Minithoracotomy for mitral valve repair improves inpatient and postdischarge economic savings

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Objective: Small series of thoracotomy for mitral valve repair have demonstrated clinical benefit. This multi-institutional administrative database analysis compares outcomes of thoracotomy and sternotomy approaches for mitral repair.

Methods: The Premier database was queried from 2007 to 2011 for mitral repair hospitalizations. Premier contains billing, cost, and coding data from more than 600 US hospitals, totaling 25 million discharges. Thoracotomy and sternotomy approaches were identified through expert rules; robotics were excluded. Propensity matching on baseline characteristics was performed. Regression analysis of surgical approach on outcomes and costs was modeled.

Results: Expert rule analysis positively identified thoracotomy in 847 and sternotomy in 566. Propensity matching created 2 groups of 367. Mortalities were similar (thoracotomy 1.1% vs sternotomy 1.9%). Sepsis and other infections were significantly lower with thoracotomy (1.1% vs 4.4%). After adjustment for hospital differences, thoracotomy carried a 17.2% lower hospitalization cost (−$8289) with a 2-day stay reduction. Readmission rates were significantly lower with thoracotomy (26.2% vs 35.7% at 30 days and 31.6% vs 44.1% at 90 days). Thoracotomy was more common in southern and northeastern hospitals (63% vs 37% and 64% vs 36%, respectively), teaching hospitals (64% vs 36%) and larger hospitals (>600 beds, 78% vs 22%).

Conclusions: Relative to sternotomy, thoracotomy for mitral repairs provides similar mortality, less morbidity, fewer infections, shorter stay, and significant cost savings during primary admission. The markedly lower readmission rates for thoracotomy will translate into additional institutional cost savings when a penalty on hospitals begins under the Affordable Care Act's Hospital Readmissions Reduction Program. (J Thorac Cardiovasc Surg 2014;148:2818-22)

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Supplemental material is available online.

In the 1990s, there was a resurgence of thoracotomy approaches for mitral valve repair with the goal of translating the successes of laparoscopic surgery into the field of limited-access mitral surgery.[1-4] Several champions and institutional series have shown differential benefits of this approach relative to sternotomy; these benefits include reductions in cost, hospital stay, and blood transfusions. with an overall faster recovery.[5-13] Unfortunately, these studies have been limited by small size or lack of financial and long-term outcomes. To provide greater insight into the hospital costs associated with minimally invasive mitral surgery, a group of experienced minimally invasive cardiac surgeons (Economic Workgroup on Valvular Surgery; Table E1) examined a cross-section of United States hospital billing and coding data related to isolated mitral valve repair (IsoMVRep). The purpose of this study was to analyze the real-world clinical and economic outcomes of thoracotomy compared with those of sternal approaches for IsoMVRep.

MATERIALS AND METHODS

Data Source

The Premier database is extensively used for economic analyses, including those of cardiothoracic surgery.[14-18] It contains, with patient identifying data removed, complete patient billing, hospital cost, and coding histories from more than 600 US health care facilities.[19] This study

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Abbreviations and Acronyms

ICD-9 = *International Classification of Diseases, Ninth Edition*

IsoMVRep = isolated mitral valve repair

extracted data from more than 25 million inpatient discharges. An institutional review board waiver of informed consent was obtained from the New England Institutional Review Board, and an exemption was obtained (NEIRB 13-203). Patients included those older than 18 years who underwent IsoMVRep through either a thoracotomy or sternotomy incision between 2007 and 2011. IsoMVRep was identified for visits having the primary *International Classification of Diseases, Ninth Edition* (*ICD-9*) procedure code classification of 35.12. Patients who underwent coronary artery bypass grafting in conjunction with IsoMVRep, underwent another concomitant valve operation, or underwent procedures utilizing robotic technology were excluded.

