Relationship among surgical volume, repair quality, and perioperative outcomes for repair of mitral insufficiency in a mitral valve reference center

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Objective: Although it has been demonstrated that the repair rates and quality of the repair of mitral insufficiency are superior in mitral valve reference centers, it has not been studied whether an advantage exists for perioperative morbidity and mortality. We report 1 surgeon's evolution over 7 years, specifically considering the changes in perioperative morbidity and mortality.

Methods: We performed a retrospective review of 1054 patients who had undergone elective, day-of-surgery-admission mitral valve repair by a single surgeon (D.H.A.) at our institution from April 2005 to June 2012. The outcome variables studied were operative mortality (30-day or in-hospital mortality, if longer), length of stay, low cardiac output state after cardiopulmonary bypass, and major morbidity.

Results: The overall operative mortality was 0.58%. Of the 1054 patients, 31% developed a low cardiac output state postoperatively and 6.52% experienced at least 1 of the composite morbidity events. Increased aortic crossclamp times were significantly and independently associated with a low cardiac output state, length of stay, and morbidity. When divided by service year, a statistically and clinically significant decrease was found in the aortic crossclamp time, despite an increase in the complexity of cases. The morbidity decreased concurrently with the decreases in crossclamp times.

Conclusions: As the number of mitral valve repairs performed each year by a single surgeon at a single institution increased, morbidity, including postoperative heart function and length of stay, decreased. This was demonstrated to occur in large part from a reduction in the aortic crossclamp times, despite an increase in the complexity of the procedures. This further demonstrates the value of reference centers for mitral valve surgery. (J Thorac Cardiovasc Surg 2014;148:2021-6)

ACD

Mitral valve (MV) repair has become the reference standard procedure for degenerative MV disease that requires surgical intervention.[1] Degenerative MV disease is different from other valvular heart diseases because most of the lesions caused by the degenerative changes are amenable to MV repair.[2] Additionally, many surgeons repair MV lesions resulting from other causes such as endocarditis or rheumatic heart disease. MV repair for mitral regurgitation has been associated with excellent long-term survival and remains superior to MV replacement after 10 years to ≤20 years after surgery.[3,4] The guidelines from the American College of Cardiology and the American Heart Association[5] strongly encourage referral to MV reference centers, in particular, for complex repairs, to ensure a successful repair rate of >90%.

Although it has been clearly demonstrated that the repair rates and repair quality are superior in reference centers,[6] it has not been studied extensively whether the immediate perioperative course, in terms of morbidity and mortality, will be better in a reference center. We report 1 surgeon's evolution by examining a consecutive series of patients during a 7-year period, considering the changes in perioperative morbidity and mortality after MV repair.

METHODS

After receiving institutional review board approval, we performed a retrospective review of a prospectively collected departmental database. The database included data from all patients who had undergone elective, day-of-surgery-admission MV repair, either isolated or combined with another procedure, by a single surgeon (D.H.A.) from April 2005 to June 2012. A total of 1054 patients were included in the present study. The medical record were then reviewed to obtain patient demographics and surgical characteristics, including age, weight, height, gender, procedure type, American Society of Anesthesiologists classification, European

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Abbreviations and Acronyms

EuroSCORE = European System for Cardiac Operative Risk Evaluation
ICU = intensive care unit
MV = mitral valve

System for Cardiac Operative Risk Evaluation (EuroSCORE),[7] preoperative cardiac function, other comorbidities, surgical date, type of MV dysfunction, and aortic crossclamp times. The outcome variables studied were operative mortality (30-day or in-hospital mortality, if longer), intensive care unit (ICU) length of stay, low cardiac output state after cardiopulmonary bypass, hospital length of stay, and a composite of major morbidities (because all occurred to infrequently to be analyzed individually) that included major stroke (permanent neurologic deficit), myocardial infarction (new Q waves on electrocardiogram), sternal wound infection, sepsis, reoperation for bleeding, respiratory failure (requiring tracheostomy), renal failure (requiring renal replacement therapy), and gastrointestinal bleeding (requiring transfusion).

