Multiple Valve Surgery with Beating Heart Technique

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Background. **Multiple valve sugery was performed utilizing beating heart technique through simultaneous antegrade/retrograde perfusion with blood. We herein report our experience with this technique in patients with multiple valve disease processes.**

Methods. **Of 520 consecutive patients operated upon utilizing this method between 2000 and 2007, 59 patients underwent multiple valve surgery. Mean age was 54.2 ± 13.8 years (range, 21 to 83) with 41 males (69.5%) and 18 females (30.5%). Double-valve and triple-valve operations were performed in 54 and 5 patients, respectively.**

Results. **Of 32 mitral valve replacements, there were 30 biological (93.8%) and 2 mechanical (6.2%) mitral valves. Aortic valve replacement was performed in 25 patients: 22 (88%) with biological and 3 (12%) with mechanical prostheses. Two patients had mitral and tricuspid valve repair. The most common procedure was mitral valve replacement plus tricuspid valve repair (16 patients; 27.1%), mitral valve replacement plus aortic replacement (14 patients; 23.7%), and mitral valve repair plus tricuspid repair (13 patients; 22%). Concomitant coronary artery bypass grafting was performed in 7 (11.8%) of 59 patients. Mean hospital stay was 25.6 ± 29.6 days (range, 3 to 195; median, 17). Early mortality (less than 30 days) occurred in 5 patients (8.4%), and late mortality (more than 30 days) occurred in 2 patients (3.4%). Reoperation for bleeding was needed in 5 patients (8.4%). Intra-aortic balloon pump was required preoperatively and postoperatively in 4 and 1 patients, respectively. Clinical and echocardiographic follow-up in 33 patients at 11.8 ± 16.4 months (range, 1 to 80) showed preserved postoperative left ventricular ejection fraction. Three patients had perivalvular leaks on follow-up but required no surgery. Nineteen patients were lost to follow-up.**

Conclusions. **This study demonstrates the feasibility and safety of beating heart techniques in multiple valve operations. Further studies are needed to fully evaluate the potential benefits of this method of myocardial perfusion as a means to eliminate ischemia-reperfusion injury, and to preserve ventricular function in multiple valvular surgery.**

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Several heart disease processes, namely, rheumatic disease and endocarditis, may affect multiple cardiac valves and may require double- or triple-valve operations [1]. Concomitant mitral and aortic valve replacement was initially performed in the 1960s with the development of mechanical valves. Despite documented improvements in management of patients requiring multiple valve surgery, satisfactory outcomes remain a challenge, partly as result of prolonged periods of cardiopulmonary bypass and myocardial ischemia [2].

Adequate myocardial protection is essential during multiple valve surgery. Alterations in myocardial contractile function may lead to postoperative low cardiac output syndrome and, consequently, poor prognosis [3]. In spite of efforts to improve surgical outcomes of patients undergoing multiple valve operations, mortality remains high [4]. High mortality rates can be partly related to conventional myocardial protection strategies, which may result in postoperative left ventricular dysfunction. This is especially important in patients with preoperative myocardial hypertrophy and in those with poor ventricular function who require prolonged periods of aortic cross-clamping [5].

Based on previous reports [6, 7], Salerno and colleagues [5] further refined a strategy of myocardial perfusion for valve surgery that abolishes the use of hyperkalemic blood cardioplegia and cardioplegic arrest. With this technique, the heart is kept beating throughout the operation and is perfused simultaneously in an antegrade/retrograde fashion with warm, oxygenated blood [5]. This technique eliminates ischemia-reperfusion injury, allowing for sustained normal myocardial energy metabolism throughout the period of aortic clamping. The aim of this study is to report our initial clinical experience with beating heart technique in patients requiring multiple valve surgery.