A set of expert rules were developed to text mine the charge master billing files of the Premier database to identify surgical approach as either thoracotomy or sternotomy (any type, including partial). Figure E1 displays these expert rules for procedure identification and attrition. For all eligible patients, elements describing adverse events, hospital cost, surgery time, hospital stay, and readmissions were obtained from the database. Cost analysis reflected the actual cost of the procedure to the hospital. The preoperative All Patient Refined Diagnosis-Related Groups severity level was used as an index of clinical comorbidity. The 3M All Patient Refined Diagnosis-Related Groups Classification System, a widely adopted proprietary risk-adjustment classification tool, uses information from routine claims data to produce valid and reliable severity measurement and risk-adjustment scores.[20] It is used to account for differences related to an individual's severity of illness or risk of mortality in large data sets. Comorbid conditions that might influence procedure selection or outcomes of interest, such as previous organ transplant, the presence of pulmonary disease, or diabetes mellitus, were obtained through *ICD-9* diagnosis and procedure codes. Information on sociodemographic characteristics and health insurance status was also included, as were descriptors of the care setting, namely census region, urban or rural setting, teaching hospital status, and facility bed count. Adverse events were identified by *ICD-9* codes and summed into categories (Table E2).

Statistical Analyses

The objective of this study was to use the Premier hospital database to compare clinical and economic outcomes among patients undergoing IsoMVRep through a thoracotomy versus any sternal approach. Outcomes of interest included adverse events, hospital costs, hospital stay, and readmission rates. Propensity scoring was used to create well-matched groups for comparison. Extensive details of the statistical methodology are contained in the Appendix E1.

RESULTS

Data analysis identified 6007 patients undergoing IsoMVRep. Expert rule analysis positively identified IsoMVRep by thoracotomy in 847 cases and by sternotomy in 566 cases. By means of propensity matching, 2 balanced groups of 367 patients were created (Table 1). Frequencies of comorbid conditions were equally distributed. Mortality was not statistically different between the 2 groups (1.1% for thoracotomy approach vs 1.9% for any sternotomy approach). Important clinical outcomes are listed in Table 2. Neurologic (2.5% vs 2.2%), pulmonary (39.5% vs 37.3%), and wound complications (4.9% vs 6.5%) were not statistically different between the thoracotomy and sternotomy groups, respectively. Sepsis and other infections were significantly lower with a thoracotomy approach (1.1% vs 4.4%; $P < .0065$). A thoracotomy was more likely than a sternotomy to be performed in southern and northeastern hospitals (63% vs 37% and 64% vs 36% respectively; $P < .0001$), teaching hospitals (64% vs 36%; $P < .0001$), and larger hospitals (>600 beds, 78% vs 22%; $P < .0001$; Table 3). Table 4 lists expenditures by surgical approach, as broken into various cost centers. After adjustment for hospital differences, patients treated through a thoracotomy had a 17.2% lower average primary hospitalization cost (−$8289). The mean stay with a thoracotomy approach was 7.94 days, versus 10.2 days with any sternotomy approach. Significantly, 30- and 90-day readmission rates were lower in the thoracotomy group (26.2% vs 35.7%; $P < .0052$; and 31.6% vs 44.1%; $P < .0005$, respectively).

DISCUSSION

This study is a real-world analysis of IsoMVRep that draws its data from more than 600 diverse hospitals participating in the Premier database. These institutions have contributed their data, stripped of patient identifiers, for patient billing, hospital cost, and coding histories into a communal database to allow effective comparative cost analysis. With such geographic and demographic variations, we were able to note significant regional differences in greater use of thoracotomy for IsoMVRep in southern and northeastern, teaching, and larger hospitals. Although one could argue that larger hospitals and teaching hospitals have the necessary critical mass to support lesser invasive cardiac surgery, it is unknown why thoracotomies were performed in greater proportion in southern and northeastern geographic areas.

The overall mortality reported here for mitral repair (1.49%) is similar to that reported in the Society of Thoracic Surgeons registry for the same period and reinforces the validity of this data set. As reported before, this large propensity-matched series confirmed that IsoMVRep through a thoracotomy carried comparable mortality and significantly decreased rates of sepsis and infection, hospital cost, and length of stay relative to sternotomy. These differences are in contrast to an earlier report by Suri and colleagues,[21] which propensity matched and compared sternotomy versus port-access approaches for mitral repair. Although Suri and colleagues[21] did demonstrate significant decreases in postoperative ventilatory support with port-access procedures, there were no other differences in outcomes. It is unclear whether this difference was due to its comparison of 2 university series, as opposed to real-world data, or whether there was more discriminatory power in our multi-institutional analysis.