For the analysis of the surgery type, the patients were divided into 3 groups. One group consisted of patients who had undergone isolated MV repair. The second group included patients who had undergone MV and tricuspid valve repair. The third group included all patients who had undergone MV repair with or without tricuspid repair combined with any other cardiac operation, including a cryomaze procedure for atrial fibrillation.

For the analysis related to the complexity of MV repair, the patients were divided into 3 categories. Category 1 included patients with Carpentier type I or IIIb dysfunction.[8] Category 2 included all patients with single segment posterior leaflet prolapse. Category 3 included patients with more complex dysfunction, including multisegmental posterior leaflet prolapse, any anterior leaflet prolapse, bileaflet prolapse, Carpentier type IIIa dysfunction (eg, rheumatic heart disease), primary systolic anterior motion, repeat repair of the MV, endocarditis, and complex congenital lesions.

A low cardiac output state after cardiopulmonary bypass was defined by the dose of epinephrine (the standard inotropic medication used at our institution after cardiopulmonary bypass) needed when leaving the operating room. A dose of 50 to 100 ng/kg/min was defined as a mildly impaired cardiac output state, 100 to 150 ng/kg/min was considered moderate, and >150 ng/kg/min was considered severe.

The procedures were performed through a midline approach in nearly all the patients with, predominately, central cannulation for cardiopulmonary bypass. All patients received bicaval venous cannulation. Direct aortic crossclamping and cardioplegic arrest, using cold blood cardioplegia given in both antegrade and retrograde fashion, was used. The cardiopulmonary bypass flow rates were maintained to provide a perfusion index of 2.2 to 2.4 L/min/m^2. The hematocrit was maintained at >18%, and mild hypothermia (34°C) was used. Lower temperatures were only used if the patients required circulatory arrest. The MV was accessed through a left atriotomy by dissection of Sondergaard's groove. The quality of the repair was assessed with saline testing and intraoperative transesophageal echocardiography after separation from cardiopulmonary bypass.

Statistical Analysis

The patient and disease characteristics are presented as percentages, median and interquartile range, or mean ± standard deviation. Univariate analyses of postoperative outcomes were performed for the crossclamp time (grouped as 0-2, 2-3, and >3 hours) and for service year, using chi-square tests or Kruskal-Wallis tests, as appropriate. Covariate-adjusted associations between the crossclamp time and postoperative outcomes were determined using various regression techniques: specifically, logistic regression for the composite of morbidities, linear regression for the dose of epinephrine, and Cox regression for the interval to ICU and hospital discharge. Stepwise forward selection, with both entry and stay criteria set at 0.05, was implemented to identify the most important risk factors for adjustment. The initial list included age, gender, body mass index, service year, EuroSCORE, procedure type, American Society of Anesthesiologists class (≥4 vs ≤3), preoperative medical conditions (eg, hypertension, chronic obstructive pulmonary disease, coronary artery disease, pulmonary hypertension, arrhythmia, and diabetes), right and left ventricular functional grade (ie, mild, moderate, or severe), and crossclamp time. The effects for the crossclamp time are expressed in terms of odds ratios (for the composite of morbidities), change (for epinephrine), and hazard ratios (for ICU and hospital length of stay), with the 95% confidence intervals.

RESULTS

A total of 1054 day-of-surgery-admission patients underwent MV repair by 1 surgeon (D.H.A.) during the study period, with a trend toward an increasing number of annual cases (Table 1). The repair rate was >99.9% for patients presenting for repair. The patient demographics, comorbidities, and surgical characteristics are summarized in Table 2. The overall 30-day mortality rate for the cohort