Patients and Methods

From June 2000 to November 2007, 520 consecutive patients with a variety of cardiac pathologies underwent beating heart surgery at our institution utilizing the myocardial perfusion strategies described above. Institu-

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Table 1. Patients' Characteristics

Variables	Number	Percent
Age at surgery, years (range)	54.2 ± 13.8 (21–83)	
Male	41	69.5
Female	18	30.5
Procedure		
Emergent/urgent	34	57.6
Elective	18	30.5
Salvage	7	11.8
Endocarditis	20	33.8
Hospital stay, days (range)	25.6 ± 29.6 (3–195)	
Congestive heart failure	34	57.6
Hypertension	34	57.6
Diabetes mellitus	13	22
Coronary artery disease	11	18.6
Renal failure	9	15.2
Sepsis	4	6.7
Stroke	3	5.1
NYHA functional class		
II	2	3.4
III	24	40.6
IV	33	56
LVEF, % (range)	39.4 ± 17.9 (11–75)	
EF >50%	18	30.5
EF = 31% to 50%	15	25.4
EF = 16% to 30%	23	39
EF <15%	3	5.1

LVEF = left ventricular ejection fraction; NYHA = New York Heart Association.

tional Review Board approval for this study (HSRO study 20060204) was obtained to retrospectively review the medical records of these patients, waiving the need for informed consent. Among them, 59 patients were diagnosed with double- or triple-valve disorders and underwent multiple valvular procedures. The etiology of valvular disease was infective endocarditis (20 patients; 33.8%), rheumatic disease (4 patients; 6.7%), and degenerative disease in the remaining 35 patients (59%). In 9 patients, the endocarditic process involved the mitral valve, whereas in 11 patients it affected both the mitral and the aortic valves. One patient had fungus endocarditis, and all others had bacterial endocarditis.

Preoperative demographics and clinical data are summarized in Table 1. There were 41 males (69.5%) and 18 females (30.5%). Mean age was 54.2 ± 13.8 years (range, 21 to 83; median, 53). Preoperatively, 34 patients (57.6%) had hypertension, 13 (22.0%) had diabetes, 9 (15.3%) had end-stage renal disease, and 34 patients (57.6%) presented with congestive heart failure. Also, 4 patients (6.7%) had sepsis, 11 patients (18.6%) had coronary artery disease, and 3 patients (5.1%) had a stroke before surgery (Table 1). Preoperative transesophageal echocardiography revealed mitral regurgitation graded equal to, or greater than, 3+ (on a scale from 1+ to 4+) in 29 patients (49.2%), tricuspid regurgitation in 11 (18.6%), aortic stenosis in 5 (8.5%), aortic insufficiency in 5 (8.5%), and intracardiac fistula in 1 patient (1.7%). Early mortality was defined as death occurring within 30 days of surgery, whereas late mortality was defined as death occurring after 30 days. Mean ejection fraction (EF) was 39.4% ± 17.9% (range, 11% to 75%; median, 40%) based on echocardiographic assessment (Table 1). Three patients (5.1%) had EF below 15%, 23 patients (39%) had EF between 16% and 30%, 15 patients (25.4%) between 31% and 50%, and 18 patients (30.5%) had EF above 50%. Renal failure was defined as renal dysfunction with creatinine level greater than 2.0 mg/dL. Heart failure was classified as per standard New York Heart Association functional class guidelines from I to IV, as shown in Table 1.

All patients received oral anticoagulation therapy as clinically indicated based on the type of valve prosthesis utilized as well as on the presence or absence of comorbidities such as atrial fibrillation. Clinical follow-up was performed by questionnaire, telephone calls, and review of records relative to clinic visits.

Surgical Technique

Surgical procedures were performed at systemic cardiopulmonary bypass temperature of 34° to 35°C. After heparinization, the ascending aorta and both superior and inferior venae cavae were cannulated. Cardiopulmonary bypass was initiated and both cavae were snared. For combined aortic and mitral valve surgery, the right atrium was opened and a purse-string of 40 polypropylene was placed around the mouth of the coronary sinus. A catheter was inserted into the coronary sinus, which was then snared. Perfusion of the coronary sinus was initiated with warm blood at mean pressures of 50 mm Hg to 55 mm Hg, and flows greater than 280 mL/min. The aorta was then cross-clamped, and the aortic root was opened. The coronary ostia were cannulated with Polystan (Vital Core Inc, West Mont, IL) cannulas, connected to the aortic cannula as inflow [5], thereby providing simultaneous antegrade and retrograde warm blood myocardial perfusion. The aortic valve was excised,

Table 2. Multiple Valve Operations

Procedure	Number	Percent
Double valve		
MV Rep + TVR	16	27.1
MV Rep + AV Rep	14	23.7
MVR + TVR	13	22
MVR + AV Rep	5	8.4
MVR + AVR	4	6.7
AVR + TVR	1	1.6
AV Rep + TV Rep	1	1.6
Triple valve		
MV Rep + TVR + AV Rep	2	3.3
MVR + TVR + AV Rep	2	3.3
MVR + TVR + AV Rep	1	1.6
Total	59	100

AV = aortic valve; MV = mitral valve; R = repair; Rep = replacement; TV = tricuspid valve.