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TABLE 1. Demographic characteristics after matching of patients undergoing mitral repair

Category	Thoracotomy N	Thoracotomy %	Sternotomy N	Sternotomy %	*P* value
Total	367	100	367	100	
Age (y)					.7155
<30-60	138	37.6	146	39.8	
60-69	106	28.9	97	26.4	
≥70	123	33.5	124	33.8	
Race or ethnicity					.2049
White	279	76.0	263	71.7	
African American	24	6.5	37	10.1	
Hispanic	4	1.1	8	2.2	
Other	60	16.4	59	16.1	
Sex					>.9999
Female	161	43.9	161	43.9	
Male	206	56.1	206	56.1	
Insurance					>.9999
Commercial	12	3.3	12	3.3	
Medicare	179	48.8	179	48.8	
Medicaid	12	3.3	12	3.3	
Managed care	147	40.1	147	40.1	
Other	17	4.6	17	4.6	
Health status					.4919
APR-DRG severity level 1 or 2	141	38.4	132	36.0	
APR-DRG severity level 3 or 4	226	61.6	235	64.0	

APR-DRG, All Patient Refined Diagnosis-Related Groups.

The current economic cost analysis also demonstrates significant savings with the thoracotomy approach, with a reduction in the average primary hospitalization cost of $8289 (17.2%). Part of this savings is attributable to a 2-day reduction in hospital stay associated with a thoracotomy approach. In addition, as previously reported,[10,22] blood use (as inferred from mean cost of $1122 for thoracotomy vs $1671 for sternotomy) was significantly reduced with a thoracotomy approach.

TABLE 2. Adverse events of propensity-matched groups after mitral repair

Category	Thoracotomy N	Thoracotomy %	Sternotomy N	Sternotomy %	*P* value
Total	367	100	367	100	
Neurologic complications*	9	2.5	8	2.2	.8062
Total pulmonary complications (infections plus noninfections)†	145	39.5	137	37.3	.5438
Pulmonary complications excluding infections	126	34.3	105	28.6	.0951
Total infections‡	23	6.3	43	11.7	.0099
Pulmonary infections§	19	5.2	32	8.7	.0591
Sepsis and other infections‖	4	1.1	16	4.4	.0065
Wound complications¶	18	4.9	24	6.5	.3403
In-hospital deaths	4	1.1	7	1.9	.3621

*Ischemic stroke, hemorrhagic stroke, transient cerebral ischemic attack. †Acute respiratory failure, pulmonary insufficiency, atelectasis or pulmonary collapse, pneumonia. ‡Pneumonia, sepsis, bacteremia or systemic inflammatory response syndrome, postoperative infection. §Pneumonia. ‖Sepsis, bacteremia or systemic inflammatory response syndrome, postoperative infection. ¶Hematoma, seroma, or hemorrhage complicating a procedure; wound disruption or dehiscence.

TABLE 3. Hospital characteristics after matching

Category	Thoracotomy By visits N	%	Thoracotomy By hospital N	%	Sternotomy By visits N	%	Sternotomy By hospital N	%	*P* value
Total	367	100	39	100	367	100	52	100	
Census region									
Northeast	80	21.8	11	28.2	51	13.9	7	13.5	<.0001
Midwest	17	4.6	7	18.0	29	7.9	7	13.5	
South	249	67.9	12	30.8	146	39.8	24	46.2	
West	21	5.7	9	23.1	141	38.4	14	26.9	
Location									
Urban	363	98.9	37	94.9	350	95.4	46	88.5	.0040
Not urban	4	1.1	2	5.1	17	4.6	6	11.5	
Type									
Teaching	325	88.6	21	53.9	185	50.4	24	46.2	<.0001
Nonteaching	42	11.4	18	46.2	182	49.6	28	53.9	
Bed count									
<200	3	0.8	2	5.1	6	1.6	1	1.9	<.0001
200-400	22	6.0	13	33.3	122	33.2	22	42.3	
401-600	75	20.4	11	28.2	163	44.4	17	32.7	
>600	267	72.8	13	33.3	76	20.7	12	23.1	