TABLE 1. Aortic crossclamp times and major morbidity by service year

Variable	2005 (Apr-Dec) (n = 64)	2006 (n = 79)	2007 (n = 128)	2008 (n = 144)	2009 (n = 172)	2010 (n = 170)	2011 (n = 203)	2012 (Jan-Jun) (n = 94)	*P* value
Crossclamp time (min)	179 (140-228)	183 (151-225)	151 (121-184)	140 (115-169)	115 (91-139)	108 (88-135)	94 (76-114)	94 (80-114)	<.001
Operative mortality	1		1		1	1	1	1	NA*
Epinephrine dose (ng/kg/min)	40 (0-80)	50 (0-100)	50 (0-100)	40 (0-80)	45 (0-100)	25 (0-50)	30 (0-70)	30 (0-50)	<.001
Epinephrine dose ≥ 50 ng/kg/min	67	72	56	48	50	45	47	39	<.001
Postoperative adverse event†	4 (6.9)	13 (16.88)	7 (5.56)	11 (8.46)	11 (6.4)	5 (2.94)	13 (6.4)	3 (3.3)	.006
Hospital length of stay (d)	6 (5-8)	7 (5-11)	6 (5-8)	6 (5-7.5)	6 (5-7)	6 (5-7)	7 (5-8)	6 (5-7)	<.001
ICU length of stay (d)	NA	NA	2 (1-3)	2 (1-3)	1 (1-2)	2 (1-2)	2 (1-3)	1 (1-2)	.077

Data presented as median (interquartile range), %, or n (%). *P* values compared the value over time and were based on chi-square test for categorical outcomes and the Kruskal-Wallis test for continuous outcomes. *NA*, Not available; *ICU*, intensive care unit. *Too few deaths to statistically evaluate. †The composite of morbidities included stroke, myocardial infarction, sternal wound infection, sepsis, reoperation for bleeding, respiratory failure (requiring tracheostomy), renal failure (requiring renal replacement therapy), and gastrointestinal bleeding (requiring transfusion).

TABLE 2. Patient and surgical characteristics (n = 1054)

Variable	Value
Age (y)	
Mean ± SD	56.94 ± 13.33
Range	20-89
Male gender (%)	61
Height (cm)	171.19 ± 14.12
Weight (kg)	77.37 ± 16.55
ASA class (%)	
2	1.42
3	54.17
4	44.4
EuroSCORE[7]	
Median	2.1
Interquartile range	1.5-4.23
Preoperative hypertension (%)	66.51
COPD (%)	1.9
CAD (%)	24.48
Atrial fibrillation (%)	16.89
LV function (%)	
Normal	54.46
Mild dysfunction	28.27
Moderate dysfunction	13.09
Severe dysfunction	2.66
Missing data	1.52
RV function (%)	
Normal	79.13
Mild dysfunction	11.95
Moderate dysfunction	3.61
Missing data	5.31
Procedure (%)	
MV only	28.46
MV and tricuspid valve	5417
MV and other	17.36
Crossclamp time (min)	
Median	120
Interquartile range	92-158
MV complexity of repair* (%)	
Category 1	14
Category 2	37.5
Category 3	48.5

ASA, American Society of Anesthesiologists; *EuroSCORE*, European System for Cardiac Operative Risk Evaluation; *COPD*, chronic obstructive pulmonary disease; *CAD*, coronary artery disease; *LV*, left ventricular; *RV*, right ventricular; *MV*, mitral valve; *SD*, standard deviation. *Category 1 included patients with Carpentier type I or IIIB dysfunction; category 2, all patients with single segment posterior leaflet prolapse; and category 3, patients with more complex dysfunctions, including multisegmental posterior leaflet prolapse, any anterior leaflet prolapse, bileaflet prolapse, Carpentier type IIIA dysfunction (ie, rheumatic heart disease), primary systolic anterior motion of the anterior leaflet of the MV, repeat MV repair, endocarditis, and complex congenital lesions.

was 0.58%. Of the 1054 patients, 31% had a low cardiac output state postoperatively, and 6.52% had ≥1 of the morbidities included in the composite (Table 3).

Crossclamp Time

Increased aortic crossclamp times were significantly associated with a low cardiac output state, ICU length of stay, hospital length of stay, and major morbidity (Table 4). Mortality occurred too infrequently for analysis. Multivariate analysis using forward stepwise regression confirmed that an increasing aortic crossclamp time was independently associated with an increased risk of postoperative morbidity, higher dose of epinephrine, and prolonged interval to ICU and hospital discharge, when controlling for all the preoperative variables (Table 5).

