A minimally invasive approach is more cost-effective than a traditional sternotomy approach for mitral valve surgery

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Objective: The aim of this study was to compare the cost and effectiveness of a minimally invasive (MI) versus traditional sternotomy (ST) approach for mitral valve surgery (MVS).

Methods: From January 1, 2003, to December 31, 2008, a total of 847 patients underwent isolated MVS at our institution. Propensity matching on 22 clinical variables was carried out to generate a study cohort of 434 patients (217 matched pairs). Direct and indirect costs from the hospital perspective were retrospectively obtained from our finance department. Total hospital costs were further stratified into 13 standardized institutional billing categories. In addition, data on morbidity, mortality, discharge location, hospital readmissions within 1 year, and freedom from reoperation were obtained.

Results: Compared with ST, MIMVS was associated with a \$9054 ± \$3302 lower mean total hospital cost ($P = .006$), driven largely by a reduction in direct ($P = .003$) versus indirect costs ($P = .06$). Among the 13 billing categories, MIMVS was associated with a significant reduction in costs of cardiac imaging ($P = .004$), laboratory tests ($P = .005$), boarding and nursing ($P = .001$), and radiology ($P = .002$). More patients in the ST group required intubation for more than 72 hours ($P = .019$); however, there were no differences in morbidity or long-term survival ($P = .334$). A higher proportion of MI patients were discharged home with no nursing services ($P = .018$), and a higher proportion of ST patients required readmission within 1 year ($P = .023$). There were no differences in freedom from reoperation between groups ($P = .574$).

Conclusions: With equivalent efficacy across a range of measures and lower costs compared with ST, MIMVS represents a cost-saving strategy for MVS. (J Thorac Cardiovasc Surg 2011;142:1507-14)

During the past 10 years, there has been an increase in the number of studies on outcomes of minimally invasive mitral valve surgery (MIMVS).¹⁻⁴ Since the first description of MIMVS by Cohn and associates⁵ and Navia and Cosgrove⁶ in the mid-1990s, various minimally invasive (MI) approaches have been reported including the parasternal, hemisternotomy, minithoracotomy, and totally endoscopic approach.⁵⁻⁸ Despite the variation in surgical approaches, the shared goal of MIMVS is to provide a safe and effective option for mitral valve surgery (MVS) with the clinical benefits associated with a minimal access approach.

Some of the reported benefits of MIMVS include decreased postoperative pain, improved postoperative

respiratory function, reduced surgical trauma, and improved cosmesis and patient satisfaction.⁹⁻¹¹ In addition, other reported benefits include decreased intensive care unit and total hospital length of stay, faster physical rehabilitation, and decreased overall hospital resource use.^{5,12-14}

These reported benefits have often been tempered by concerns regarding the safety and durability of an MI approach, the potential disadvantages of decreased surgical exposure, and the potential for increased operative times. Although there are currently no prospective, randomized trials comparing an MI to a sternotomy (ST) approach for MVS, several single-institution studies have confirmed that many of the proposed benefits of MIMVS can be achieved with no detrimental effects on morbidity, mortality, or long-term valve function.¹⁵⁻¹⁸

Although early studies have suggested lower hospital costs associated with MIMVS,^{7,19,20} no studies in the past decade have specifically performed a detailed economic evaluation of this approach. In this analysis we assess the cost-effectiveness of an MI versus an ST approach for MVS.

METHODS AND PATIENTS

Study Population

From January 1, 2003, to December 31, 2008, a total of 847 patients underwent isolated MVS at our institution. After obtaining institutional

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This work was supported in part by National Institutes of Health Training Grant 5T32HL007854-13 (to Dr Iribarne).

Disclosures: Authors have nothing to disclose with regard to commercial support. Received for publication Oct 3, 2010; revisions received March 20, 2011; accepted for publication April 11, 2011; available ahead of print June 13, 2011.