Although robotic mitral repairs were specifically excluded from this study, parallels between recent robotic economic studies and ours can be noted. Suri and associates[23] recently reviewed the Mayo Clinic experience and concluded that robotics along with process improvement can be cost neutral, increasing "the affordability of new technologies capable of improving early patient outcomes." Likewise, Mihaljevic and colleagues[24] performed propensity-based analyses of the economic cost of robotics for degenerative mitral repairs. They noted that after a threshold of 50 to 100 cases a year the cost of robotically assisted operations overlapped those of conventional approaches. As such, in exchange for higher procedural costs, robotic valve repair offered the clinical benefit of the least invasive surgery, the lowest postoperative cost, and the fastest return to work.

An important and interesting discovery in this analysis was the decreased readmission rates associated with the thoracotomy approach. At both 30 and 90 days, the thoracotomy cohort had significantly lower readmission rates. Although this difference was not calculated into the hospital cost saving presented here, it will certainly translate into further institutional cost savings as the Patient Protection and Affordable Care Act (Obama Care) penalty on hospitals begins under the Act's Hospital Readmissions Reduction Program.[25]

TABLE 4. Health care use and costs after matching

	Thoracotomy	Sternotomy
Total hospital costs		
Median	$31,515	$37,495
Mean	$37,156	$47,683
SD	$19,624	$35,865
Hospital costs by cost center		
Blood bank		
Median	$507	$799
Mean	$1122	$1671
SD	$2241	$2436
Operating room		
Median	$8886	$8029
Mean	$9602	$8929
SD	$4679	$5685
Other		
Median	$523	$246
Mean	$3566	$1162
SD	$4833	$3156
Pharmacy		
Median	$2078	$2232
Mean	$2823	$4876
SD	$2947	$15,211
Radiology		
Median	$438	$460
Mean	$673	$807
SD	$699	$1125
Respiratory		
Median	$688	$949
Mean	$1226	$1664
SD	$1788	$2417
Room and board		
Median	$5622	$9075
Mean	$7372	$13,655
SD	$9090	$17,226
Intensive care unit		
Median	$2662	$4177
Mean	$4311	$8091
SD	$7257	$15,073

Limitations

This study had some important limitations. This analysis was limited to a 90-day perioperative period, which limits any analyses related to potential long-term complications. Although thoracotomy approaches and partial sternotomy approaches are considered minimally invasive, data limitations did not allow for a distinction between and full and partial sternotomy approaches in this study. This large multi-institutional comparison of the sternal versus non-sternal approach for IsoMVRep, however, at the minimum shows the benefits of thoracotomy versus any sternal approach. These differences would be even greater if partial sternotomies were not included in the control group.[26] In addition, although the total hospital costs are accurate, different institutions may have placed various items into different cost centers, and these differences may limit the usefulness of individual cost center analyses.

Finally, the arterial perfusion approach (antegrade or retrograde) was not available to analyze in this data set. The senior author (E.A.G.) has previously reported on both the changing incidence of arterial perfusion strategies and their differential outcomes.[27] This study was designed to accurately test differences of surgical incision, however, not perfusion strategies. As such, our algorithm included the possibility of either femoral perfusion or central aortic perfusion.

CONCLUSIONS

Relative to sternal approaches, a thoracotomy approach for IsoMVRep provides similar mortality and less morbidity with fewer infections, shorter hospital stay, and significant cost savings during the primary admission. From an economic perspective, the markedly lower readmission rates associated with thoracotomy will translate into additional institutional cost savings when the Patient Protection and Affordable Care Act (Obama Care) penalty on hospitals begins with the Act's Hospital Readmissions Reduction Program.

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APPENDIX E1. DETAILED STATISTICAL STRATEGY AND METHODOLOGY

From more than 25 million inpatient admissions in the Premier database, 6007 IsoMVRep procedures were identified. Next, the type of arterial cannulation (aortic, femoral, both, or unspecified) was determined. Of those patients who had femoral arterial cannulation or both femoral and aortic cannulation, we looked at whether a bone saw blade or bone wax was ever used as a determinant of sternotomy approach. These 847 patients—with femoral or combined arterial cannulation, no bone saw use, and no bone wax use—comprised the thoracotomy cohort.

