female	0.96	0.94	0.98	.0001
Hypertension	0.94	0.92	0.96	.0001
Diabetes	1.37	1.34	1.40	.0001
PVD	1.20	1.15	1.26	.0001
Stroke	1.24	1.20	1.28	.0001
Heart failure	1.40	1.37	1.43	.0001
CAD	1.06	1.04	1.09	.0001
COPD	1.52	1.48	1.55	.0001
Respiratory failure	1.26	1.23	1.30	.0001
Renal failure	1.78	1.72	1.83	.0001
Atrial fibrillation	1.09	1.07	1.12	.0001
Anemia	1.13	1.10	1.16	.0001
History of MI	1.11	1.08	1.14	.0001
Previous cardiac surgery	1.22	1.16	1.27	.0001
Urgent admission	1.10	1.08	1.13	.0001
CABG	1.14	1.11	1.16	.0001
Other valve surgery	1.20	1.18	1.23	.0001
Hospital annual volume of mitral valve procedures				
$\leq 5^*$	1.11	1.06	1.18	
6-10*	1.06	1.02	1.10	.0002
11-20*	1.02	0.98	1.05	
21-40*	1.01	0.98	1.04	
Repair rate				
First quartile**	1.12	1.08	1.16	
Second quartile**	1.08	1.05	1.12	.0001
Third quartile**	1.07	1.04	1.10	

PVD, Peripheral vascular disease; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; MI, myocardial infarction; CABG, coronary artery bypass graft. *Versus >40 per year. **Versus top quartile.

hospitals performing more than 40 cases per year: 5 cases or less per year, HR 1.11 (95% CI, 1.06-1.18); and 6 to 10 cases per year, HR 1.06 (95% CI, 1.02-1.10). A statistically significant relationship between repair rate and long-term mortality was also noted ($P = .0001$). Hospitals with the lowest annual repair rates had an increased likelihood of long-term mortality relative to those in the top quartile: lowest quartile, HR 1.12 (95% CI, 1.08-1.16); second quartile, HR 1.08 (95% CI, 1.05-1.12); third quartile, HR 1.07 (95% CI, 1.04-1.10) (Table 4).

Although low hospital volumes were associated with long-term mortality beyond 6 months, patient characteristics were also strongly associated with survival. Patients undergoing concomitant CABG or other valve surgery (HR, 1.14; 95% CI, 1.11-1.16; and HR, 1.20; 95% CI, 1.18-1.23) were also at increased risk for long-term mortality. Similarly, patients presenting with an urgent admission status were at greater risk (HR, 1.10; 95% CI, 1.08-1.13) (Table 4). Additional patient characteristics predictive of long-term mortality included history of COPD (HR, 1.52; 95% CI, 1.48-1.55), renal failure (HR, 1.78; 95% CI,

1.72-1.83), and age 75 years or more (HR, 1.54; 95% CI, 1.51-1.57).

DISCUSSION

In this large, national study using the Medicare database, we examined the association between hospital annual volume of Medicare mitral procedures, mitral repair rates, and mortality. A critically important observation in this study was the relatively small number of mitral valve procedures performed in elderly patients at most US hospitals. Most of these hospitals (83.9%) performed 10 or less mitral repairs per year in this cohort of Medicare beneficiaries with a median age of 75 years. After accounting for several patient and treatment characteristics associated with 30-day and long-term mortality, we found a significant association between hospital volume of mitral procedures and outcomes. The hospital groups with the lowest volume (≤ 5 and 6-10 mitral procedures per year) had substantially worse short- and long-term survival than higher-volume hospitals (>40 mitral cases per year). Similarly, lower annual hospital mitral valve repair rates were also independently predictive of higher operative and long-term mortality in this Medicare population.

Our findings support and extend previous reports suggesting specific volume thresholds for hospitals wishing to perform mitral valve surgery. Bridgewater and colleagues⁵ recommended a minimum annual volume of 50 mitral valve repairs for hospitals performing mitral valve repair. In a previous study using data from the Nationwide Inpatient Sample (NIS) database,⁶ we found that less than 20% of the hospitals performed more than 50 mitral procedures per year, and only 7% of the hospitals performed more than 50 mitral repairs per year. High-volume mitral valve centers are not evenly distributed across the United States, raising concerns that volume restrictions could limit access to care unless regional referral networks are developed. Such networks would affect the elderly in particular, because those in more geographically isolated areas might have to travel hundreds of miles to undergo surgery.

The low repair rates in this cohort are disappointing. This study included all hospitals in the United States that use Medicare. Most hospitals in the United States perform a limited number of mitral valve operations, and especially mitral valve repair, on elderly patients. Although the prevalence of mitral valve disease increases with age such that by age 75 years, it affects a significant portion of the population, only 5.6% of the hospitals in our study cohort performed more than 20 mitral repairs per year.⁷ The reasons for these findings cannot be studied using this administrative database.

Beyond our observations of overall mitral valve procedures, we also found significant variations in the use of mitral valve repair, with greater rates of repair observed in hospitals with higher annual volumes of mitral procedures. The ability to perform mitral valve repair is

considered an important quality measure in mitral valve surgery. We found that lower repair rates were independently predictive of higher operative mortality and lower long-term survival. These data bear direct relevance to the recently proposed CMS guidelines for coverage for transcatheter mitral valve repair. The proposed guidelines of at least 25 total mitral valve procedures in the previous year of which at least 10 must be mitral valve repairs, is an exceedingly low threshold that will likely allow dissemination of this technology to centers with suboptimal mitral experience and higher mortality rates. Whether patients seen at these centers are more likely to be referred to transcatheter mitral repair because of a lack of expert mitral repair surgeons remains to be seen.