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0022-5223/\$36.00

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doi:10.1016/j.jtcvs.2011.04.038

Abbreviations and Acronyms

MI	= minimally invasive
MIMVS	= minimally invasive mitral valve surgery
MVS	= mitral valve surgery
ST	= sternotomy

review board approval, we retrospectively gathered data on patient demographics, hospital costs, operative parameters, and both short- and long-term morbidity and mortality using data from our hospital finance department, institutional medical records, and operative reports that comprise our internal cardiac surgery registry, as well as data from the New York State Cardiac Surgery Database.²¹

Isolated MVS was defined as any mitral valve repair or replacement performed in the absence of a major concomitant procedure such as coronary artery bypass grafting or other valve surgery. A total of 209 (24.7%) patients underwent minor concomitant procedures including atrial fibrillation ablation (n = 149, 17.6%) and atrial septal defect repair (n = 60, 7.1%). There were 316 mitral valve replacements (37.3%) and 531 mitral valve repairs (62.7%). A traditional median ST approach was used in 348 (41.1%) patients and an MI approach was used in 499 (58.9%) patients. Although MIMVS can be defined broadly as per Society of Thoracic Surgeons Database guidelines as any mitral valve repair or replacement performed through an incision other than a full median sternotomy, in our analysis MIMVS was isolated to either a minithoracotomy, which was used in the majority of cases, or a hemisternotomy approach.²² Robotic mitral valve surgery was not included in the analysis.

Operative Technique

Among the MIMVS cases, 496 (99.4%) were performed through a right minithoracotomy and 3 (0.6%) were performed through a hemisternotomy. Our operative approach for MIMVS performed through a minithoracotomy has been described previously.¹⁸ Of note, aortic cannulation was most commonly performed in a central fashion and venous drainage was most commonly achieved through a percutaneous femoral vein approach using single multistage venous cannulation. Central aortic cannulation was performed through the initial thoracotomy incision and a transthoracic aortic cross-clamp (Chitwood) was passed through a stab wound in the right axilla. It has been our institutional preference to use a central approach for arterial cannulation to avoid the potential complications associated with peripheral cannulation such as arterial dissection, embolism, retroperitoneal hematoma, and wound infection.

Cost outcomes. The primary end point of the analysis was total hospital cost of the surgical admission. From the hospital perspective, we estimated total cost as all costs incurred from the time of operation to the time of hospital discharge, including intraoperative and postoperative costs. Hospital cost data were obtained from our institutional finance department decision support system (Eclipsys Transition System Incorporated, Atlanta, Ga), which provides audited clinical, financial, and operational data.²³ Of note, the reported cost data represent actual resource costs to the hospital for services rendered rather than billed charges.

Total hospital cost was stratified into direct and indirect costs. Direct costs represent costs associated with providing services or products to the patient, such as laboratory tests, diagnostic imaging, medications, or surgical procedures. Indirect costs represent hospital administrative expenses not directly generated by patient care activities, such as facility maintenance and administration. Total hospital cost was also stratified into 13 standardized institutional billing categories, including blood bank, cardiac imaging, cardiac catheterization laboratory, dialysis,

emergency room, laboratory, neurology, boarding and nursing, operating room, pharmacy, radiology, rehabilitation, and respiratory care.

Clinical outcomes. Both short- and long-term clinical outcomes were analyzed to assess the efficacy of MIMVS. Short-term outcomes included cardiopulmonary bypass time, crossclamp time, hospital length of stay, discharge location, and major in-hospital complications (ie, intubation greater than 72 hours, renal failure, sepsis, reoperation for bleeding, stroke less than 24 hours after surgery, stroke 24 hours or more after surgery, gastrointestinal bleeding, and transmural myocardial infarction). Long-term outcomes included survival, freedom from reoperation, and the number of medical or surgical readmissions occurring within 1 year of discharge. Reasons for readmissions were categorized into the following: cardiac surgery, pacemaker placement, percutaneous coronary intervention, arrhythmia, pleural effusion, neurologic, or other causes.

Propensity matching. To account for differences in baseline characteristics between groups, we used propensity score matching. A parsimonious model of risk factors for selection to an MI versus ST approach was created using 22 baseline patient characteristics and relevant operative variables including mitral repair versus replacement, presence of a concomitant procedure, and surgeon (Appendix 1). A stepwise logistic regression approach (backward, remove $P > .20$) was used for variable selection to create the final model (Appendix 2). From this model, propensity scores were generated for each patient. Propensity scores were then nearest neighbor matched 1:1 to create ST- and MI-matched pairs for analysis.

Statistical Analysis

Standard cost-effectiveness analyses are traditionally based on the difference in arithmetic mean cost.²⁴ However, inasmuch as medical costs are usually right skewed, as costs cannot be negative, we reported both mean and median costs. For mean costs, we estimated associated bootstrapped standard errors, using 1000 iterations, and applied the nonparametric bootstrap t test, again using 1000 iterations, to compare costs between groups.²⁵ For median costs, results of the Wilcoxon rank sum test are reported. To assess the independent effect of multiple baseline variables (Appendix 1) and presence of complications on total hospital costs, we used generalized linear models. Variable selection for generalized linear models was performed via backward, stepwise regression (remove $P > .20$); the traditional log-link function and gamma distribution we used as per the modified Parks test.²⁶ Owing to the log transformation, regression coefficients are reported in exponentiated form to highlight the multiplicative effect of a unit change in the independent variable on total hospital cost.