Table 3. Operative Data

Variable	Number	Percent
CPB time, minutes (range)	119.3 ± 62.4 (45–324)	
IABP, number of patients	5	8.4
ICU stay, days (range)	8.1 ± 3.3 (5–19)	
Complications		
Low-output syndrome	7	11.9
Prolonged ventilator	6	10.2
Reexploration for bleeding	5	8.4
Atrial fibrillation	5	8.4
Infection	3	5.1
Neurologic event	2	3.4
Renal failure	2	3.4
Myocardial infarction	0	0

CPB = cardiopulmonary bypass; IABP = intra-aortic balloon pump; ICU = intensive care unit.

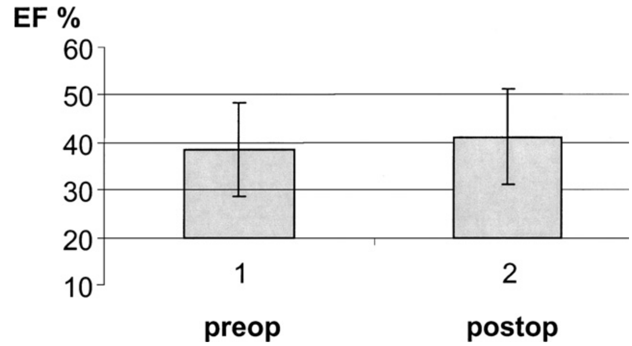

Fig 1. Preoperative (preop) versus postoperative (postop) ejection fraction (EF [%]) in 33 patients (p = 0.109). Effect of multiple valve surgery on left ventricular EF estimated by echocardiography. There was a trend toward higher EF in the postoperative state as compared with preoperative state by paired t test, although this did not reach statistical significance (p = 0.109).

and the annulus was sized. Attention was then directed to the interatrial septum, which was opened longitudinally at the level of the oval fossa. The mitral valve was exposed and either repaired or replaced. The interatrial septum was closed, paying attention to avoiding the conduction system. Attention was then directed to the aortic valve, which was replaced in the standard fashion. The aorta was then closed after deairing maneuvers [5]. If needed, a tricuspid valve procedure was performed with the heart perfused and beating, and the aorta unclamped.

Table 4. Patient Follow-Up

Variable	Number	Percent
Mean follow-up, months (range)	11.8 ± 16.4 (1–80)	
Preoperative LVEF, % (range)	39.4 ± 17.9 (11–75)	
EF >50%	18	30.5
EF = 31% to 50%	15	25.4
EF = 16% to 30%	23	39.0
EF <15%	3	5.1
Postoperative LVEF, % (range)	43.2 ± 17.4 (10–70)	
EF >50%	13	22.0
EF = 31% to 50%	11	18.6
EF = 16% to 30%	5	8.4
EF <15%	4	6.8
Unknown	26	44.0
Postoperative echocardiography findings, n	33	55.9
No leak	30	91
Small perivalvular leak MV	2	6
Small perivalvular leak AV	1	3
Death	7	11.8
Late death	2	3.3
Early death	5	8.4
Heart failure	3	5
Multisystem organ failure	2	3.3
Unknown	2	3.3
Lost to follow-up	19	32

AV = atrial valve; LVEF = left ventricular ejection fraction; MV = mitral valve.