TABLE 3. Outcomes (n = 1054)

Outcome	Value
Operative mortality* (%)	0.58
ICU length of stay (d)	
Median	1
Interquartile range	1-3
Low cardiac output state (%)	
Mild	21.92
Moderate	6.17
Severe	2.94
Hospital length of stay (d)	
Median	6
Interquartile range	5-8
Composite of morbidities† (%)	6.52

ICU, Intensive care unit. *Defined as death within 30 days of the procedure or in-hospital death. †Stroke, myocardial infarction, sternal wound infection, sepsis, reoperation for bleeding, respiratory failure (requiring tracheostomy), renal failure (requiring renal replacement therapy), and gastrointestinal bleeding (requiring transfusion).

Service Year

We then analyzed the data divided by service year and found a statistically and clinically significant decrease in the aortic crossclamp times over time (Table 1 and Figure 1). The mean crossclamp times were nearly halved, despite an increase in the number of more complex MV

TABLE 4. Univariate analysis comparing aortic crossclamp times and outcomes

	Aortic crossclamp time group			
Outcome	1-2 h (n = 531)	2-3 h (n = 362)	>3 h (n = 161)	*P* value*
Operative mortality† (n)	3	1	2	.3868
ICU length of stay (d)				<.001
Median	1	2	3	
Interquartile range	1-2	1-3	2-4	
Low cardiac output state (%)				<.001
None	77.97	64.92	48.45	
Mild	17.51	23.48	32.92	
Moderate	2.64	8.84	11.8	
Severe	1.88	2.76	6.83	
Hospital length of stay (d)				<.001
Median	6	6	7	
Interquartile range	5-7	5-8	5-9	
Composite of morbidities (%)	4.21	6.57	14.29	<.001

ICU, Intensive care unit. *Based on chi-square test. †Defined as death within 30 days of the procedure or in-hospital death.

TABLE 5. Multivariate analyses of postoperative morbidities for crossclamp time

		Crossclamp time					
		2-3 h		>3 h			
Outcome	Model	Effect*	95% CI	Effect*	95% CI	Overall *P* value	Covariates remaining in final model
Major morbidity composite	Logistic	1.58	0.81-3.08	4.70	2.07-10.67	.001	Age, RV function, service year
Epinephrine (ng/kg/min)	Linear	13.33	6.82-19.83	33.38	24.75-42.02	<.001	Age, gender, ASA status, RV function
ICU discharge	Cox	0.74	0.63-0.88	0.51	0.38-0.70	<.001	Age, gender, EuroSCORE, RV function, CAD
Hospital discharge	Cox	0.80	0.69-0.93	0.57	0.46-0.71	<.001	Age, gender, procedure type, service year, ASA status, RV function

CI, Confidence interval; *RV*, right ventricular; *ASA*, American Society of Anesthesiologists; *ICU*, intensive care unit; *EuroSCORE*, European System for Cardiac Operative Risk Evaluation; *CAD*, coronary artery disease. *Effect indicates the odds ratio, mean difference, or hazard ratio compared with the reference (crossclamp time < 2 h); an odds ratio >1 was associated with an increased risk of morbidity and a hazard ratio < 1 was associated with less likelihood of ICU or hospital discharge.

procedures and no difference in the number of cases with a concurrent cardiac procedure (Table 6). Morbidity decreased concurrently with the decreases in crossclamp times (Table 1). The other preoperative variables associated with longer aortic crossclamp times were preoperative right ventricular dysfunction and when the procedure involved more than isolated MV repair.