For clinical data, continuous variables were reported as mean $\pm$ standard error and were compared using the Student t test or Wilcoxon rank sum test when noted. Categorical variables were reported as percentages and compared using the χ^2 or Fisher's exact test when appropriate. Long-term survival and freedom from reoperation were assessed using the Kaplan-Meier method and were compared using the log-rank test. Survival data were obtained from the Social Security Death Index and provided through December 14, 2009. Follow-up freedom from reoperation data were obtained through June 1, 2010. All reported P values are 2-sided. All statistical analyses were performed using Stata 10 (Stata Corp, College Station, Tex).

RESULTS**Study Population**

Between January 1, 2003, and December 31, 2008, 847 patients underwent isolated MVS at our institution. Table 1 summarizes the baseline characteristics of the original study population, with significant differences observed between MI and ST groups across most variables. The final model for propensity matching (Appendix 2) had an area under

TABLE 1. Baseline characteristics of original study population

	ST (n = 348)	MI (n = 499)	P value
Age	63.2 ± 0.82	58.8 ± 0.61	<.0001
Body mass index	26.6 ± 0.33	25.1 ± 0.18	<.0001
Cerebrovascular accident	34 (9.8%)	21 (4.2%)	.002
Chronic obstructive pulmonary disease	27 (7.8%)	21 (4.2%)	.034
Creatinine	1.31 ± 0.08	0.97 ± 0.02	<.0001
Current congestive heart failure	110 (31.6%)	70 (14.0%)	<.001
Current smoker	13 (3.7%)	21 (4.2%)	.859
Diabetes	41 (11.8%)	29 (5.8%)	.002
Ejection fraction (%)	48.9 ± 0.61	51.6 ± 0.42	<.001
Gender (male)	192 (55.2%)	230 (46.1%)	.009
Hepatic failure	1 (0.29%)	1 (0.20%)	1.0
History of endocarditis	15 (4.3%)	4 (0.80%)	.098
History of ventricular arrhythmias	2 (0.57%)	2 (0.40%)	1.0
Immune system deficiency	22 (6.3%)	8 (1.6%)	<.001
Intra-aortic balloon pump	4 (1.1%)	0	.028
Peripheral vascular disease	9 (2.6%)	4 (0.80%)	.047
Previous myocardial infarction	26 (7.5%)	27 (5.4%)	.249
Previous surgery	99 (28.5%)	30 (6.0%)	<.001
Renal failure or dialysis	14 (4.0%)	2 (0.40%)	<.001
Vasodilatory shock (preoperative)	4 (1.1%)	1 (0.20%)	.654

ST, Sternotomy; MI, minimally invasive.

the receiver operating characteristic curve of 0.813 ± 0.025 , demonstrating good model discrimination.

A total of 217 matched pairs were generated for a resulting sample size of 434 patients or 51.2% of the original study population. Among the matched pairs, there were no significant differences in major baseline characteristics (Table 2).

Operative Characteristics

Among propensity matched MI patients, all mitral valve operations were performed through a right minithoracotomy. There was no difference in the proportion of repairs versus replacements ($P = .768$), with mitral valve repair being more common than replacement among both ST and MI groups. Also, there was no difference in mitral valve disease ($P = .424$) or mitral valve disease etiology ($P = .594$) (Table 3). In addition, there was no difference in the proportion of concomitant procedures between groups ($P = .141$). The cardiopulmonary bypass time was longer among MI patients by 24.6 ± 4.1 minutes ($P < .0001$), but the cross-clamp time did not differ between groups ($P = .135$). Among MI patients, there were no conversions to a median ST approach.