A quasi-randomization method, called propensity scoring, was used to create groups of analyzable patients who were well matched. Propensity scores were assigned on the basis of likely predictors of the outcome of interest. Covariates on which to match were selected on the basis of their availability in the Premier database as well as their general acceptance as factors associated with the outcomes of interest.

The goal of this propensity-matching analysis was to find pairs of patients undergoing and not undergoing a thoracotomy for IsoMVRep who shared similar propensities for candidacy for the procedure on the basis of the matching variables. In addition, this analysis sought to maximize the number of matched patients while ensuring that cohorts were not significantly different with respect to relevant characteristics.

A statistical software (SAS Institute Inc, Cary, NC) macro from the Mayo Clinic was used; this macro used ''nearest neighbor matching'' on the estimated propensity scores to choose matches for the patients who underwent a thoracotomy procedure.[26] Propensity scores were calculated for likelihood of thoracotomy procedures for each of the patients included in the analysis on the basis of a nonparsimonious multivariable logistic regression model. Patients undergoing a thoracotomy for IsoMVRep were then matched with patients undergoing any sternotomy for IsoMVRep with a 1:1 ratio exactly (caliper = 0) on their sex. They were simultaneously matched within ±5 years on age and within a value of 0.0001 on their propensity for undergoing a sternotomy for IsoMVRep. Patient characteristics (race or ethnicity, marital status, region, and insurance) and co-morbid conditions (severity index, angina, dysrhythmias, chronic obstructive pulmonary disease, depression, extensive aortic atherosclerosis, kidney disease, previous coronary angioplasty, myocardial infarction [acute or old], and other coronary artery disease) were adjusted in the propensity score model.

Once the matched pairs had been obtained, to assess the extent to which the propensity matching reduced confounders, the distribution of several variables before and after matching were compared among the patients in the cohorts, including age, sex, race or ethnicity, insurance type, health status, region, and comorbid conditions. Group comparisons were made with χ^2 tests.

Because hospital costs have been found to be positively skewed, a generalized linear model with a gamma distribution and a log link function was used to adjust for differences in hospital characteristics (teaching vs nonteaching, urban vs rural, and bed count) and to calculate the corresponding least square means of overall cost for the hospital stay within each matched cohort. Adverse events (defined by *ICD-9* coding in Table 2) were summarized in tables by cohort, with *P* values for the differences in event rates calculated for each event category (neurologic, pulmonary, infection, and wound). Analyses were performed with SAS software (version 9.2).

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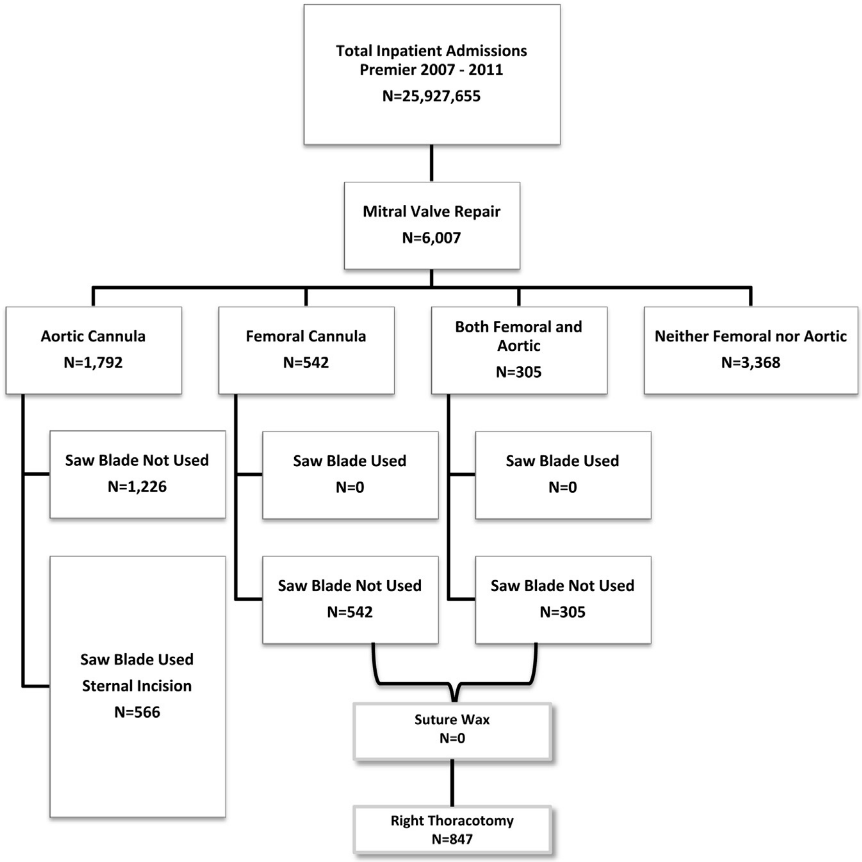