DISCUSSION

The present study found that as the number of MV repairs performed by a single surgeon in a MV reference center increased, the rate of morbidity decreased. The mortality rate was too low to analyze. The decrease was demonstrated to be due, in large part, to a reduction in the aortic crossclamp times during the study period, despite an increase in the number of more complex types of MV operations and no difference in the number of MV procedures with other concurrent cardiac procedures. Previous work in degenerative MV disease from our center has shown that this was not at the expense of the quality of the repair.[1,9]

Myocardial protection strategies with intermittent cardioplegia, cooling, and blood are intended to extend the safe period that the heart can remain arrested without compromising adequate return of function.[10] However, despite this, longer aortic crossclamp times have been shown in multiple studies to correlate significantly with major postoperative morbidity and mortality in both low- and high-risk patients, with the effect increasing with increasing crossclamp times.[11-13] Al-Sarraf and colleagues[14] found that each incremental increase of 1 minute in the crossclamp time was associated with an increase in mortality. The morbidities associated with prolonged crossclamp times have included a low cardiac output state, prolonged ventilation time, renal complications, blood transfusion, and prolonged hospital stays. This association has continued into the modern era of cardiac surgery despite improvements in myocardial protection.[14]

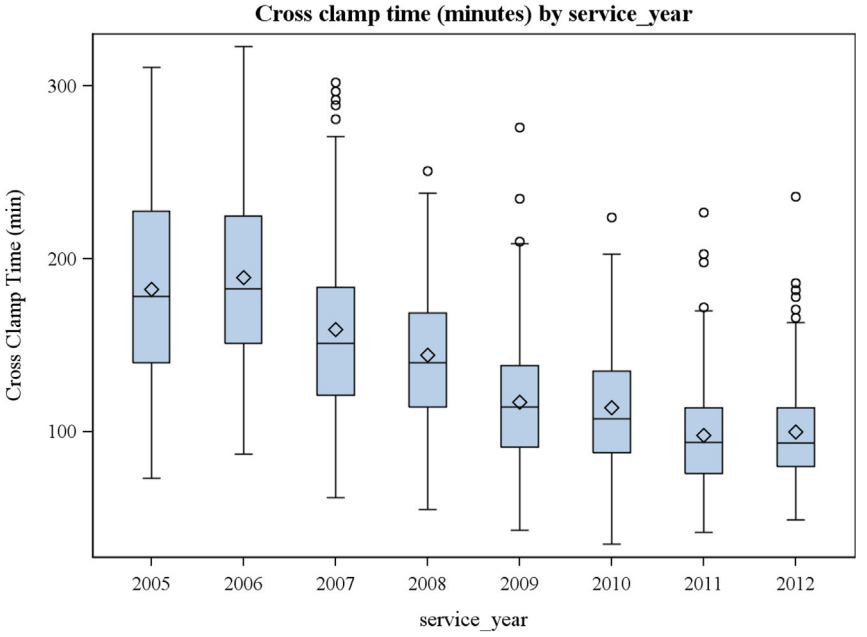

FIGURE 1. When analyzed by service year, a statistically and clinically significant decrease in aortic crossclamp times was seen.

TABLE 6. Type of surgery and complexity of mitral valve dysfunction by service year

	2005 (Apr-Dec) (n = 64)	2006 (n = 79)	2007 (n = 128)	2008 (n = 144)	2009 (n = 172)	2010 (n = 170)	2011 (n = 203)	2012 (Jan-Jun) (n = 94)	*P* value*
Procedure									<.001
MV only	31 (48.5)	13 (16.5)	10 (7.8)	46 (31.9)	44 (25.6)	50 (29.4)	82 (40.4)	24 (25.5)	
MV and tricuspid valve	28 (43.8)	40 (50.6)	83 (64.8)	69 (47.9)	102 (59.3)	95 (55.9)	101 (49.8)	53 (56.4)	
MV and other	5 (7.8)	26 (32.9)	35 (27.3)	29 (20.2)	26 (15.1)	25 (14.7)	20 (9.8)	17 (18.1)	
MV complexity of repair†									<.001
Category 1	8 (12.5)	22 (27.8)	24 (18.8)	24 (16.7)	23 (13.4)	18 (10.6)	20 (9.6)	9 (9.6)	
Category 2	30 (46.9)	25 (31.7)	46 (35.9)	48 (33.3)	70 (40.7)	67 (39.4)	77 (37.9)	32 (34.0)	
Category 3	26 (40.6)	32 (40.5)	58 (45.3)	72 (50)	79 (45.9)	85 (50)	106 (52.4)	53 (56.4)	

Data presented as n (% of service year). *MV*, Mitral valve. *Based on chi-square test. †Category 1 included patients with Carpentier type I or IIIB dysfunction; category 2, patients with single segment posterior leaflet prolapse; and category 3, patients with more complex dysfunctions, including multisegmental posterior leaflet prolapse, any anterior leaflet prolapse, bileaflet prolapse, Carpentier type IIIA dysfunction (ie, rheumatic heart disease), primary systolic anterior motion of the anterior leaflet of the mitral valve, repeat MV repair, endocarditis, and complex congenital lesions.