Cost Analysis

The MI approach was associated with a $\$9,054 \pm \$3,302$ lower mean hospital cost of admission (ST: $\$50,060 \pm \2659 ; MI: $\$41,006 \pm \1887 ; $P = .006$). When median cost was used, the reduction in total hospital cost was

TABLE 2. Baseline characteristics of matched pairs

	ST (n = 217)	MI (n = 217)	P value
Age (y)	61.5 ± 1.10	59.3 ± 0.94	.117
Body mass index	25.7 ± 0.38	25.6 ± 0.30	.819
Cerebrovascular accident	19 (8.8%)	13 (6.0%)	.359
Chronic obstructive pulmonary disease	16 (7.4%)	10 (4.6%)	.312
Creatinine (mg/dL)	1.21 ± 0.10	1.02 ± 0.05	.101
Current congestive heart failure	51 (23.5%)	47 (21.7%)	.731
Current smoker	5 (2.3%)	11 (5.1%)	.202
Diabetes	17 (7.8%)	19 (8.8%)	.862
Ejection fraction (%)	49.7 ± 0.78	50.3 ± 0.71	.576
Gender (male)	111 (51.2%)	111 (51.2%)	1.0
Hepatic failure	1 (0.46%)	0	1.0
History of endocarditis	5 (2.3%)	3 (1.4%)	.724
History of ventricular arrhythmias	1 (0.46%)	1 (0.46%)	1.0
Immune system deficiency	10 (4.6%)	7 (3.2%)	.622
Intra-aortic balloon pump	3 (1.4%)	0	.248
Peripheral vascular disease	2 (0.92%)	2 (0.92%)	1.0
Previous myocardial infarction	18 (8.3%)	18 (8.3%)	1.0
Previous surgery	26 (12.0%)	22 (10.1%)	.647
Renal failure or dialysis	5 (2.3%)	2 (0.92%)	.449
Vasodilatory shock (preoperative)	2 (0.92%)	1 (0.46%)	1.0

ST, Sternotomy; MI, minimally invasive.

$\$3595$ (ST: $\$37,013$; MI: $\$33,418$; $P = .003$). The MI approach was also associated with a $\$5993 \pm \2008 lower mean direct cost (ST: $\$29,273 \pm \1610 ; MI: $\$23,279 \pm \1207 ; $P = .003$), but there was no difference in mean indirect cost between groups (ST: $\$20,787 \pm \1320 ; MI: $\$17,727 \pm \993 ; $P = .06$) (Figure 1). When median cost was used, the reduction in direct cost was $\$3270$ (ST: $\$21,674$; MI: $\$18,404$; $P = .001$) and the reduction in indirect cost was $\$1896$ (ST: $\$15,185$; MI: $\$13,289$; $P = .023$). Among our institutional billing categories (Table 4), the lower cost of the MI approach was primarily driven by a reduction in cost of boarding and nursing ($P = .001$). There was a significant positive correlation between hospital length of stay and the cost of boarding and nursing ($0.923 [0.912-0.932]$; $P < .0001$). Lower costs were also observed among MI patients in the categories of cardiac imaging ($P = .004$), laboratory tests ($P = .005$), and radiology ($P = .002$).

In multivariable analysis, age ($P = .003$), diabetes ($P = .039$), and previous surgery ($P = .001$), as well as intubation for more than 72 hours ($P < .001$) and sepsis ($P = .03$) were associated with higher total hospital costs among MI patients. Among ST patients, peripheral vascular disease ($P = .036$), intubation for more than 72 hours ($P < .001$), and reoperation ($P = .005$) were associated with higher costs (Table 5).

TABLE 3. Operative characteristics of matched pairs

	ST (n = 217)	MI (n = 217)	P value
Mitral valve surgery type			
Replacement	87 (40.1%)	83 (38.3%)	.768
Repair	130 (59.9%)	134 (61.8%)	
Mitral valve disease			
Mitral regurgitation	185 (85.3%)	183 (84.3%)	.424
Mitral stenosis	24 (11.1%)	30 (13.8%)	
Mitral valve disease etiology			
Degenerative	130 (59.9%)	128 (59.0%)	.594
Anterior leaflet prolapse	28 (12.9%)	16 (7.4%)	
Bileaflet prolapse	21 (9.7%)	33 (15.2%)	
Posterior leaflet prolapse	81 (37.3%)	79 (36.4%)	
Dilated cardiomyopathy	13 (6.0%)	10 (4.6%)	
Endocarditis	19 (8.8%)	14 (6.5%)	
Ischemic	9 (4.2%)	15 (6.9%)	
Rheumatic	17 (7.8%)	25 (11.5%)	
Calcific	22 (10.1%)	20 (9.2%)	
Other	7 (3.2%)	5 (2.3%)	
Concomitant procedures			
Atrial septal defect repair	14 (6.5%)	18 (8.3%)	.141
Atrial fibrillation ablation	50 (23.0%)	32 (14.7%)	
Operative times (min)			
CPB time	112.6 ± 2.2	137.3 ± 3.4	<.0001
Crossclamp time	75.8 ± 1.6	80.7 ± 2.8	.135

ST, Sternotomy; MI, minimally invasive; CPB, cardiopulmonary bypass.