FIGURE E1. Flowchart demonstrating the expert rules used for procedure identification and attrition.

TABLE E1. Economic Workgroup on Valvular Surgery

Physician	Hospital or group practice	Location
Gorav Ailawadi, MD	University of Virginia	Charlottesville, Va
Mark Anderson, MD	Einstein Medical Center	Philadelphia, Pa
Glenn Barnhart, MD	Swedish Medical Center	Seattle, Wash
Scott Goldman, MD	Main Line Cardiothoracic Surgery	Wynnewood, Pa
Eugene Grossi, MD	NYU Langone Medical Center	New York, NY
Clifton Lewis, MD	Princeton Baptist Medical Center	Birmingham, Ala
Michael Mack, MD	The Heart Hospital Baylor Plano	Dallas, Tex
Chris Malaisrie, MD	Northwestern Memorial Hospital	Chicago, Ill
John Mehall, MD	Penrose-St. Francis Health Services	Colorado Springs, Colo
Robert Riley, MD	Arizona Cardiovascular	Scottsdale, Ariz
Evelio Rodriguez, MD	Saint Thomas Heart	Nashville, Tenn
Eric Roselli, MD	Cleveland Clinic	Cleveland, Ohio
William Ryan, MD	The Heart Hospital Baylor Plano	Dallas, Tex
Arash Salemi, MD	New York Presbyterian-Weill Cornell Medical Center	New York, NY
J. Michael Smith, MD	TriHealth Heart Institute	Cincinnati, Ohio
J. Alan Wolfe, MD	Northeast Georgia Physicians Group	Atlanta, Ga

TABLE E2. Adverse events (*International Classification of Diseases, Ninth Edition* codes)

Adverse events by category	*ICD-9* codes
Neurologic complications	
Ischemic stroke	433.x1, 434.x1, 997.02
Hemorrhagic stroke	430, 431, 432.x
Transient cerebral ischemic attack	435.x
Pulmonary complications—infections	
Pneumonia	480.x, 481, 482.x-484.x, 485, 486, 487, 490, 491.21, 491.22, 507.0, 510.0, 510.9, 513, 513.0, 513.1, 519.01, 997.31, 997.32
Pulmonary complications—noninfectious	
Acute respiratory failure and pulmonary insufficiency	518.81, 518.84, 518.5
Atelectasis or pulmonary collapse	518.0
Pulmonary complications—excluding infections	
Lung complications noninfectious	511.0-511.1, 511.89, 511.9, 512.0, 512.1, 514, 518.4, and 997.39 (if patient not already in another pulmonary category)
Sepsis and other infections	
Septicemia, bacteremia, or SIRS	038.xx, 790.7, 995.9x
Postoperative infection	998.5x, 999.0, 999.3x
Wound complications	
Hematoma, seroma, or hemorrhage complicating a procedure	998.1x
Wound disruption or dehiscence	998.3x
Death	
In-hospital death	From Premier data

ICD-9, *International Classification of Diseases, Ninth Edition*; *SIRS*, systemic inflammatory response syndrome.

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