In the present study, we analyzed 1 surgeon performing 1 type of operation to remove the confounders of different cardioprotection techniques or cardiopulmonary bypass strategies. Longer aortic crossclamp times were associated with major morbidity, even when controlling for preoperative heart function, other comorbidities, and the EuroSCORE. Shorter crossclamp times led to better heart function after cardiopulmonary bypass, which led to a quicker recovery and shorter hospital length of stay.

A number of factors likely contributed to the decrease in aortic crossclamp times during the study period. These included greater surgeon experience and improved surgical techniques. An example would be the addition of ''magic sutures'' and artificial neochords to the surgeon's armentarium.[9]

The decrease in morbidity could also have resulted from other factors. With more cases performed each year, the rest of the team, including the surgical, anesthesiology, perfusion, and nursing team, would become more experienced and adept at treating this class of patient. The postoperative ICU treatment also likely improved. One study of cardiac surgery found that the cumulative surgical attending and fellow paired experience was more of a factor than the individual surgeon experience in decreasing the aortic crossclamp times.[15]

That we were able to demonstrate a decreased length of stay could have far reaching implications in the current era of healthcare reform. A decreased length of stay is likely to drive down costs. Thus, surgical reference centers could be more cost-effective than less experienced centers, further increasing their value. Although the length of stay might not seem short compared with that at other institutions, this might have been a reflection of the greater complexity of cases performed.

The limitations of the present study included its retrospective, single-center design and that the clinical care was not standardized; thus, the effects of unmeasured confounding variables could not be excluded. Thus, statistical correlation might not imply causation. We defined a low cardiac output state by the use of epinephrine. It is possible that these patients did not have a low cardiac output state but were given epinephrine owing to a perception that it was needed to aid in recovery. The decrease in use during the study period might then just reflect recognition that such doses were not necessary and was not a reflection of patient status. The decrease in the epinephrine requirement also could have resulted from subtle changes in the cardioplegia solution or delivery and adjunctive measures such as topical cooling for right ventricular preservation. Additionally, factors other than improved operator surgical experience could have contributed to the decrease in the morbidities studied. The decrease in the ICU length of stay could have resulted from factors other than the decreasing aortic crossclamp times, such as early extubation protocols and early mobilization.

A high-volume MV surgery reference center with a single surgeon's highly specialized team with a near 100% repair rate was studied.[1] A number of other factors could limit extrapolation of our results to other centers. First, the surgeon (D.H.A.) studied generally takes as long as necessary to repair a MV and accepts prolonged aortic crossclamp times if necessary for a complex repair. Thus, the aortic crossclamp times were relatively long. Second, even mild mitral regurgitation after repair has generally not been considered acceptable and will result in a return to cardiopulmonary bypass and aortic crossclamping to perfect the repair. Third, the surgeon repairs all types of degenerative MV disease, including more complex scenarios such as bileaflet or anterior leaflet involvement, significant annular calcification, reoperations, and older patients. This could also explain the relatively long aortic crossclamp times. Finally, it is possible that because of the success of the surgeon with MV repair, patient referrals began to occur earlier in the disease process, biasing the results toward better outcomes.

CONCLUSIONS

The results of the present study have shown that as the number of MV repairs performed by a single surgeon at a single institution increased, the morbidity, including postoperative heart function and length of stay, decreased. Although the results from our single study are not sufficient to conclude that these results can be extrapolated to other centers, we hope it will stimulate additional research on the subject. As we continue to strive for greater value in healthcare, our findings could prove extremely important.

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