Clinical Outcomes

The mean length of stay was approximately 2 days shorter among MI patients than ST patients (MI: 7.12 ± 0.36 days; ST: 9.19 ± 0.52 days; $P = .001$). The difference in median lengths of stay for MI and ST patients was also statistically significant (MI: 6 days; ST: 7 days; $P = .0001$). In terms of postoperative complications, there were no significant differences in gastrointestinal bleeding

($P = 1.0$), renal failure ($P = .284$), reoperation for bleeding ($P = .544$), sepsis ($P = 1.0$), stroke less than 24 hours after surgery ($P = .623$), stroke 24 hours or more after surgery ($P = .685$), or transmural myocardial infarction ($P = 1.0$). There was, however, a greater proportion of patients in the ST group who required intubation for more than 72 hours: ST: 8.3% ($n = 18$), MI: 2.8% ($n = 6$); $P = .019$. The mean duration of survival follow-up was 3.2 ± 1.6 years. There was no difference in survival at 30 days ($P = .503$) or 1-year ($P = .827$) between groups. There was also no significant difference in long-term survival ($P = .334$).

There was a significant difference in the distribution of discharge locations between MI and ST patients ($P = .018$) (Table 6). A higher proportion of MI patients (66.8%, $n = 135$) were discharged home with no nursing services compared with ST (54.4%, $n = 111$), whereas a higher proportion of ST patients were discharged home with a nursing aide (30.9%, $n = 63$) compared with MI (25.7%, $n = 52$). In addition, a higher proportion of ST patients (14.7%, $n = 30$) were discharged to rehabilitation facilities when compared with MI patients (7.5%, $n = 15$).

Hospital readmissions within 1 year of surgery were also studied between groups, and there were a higher proportion of readmissions among ST patients (ST: 13.7%, $n = 28$; MI: 6.8%, $n = 14$; $P = .023$). In both groups, the most common cause for readmission was arrhythmias managed medically (Table 6). With regard to freedom from reoperation, there was no significant difference between groups ($P = .574$) (Figure 2). The average duration of follow-up was 4.5 ± 1.7 years.

DISCUSSION

Over the past 2 years, there has been a growth of interest in the economic evaluation of new surgical technologies and techniques, coinciding with increased national attention to comparative effectiveness research.^{27,28} While early studies by Chitwood,^{7,19} Cohn,⁵ Cosgrove,²⁰ and their associates in the 1990s reported 7% to 34% cost savings associated with MIMVS, no studies in the past decade have specifically compared costs between MI and ST approaches as a primary end point.

In our analysis, patients undergoing MIMVS had a \$9054 lower mean total cost of admission resulting in cost savings of 18% compared with the ST approach. In addition, we demonstrate that the difference in hospital cost between groups was largely driven by differences in direct rather than indirect costs. These results support the generalizability of our findings as direct costs involve costs related to patient care, whereas indirect costs represent costs attributable to hospital maintenance and utilities, which may vary from region to region.

The hypothesis that MIMVS could be cost saving has been driven largely by the observation that patients

FIGURE 1. Total and stratified hospital costs with bootstrapped standard error estimates. ST, Sternotomy; MI, minimally invasive. *Statistically significant difference between groups.

TABLE 4. Total hospital costs stratified by billing category

Cost category	Mean cost			Median cost		
	ST (n = 217)	MI (n = 217)	P value	ST (n = 217)	MI (n = 217)	P value
Blood bank	\$1426 ± 131	\$1605 ± 238	.151	\$898	\$585	.262
Cardiac imaging	\$297 ± 27	\$201 ± 19	.004	\$188	\$56	.002
Cardiac catheterization	\$4344 ± 218	\$4500 ± 179	.588	\$4,165	\$4343	.130
Dialysis	\$5313 ± 4649	\$556 ± 500	.487	\$1,361	\$556	.564
Emergency room	\$1452 ± 214	\$1032 ± 296	.234	\$1,756	\$324	.551
Laboratory tests	\$1953 ± 159	\$1404 ± 108	.004	\$1,282	\$1006	<.001
Neurology	\$1919 ± 1451	\$407 ± 301	.309	\$127	\$152	.952
Boarding and nursing	\$21,950 ± 1565	\$15,798 ± 1027	.001	\$13,367	\$11,157	<.001
Operating room	\$15,905 ± 438	\$15,984 ± 322	.888	\$14,699	\$14,874	.356
Pharmacy	\$3157 ± 413	\$2668 ± 275	.330	\$1,859	\$1569	.064
Radiology	\$1770 ± 236	\$954 ± 97	.002	\$733	\$608	.004
Rehabilitation	\$853 ± 98	\$723 ± 85	.344	\$591	\$464	.005
Respiratory care	\$1632 ± 329	\$1349 ± 215	.466	\$578	\$661	.464