Results

There were 18 elective (30.5%), 34 urgent/emergent (57.6%), and 7 "salvage" patients (11.8%) undergoing multiple valve procedures. Salvage operations were defined as those performed under extreme conditions, namely, for patients in critical condition, who were ventilator dependent, in cardiogenic shock, had severe metabolic acidosis, were in septic shock, had a recent history of cardiac arrest and cardiopulmonary resuscitation, and who had at least two organ failures. The most common procedure performed was mitral valve replacement associated with tricuspid repair (16 patients; 27.1%), mitral-aortic valve replacement (14 patients; 23.7%), and mitral-tricuspid valve repair (13 patients; 22%; Table 2). Coronary artery bypass graft surgery was performed concomitantly in 7 patients (11.8%). Other multiple operations utilizing beating heart technique are listed in Table 2. There was 1 case of triple-valve surgery performed with concomitant oronary artery bypass graft surgery.

Table 3 summarizes operative variables and observed rate of postoperative complications. Mean cardiopulmonary bypass time was 119.3 ± 62.4 minutes (range, 45 to 324; median, 97). Mean prosthetic valve size was 28.4 ± 2.4 mm (range, 23 to 33 mm) and 21.9 ± 2.0 mm (range, 19 to 27 mm) for mitral and aortic valve replacements, respectively. None of the patients had perioperative myocardial infarction. Major complications included low output syndrome in 7 patients (11.9%), need for prolonged mechanical ventilation in 6 (10.2%), and atrial fibrillation in 5 (8.4%). Five patients (8.4%) underwent reexploration for bleeding. Intra-aortic balloon pump support was required preoperatively in 4 patients (6.7%) and postoperatively in 1 patient (1.7%).

Table 4 summarizes postoperative and follow-up data. Mean length of hospital stay was 25.6 ± 29.6 days (range, 3 to 195; median, 17.0). Follow-up duration was 11.8 ± 16.4 months (range, 1 to 90). Nineteen patients were lost to follow-up. Early mortality occurred in 5 of 59 patients (8.4%): in 3 of 34 urgent patients (8.8%), and in 2 of 7 salvage patients (28.5%). There were 2 late deaths, causes unknown. The causes of death for the other patients are listed in Table 4. Echocardiographic follow-up data are also summarized in Table 4. Postoperative echocardiograpic data were available for 33 of 59 patients (56%). Of the 33 patients evaluated, 33 (90%) had no perivalvular leak or prosthetic valve dysfunction, whereas 3 had perivalvular leak, as shown in Table 4.

For the 33 patients for whom preoperative and postoperative EF data was available (Fig 1), a comparison between preoperative and postoperative EF by paired *t* test revealed a trend for greater EF postoperatively, although this did not reach statistical significance (p = 0.109).

Comment

Multiple valve surgery is associated with high early and late operative mortality [8]. Optimal timing for surgery is not well established [9]. These procedures are technically more complex than isolated valve operations, they usually require prolonged periods of aortic cross-clamping, and they are associated with serious complications. Efforts have been made in the past 2 decades to lower operative mortality in multiple valve procedures. Despite recent developments in surgical techniques, anesthesia, and postoperative care, early and late mortality remains higher for multiple valvular replacement procedures compared with isolated aortic and mitral valve replacement [8–10]. Congestive heart failure and sudden death [11] have been shown to be the most frequent causes of mortality during long-term follow-up. Also, preoperative left ventricular EF and tricuspid valve regurgitation have been identified as risk factors after multiple valve surgery [11]. Decreased long-term survival has also been reported in patients with severely reduced EF [11]. In these patients, deterioration of ventricular function is likely the result of multiple valve disease processes [12]. However, the effects of multiple valve pathology on the ventricular myocardium may be compounded by perioperative myocardial ischemia-reperfusion injury, as a result of prolonged aortic cross-clamping [12]. Although establishing the relative impact of each of these two variables on myocardial function may be difficult, myocardial ischemic injury likely plays an important role in this process.

Experimental studies by our group [13–17] demonstrated decreased accumulation of extracellular fluid, diminished lactate production, and greater preservation of high energy stores when a strategy of myocardial protection with simultaneous antegrade/retrograde continuous normothermic, normokalemic blood perfusion was used. These findings provide the rationale and the experimental basis for using beating heart technique when prolonged periods of myocardial ischemia are anticipated, as is the case during multiple valve operations. Clinically, isolated antegrade perfusion through the aorta is commonly used in conventional myocardial protective strategies. However, antegrade perfusion alone does not ensure cardioplegia delivery beyond coronary stenoses or in the presence of aortic insufficiency. Retrograde cardioplegic techniques overcome these limitations but require larger cardioplegia volumes [18]. These considerations, along with previous experimental studies supporting the use of simultaneous antegrade and retrograde myocardial perfusion, provided the basis for using simultaneous antegrade/retrograde warm blood perfusion in our beating heart valve operative strategy.