The results of this investigation should be interpreted in the context of several potential limitations. The volumes of mitral procedures reported here are only reflective of mitral valve operations in the Medicare population. This offers a partial explanation for the low volumes of mitral procedures, especially mitral repairs, in this cohort. Nevertheless, because most patients in this age group have Medicare as a primary payer, this is an excellent representation of the true repair rates in the elderly, especially because the median age of this cohort was 75 years. We also examined the annual volume of mitral valve procedures across hospitals from the NIS data (all payers) for patients 65 years of age or older. The median across these hospitals ($n = 891$) was 11 (IQR, 5-23; 10th percentile, 2; 90th percentile, 42). For the MedPar data ($n = 1239$), the median annual volume was 10 (IQR, 4.5-19.5; 10th percentile, 2.4; 90th percentile, 37.3). Therefore, although without a doubt, the Medicare volumes represent a fraction of the hospital volumes of mitral procedures, these data would suggest that for patient age 65 years and older the Medicare database captures most of the mitral valve operations in the United States. In order to more accurately gauge the true level of experience level, we then looked at the NIS data to determine annual volumes of mitral procedures based on patients of all ages. The median annual volume across these hospitals ($n = 904$) was 20.5 (IQR, 9.0-40.4; 10th percentile, 4; 90th percentile, 78). The correlation between annual volumes based on patients of all ages and based on patients aged 65 years or more having Medicare as the primary payer was $r = 0.96$. Thus, on average, the real volume of mitral procedures (experience level) at hospitals may be almost twice that calculated from the MedPar data; however, it would seem that hospitals with a higher overall volume of mitral procedures also tend to have higher volumes of Medicare patients undergoing mitral procedures.

The greater burden of comorbidities and higher perioperative risk in the elderly would support the development of volume thresholds as a marker of quality in this population. Nevertheless, our description of low volumes of procedures in this Medicare cohort may not be a good indication of the

quality of programs that provide substantial numbers of mitral valve procedures to younger patients. Despite this potential limitation, we did observe a strong volume-outcome relationship for the older population. An additional concern is that we relied on administrative data to assess comorbidities and could not account for the severity of various comorbidities or the cause of mitral valve disease. Given that different causes of disease, such as degenerative mitral regurgitation, can be associated with significantly higher repair rates than other causes such as endocarditis, end-stage renal disease, rheumatic disease, or lupus,^{2,8-10} we are limited in our ability to explain the reasons why replacement rather than repair was chosen as the treatment strategy. We also did not have access to the patients' preprocedural health status, which has previously been shown to be associated with periprocedural mortality.¹¹ Future studies that incorporate echocardiographic and intra-operative information may better address the potential selection biases between alternative treatment strategies. We were, however, able to account for some patient characteristics that are negatively associated with the performance of mitral valve repair, such as older age, urgent or emergency status, race, socioeconomic status, and female gender.¹²⁻¹⁵

The purpose of an administrative database such as Medicare is to gather billing data and therefore it does not provide as much clinical detail compared with the STS database. However, it does have the potential to capture most patients aged 65 years and older and provides data that are free of inclusion bias related to differing hospital outcomes for participating versus nonparticipating hospitals in the STS database. In addition, we cannot exclude potential unmeasured confounders associated with hospital volumes that might account for some of our observations. We cannot provide a specific volume that may be used as a cut-off to examine and compare hospital outcomes. Professional societies and health care planners will need to consider these data in the context of other economic, access to care, and health planning issues to develop rational criteria for using treatment volumes in the elderly as a potential performance measure of quality.

Although we have performed a descriptive analysis of the association between hospital volume of mitral procedures, repair rates, and outcomes in the Medicare population, we cannot make any conclusions regarding causation. Although it is plausible that higher volumes lead to improved outcomes (the learning curve), it is also possible that hospitals with improved outcomes gain volume over time (the selective referral mechanism).¹⁶

In conclusion, we found that mitral valve repair rates and mortality in the Medicare population vary by hospital annual volume of mitral procedures and that most hospitals have a limited experience in treating elderly patients with mitral valve disease. We found a significant increase in mitral repair rates and a decrease in mortality as a function of

hospital annual volume of mitral procedures. After accounting for differences in hospital volume of mitral procedures, annual hospital mitral repair rates were also independently predictive of operative mortality. Future work is needed in order to consider performance measures or regional health care planning as potential vehicles for improving outcomes.

Conflict of Interest Statement

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Key words: mitral valve, surgery, hospital volume, outcome research

TABLE E1. ICD-9-CM codes used for exclusions

Exclusions	ICD-9-CM codes
Closed heart valvuloplasty	35.00, 35.01, 35.02, 35.03, 35.04
Congenital anomaly	35.8, 35.4, 35.53, 35.54, 35.62, 35.63, 35.9, 39.0, 39.21
Heart transplant	37.51
Awaiting transplant	V49.83
History of heart transplant	V42.1
History of ventricular support procedures	37.52, 37.62, 37.64, 37.65, 37.66, 37.68, 39.65, 39.66, 97.44
Implantation of external support device	37.41
History of ventricular assist device or artificial heart	V43.21, V43.22
Excision of ventricular aneurysm	37.32, 37.35, 37.49
Replacement of thoracic aorta	38.45
Aortic fenestration	39.54
Concomitant carotid endarterectomy	38.12
Rupture of papillary muscle	429.6
Repair or replacement, unspecified valve	35.10, 35.20

ICD-9-CM, International Classification of Diseases, Ninth Edition, Clinical Modification.