ST, Sternotomy; MI, minimally invasive.

undergoing MIMVS generally have a shorter length of stay. In a recent meta-analysis by Modi and associates,²⁹ 8 of 14 studies on MIMVS reported a shorter hospital stay when compared to the ST approach.³⁰ We have previously reported a shorter length of stay among MIMVS patients.¹⁸ In this cohort, we estimated the difference was approximately 2 days on average. Notably, among our institutional billing categories we found significant differences in costs associated with boarding and nursing, laboratory tests, radiology, and cardiac imaging. As expected, there was a significant, positive correlation between length of stay and costs of boarding and nursing. Individuals in a hospital for fewer days will incur less boarding and nursing costs, and will also likely have lower costs associated with routine activities such as daily laboratory and imaging studies. In our

multivariable analysis, intubation for more than 72 hours was a significant independent predictor of total hospital cost shared by both MI and ST groups. MI patients had a 5.5% lower rate of this complication; however, the overall prevalence of this complication in the series was low. Thus, although our results demonstrate that the majority of cost savings associated with MIMVS occurred in the category of boarding and nursing, which results from a shorter length of stay, further research is necessary to determine the exact cause of the shorter hospitalization. In addition to shorter intubation times, other factors may include decreased postoperative pain and improved postoperative physical rehabilitation.

Also, it must be noted that although MI patients had a shorter length of stay than ST patients, the mean lengths of stay for MI and ST groups were 7.1 and 9.2 days, respectively. There is likely significant variability from one hospital to the next with respect to hospital stay. For example, Suri and associates³⁰ reported lengths of stay of 6.95 days for port access patients and 6.19 days among ST patients who received mitral valve repairs. A recent executive summary of The Society of Thoracic Surgeons Adult Cardiac Surgery Database reported a mean length of stay of 10.5 days for all mitral valve replacements and 7 days for all mitral valve repairs performed in 2009.³¹ Gammie and associates³² analyzed all less invasive mitral valve operations in The Society of Thoracic Surgeons Database from 2004 to 2008 and reported a 6.9-day risk-adjusted mean hospital stay for the less invasive group.³¹ Thus, hospital stays vary from one center to the next, and those reported in our analysis for MI and ST patients, which included both repairs and replacements, may be slightly higher than those observed in other centers. This variability may be explained by the fact that patients in our analysis had numerous comorbidities. For example, among propensity matched MIMVS patients, 22% had congestive heart failure, 8.8%

TABLE 5. Baseline patient characteristics and postoperative complications associated with total hospital costs significant in multivariable regression

	Exp β coefficient	95% CI	<i>P</i> value
<i>Baseline patient characteristic</i>			
ST			
Peripheral vascular disease	2.41	1.06-5.45	.036
MI			
Age	1.01	1.00-1.02	.003
Diabetes	1.39	1.02-1.90	.039
Previous surgery	1.65	1.24-2.19	.001
<i>Complications</i>			
ST			
Intubation > 72 h	3.06	2.25-4.16	<.001
Reoperation	2.02	1.24-3.28	.005
MI			
Intubation > 72 h	2.64	1.64-4.26	<.001
Sepsis	3.45	1.13-6.56	.03

CI, Confidence interval; ST, sternotomy; MI, minimally invasive.