Previous studies have shown that, when utilizing retrograde perfusion alone with cardioplegia, aortic-mitral valve surgery yields mortality of 5.1% to 8.3% [19]. Our 30-day overall mortality was 8.6% for multiple valve operations with perfusion with warm blood antegrade and retrograde simultaneously. These results are comparable to those of other reports in the literature, reporting mortality of 7.4% for double-valve surgeries [19]. Kuwaki and colleagues [20] reported early mortality of 9.9% for patients undergoing aortic and mitral valve replacement, but there were no patients undergoing triple valve surgery in their series. The type of combined mitral-aortic valve surgery may also be a factor affecting outcomes of these patients. Gillinov and coworkers [21] observed survival advantage after mitral valve repair in patients undergoing double-valve procedures. Other reports [22, 23] have shown overall mortality from 5.4% to 7.9% after aortic valve replacement combined with mitral valve surgery. However, no survival benefit was identified between mitral valve repair and replacements. In our series, we performed a greater number of mitral valve replacements than mitral valve repairs in combination with aortic valve replacement (23.7% versus 15.1%). Unfortunately, owing to the relatively small sample size, we were unable to draw conclusions on the relative impact of type of mitral procedure on outcome. Reexploration for bleeding after multiple valve surgery has been found to be associated with greater operative mortality as compared with reexploration after isolated valve surgery [8, 23, 24]. The relatively low rate of reinterventions in our series could have favorably contributed to the observed clinical outcomes. Also, we did not observe neurologic deficits in relation to air embolism, a potential concern when performing beating heart mitral valve surgery without clamping the aorta.

With respect to possible contraindications to beating heart technique during mitral valve surgery, in our experience these include the inability to obtain adequate visualization of the mitral valve apparatus (especially when mitral repair is anticipated) and the presence of extensive mitral valve vegetations, where there is the risk of embolization. Mild aortic insufficiency that does not require aortic valve replacement may also result in significant back-bleeding into the left ventricle, as the mitral retractor is placed into position to expose the mitral valve. In some cases, that can be controlled by applying external pressure on the aortic annulus by using a blunt instrument to improve aortic valve competency. In other cases, when proper visualization of the mitral valve cannot be obtained, the surgeon has the option of cross-clamping the aorta and proceeding with cardioplegic arrest. This situation was not encountered in this series of patient. In relation to the beating heart approach to aortic valve replacement, we did not observe any contraindication in this group of patients. However, when the aortic root is small, and the surgeon is unable to adequately expose the aortic valve apparatus, or maintain the coronary perfusion catheters in place, or when there is extensive aortic calcification, the surgeon may resort to hyperkalemic cardioplegic arrest.

We acknowledge that our study has several important limitations. In addition to the relatively small number of patients, we were unable to compare beating heart patients with patients receiving conventional cardioplegic techniques. The small sample size would have precluded a meaningful analysis of a patient population in which some patients were lost to follow-up and many variables could have affected outcomes (different valve disease processes, age, EF, risk factors, and so forth). Avoidance of myocardial ischemia could conceivably enhance long-term myocardial function. Our follow-up data suggest that this might be the case. However, further evidence is needed before beating heart technique can be advocated as superior to conventional myocardial protective strategies in the setting of multiple valve operations. Despite these limitations, our preliminary clinical experience shows the feasibility and safety of double- or triple-valve operations utilizing beating heart technique, at least for a relatively small number of patients.

Outcomes obtained using this strategy of myocardial protection seem to compare favorably to those of historical series in which conventional myocardial protection with cardioplegic arrest were used. Further studies are needed to fully evaluate the potential benefits of this method of myocardial perfusion as a means of eliminating ischemia-reperfusion injury in multiple valve surgery.

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