TABLE 6. In-hospital complications, short-term survival, discharge location, and readmissions

	ST (n = 217)	MI (n = 217)	P value
<i>Complications</i>			
Gastrointestinal bleed	1 (0.46%)	1 (0.46%)	1.0
Intubation > 72 h	18 (8.3%)	6 (2.8%)	.019
Renal failure	6 (2.8%)	2 (0.92%)	.284
Reoperation for bleeding	7 (3.2%)	4 (1.8%)	.544
Sepsis	2 (0.92%)	3 (1.4%)	1.0
Stroke (< 24 h)	3 (1.4%)	1 (0.46%)	.623
Stroke (≥ 24 h)	4 (1.8%)	2 (0.92%)	.685
Transmural myocardial infarction	0	0	1.0
<i>Mortality</i>			
Thirty-day mortality	3 (1.4%)	6 (2.8%)	.503
One-year mortality	12 (5.5%)	10 (4.6%)	.827
<i>Discharge location</i>			
	(n = 204)	(n = 202)	
Home with no nursing services	111 (54.4%)	135 (66.8%)	.018
Home with nursing aide	63 (30.9%)	52 (25.7%)	
Skilled nursing facility	16 (7.8%)	5 (2.5%)	
Short-term, acute rehabilitation	2 (0.98%)	0	
Other rehabilitation facility	12 (5.9%)	10 (5.0%)	
<i>Readmission</i>			
	(n = 205)	(n = 207)	
No readmissions within 1 y	177 (86.3%)	193 (93.2%)	.023
≥ 1 readmission within 1 y	28 (13.7%)	14 (6.8%)	
Cardiac surgery	3 (10.7%)	2 (14.3%)	
Pacemaker insertion	4 (14.3%)	3 (21.4%)	
PCI	4 (14.3%)	1 (7.1%)	
Arrhythmia	6 (21.4%)	4 (28.6%)	
Chest pain or CHF	6 (21.4%)	1 (7.1%)	
CVA/TIA	2 (7.1%)	1 (7.1%)	
Pleural effusion	3 (10.7%)	2 (14.3%)	

Note that readmission subcategory percentages are based on the number of ≥1 readmits. *PCI*, Percutaneous coronary intervention; *CHF*, congestive heart failure; *CVA*, cerebrovascular accident; *TIA*, transient ischemic attack.

had diabetes, 8.3% had a previous myocardial infarction, and 6% had a previous cerebrovascular accident. In addition to patient risk, hospital logistical factors such as bed availability and rehabilitation center transfer rates may result in hospital stay variability from one center to the next. Importantly, however, baseline risk did not differ among propensity matched groups and it is unlikely that logistical factors differentially affected one group versus the other in our analysis.

One of the early concerns with MIMVS was that a smaller incision would result in prolonged operative times and potentially increased resource use in the operating room. In our analysis, MIMVS was associated with an equivalent crossclamp time compared with ST and a mean bypass time that was longer by only 25 minutes. Despite this slightly longer bypass time, there was no significant difference in operating room costs between groups.

FIGURE 2. Freedom from mitral valve reoperation. *ST*, Sternotomy; *MI*, minimally invasive.

Traditional cost-effective analyses generally report the incremental cost-effectiveness ratio between 2 treatments as the difference in average cost divided by the difference in average effectiveness, often in the form of quality-adjusted life years. Inasmuch as our study was retrospective, no data on postoperative quality-adjusted life years was available. Furthermore, a literature search revealed no contemporary studies that have prospectively compared quality of life between MI and ST MVS. In the absence of such data, effectiveness could be analyzed from the perspective of valve integrity and freedom from reoperation. We found no difference in freedom from reoperation between groups, and these findings are consistent with other studies reporting freedom from reoperation rates ranging from 99.3% at 3.2 years to 91% at 4 years for MIMVS.³⁰ Although long-term postoperative echocardiographic data were not available in our retrospective analysis, a recent study by Svensson and coworkers⁹ demonstrated no difference in the proportion of patients with mitral regurgitation grade 3+ or 4+ at 1 and 5 years when compared with the ST approach.⁹ Moreover, in our analysis there was no difference in morbidity, mortality, or long-term survival between groups. Therefore, on the basis of its lower cost and equivalent efficacy and safety relative to ST, our results suggest that MIMVS is cost-saving and cost-effective.

The cost savings associated with MIMVS could potentially be an underestimate in our analysis because we only included costs associated with the surgical admission. Further cost savings associated with MIMVS could be realized if the time horizon of our economic analysis was expanded to 1 year. More patients undergoing MIMVS were discharged home with no nursing services and fewer required transfer to rehabilitation facilities on discharge, representing significant cost savings. In addition, at 1 year the rate of hospital readmission for MI patients was half that of ST patients, which represents significant additional cost

savings. Although the reasons for the observed lower readmission rate are an area of ongoing research, it is possible that improved functional status, as suggested by lower nursing and rehabilitation services, may facilitate overall recovery and prevent deconditioning associated with postoperative complications.

Limitations

There are several limitations to our analysis. First, our study is retrospective and subject to multiple potential biases. At our institution, the decision to pursue an MI approach involves an overall assessment of the feasibility and safety of such an approach based on the patient's preoperative risk. MIMVS is particularly challenging, for example, in patients with previous cardiac surgery, chronic obstructive pulmonary disease, and elevated body mass index, and this is reflected in the differences in baseline characteristics among unmatched pairs in Table 1. Although the C-statistic of our propensity score model demonstrated good model discrimination, selection bias cannot be completely eliminated through propensity matching. Also, it is possible that while 22 variables were considered in the propensity model, other risk factors may influence the selection to an MI versus an ST approach. Second, data on readmission and reoperation reflect only hospital readmissions that occurred at our institution. Therefore, a fraction of these events that occurred outside our hospital would not be included in the analysis. Nevertheless, it is unlikely that the rates of these occurrences at other institutions would have been different between groups. Last, our results do not take into account the potential effect of learning curves on clinical outcomes and the possibility that cost savings associated with MIMVS may not be realized early in the learning curve, or that overall cost savings associated with MIMVS may not be significant in magnitude at low-volume MVS centers.

CONCLUSIONS

MIMVS is a cost-effective and cost-saving strategy for mitral valve repair and replacement compared with the traditional ST approach with lower cost driven largely by a decreased length of stay. However, MIMVS demonstrated comparable efficacy across a range of efficacy measures such as freedom from reoperation, long-term survival, and in-hospital morbidity. As clinical trials emerge on the use of transcatheter mitral valve technologies and quality of life and cost become increasingly integrated into study end points, MIMVS may represent the standard on which to compare such emerging technologies.

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APPENDIX 1. Univariate analysis of variables considered for selection into logistic regression model to predict selection to MI versus ST approach

Variable	Odds ratio		P
	MI:ST	95% CI	value
<i>Patient baseline</i>			
Age	0.974	0.965-0.984	<.001
BMI	0.943	0.917-0.971	<.001
CVA	0.406	0.231-0.712	.002
COPD	0.522	0.290-0.940	.030
Creatinine	0.522	0.290-0.940	.030
Current CHF	0.353	0.252-0.495	<.001
Current smoker	1.13	0.559-2.29	.730
Diabetes	0.462	0.281-0.759	.002
Ejection fraction	1.02	1.01-1.04	<.001
Gender (male)	0.694	0.528-0.915	.009
Hepatic failure	0.697	0.043-11.18	.799
History of endocarditis	0.375	0.124-1.14	.084
History of ventricular arrhythmias	0.696	0.098-4.97	.718
Immune system deficiency	0.241	0.106-0.549	.001
Peripheral vascular disease	0.304	0.093-0.996	.049
Previous myocardial infarction	0.708	0.406-1.24	.225
Previous cardiac surgery	0.161	0.104-0.249	<.001
Renal failure or dialysis	0.096	0.022-0.425	.002
Vasodilatory shock preoperative)	0.357	0.040-3.21	.357
<i>Operative</i>			
Repair versus replacement	6.37	4.68-8.66	<.001
Secondary minor procedure	1.02	0.983-1.05	.353
Surgeon	0.917	0.850-0.988	.023

MI, Minimally invasive; ST, sternotomy; CI, confidence interval; BMI, body mass index; CVA, cerebrovascular accident; COPD, chronic obstructive pulmonary disease; CHF, congestive heart failure.

APPENDIX 2. Final regression model used to generate propensity scores

Risk factor	Odds ratio		P value
	MI:ST	95% CI	
Age	0.981	0.970-0.993	.002
BMI	0.940	0.909-0.972	<.001
Current CHF	0.565	0.372-0.856	.007
Ejection fraction	1.02	1.01-1.04	.019
Immune system deficiency	0.367	0.146-0.922	.033
Previous cardiac surgery	0.243	0.142-0.415	<.001
Previous myocardial infarction	2.12	1.04-4.33	.002
Repair versus replacement	4.65	3.26-6.62	<.001
Renal failure or dialysis	0.159	0.031-0.840	.007
Secondary minor procedure	0.962	0.921-0.997	.036

MI, Minimally invasive; ST, sternotomy; CI, confidence interval; BMI, body mass index; CHF, congestive heart failure.