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The Severity of Positional Mitral Regurgitation during Off-Pump Coronary Artery Bypass Grafting

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ABSTRACT

Background. The aims of this study were to elucidate the incidence of mitral regurgitation during off-pump coronary artery bypass (OPCAB) surgery to evaluate the relationship of the changes with ventricular function and possible mitral valve regurgitation caused by positioning.

Methods. Included in the study were 60 consecutive patients who underwent CAB grafting on the beating heart. We monitored several hemodynamic variables (systolic arterial pressure, mean arterial pressure, right atrial pressure, pulmonary capillary wedge pressure, and heart rate) at baseline and after each anastomosis and used transesophageal echocardiography (TEE) routinely after sternotomy, during each anastomosis, and after completion of the operation. Valvular functions, ejection fraction, and wall motion systolic index were recorded during each TEE evaluation.

Results. All of the patients underwent complete revascularization. We performed 132 consecutive OPCAB anastomoses in 60 patients (60 left anterior descending artery [LAD], 20 right coronary artery [RCA], 45 left circumflex coronary artery [LCX], and 7 diagonal artery grafts). During LCX anastomosis, 38 (84.4%) of 45 patients developed moderate mitral regurgitation. The wall motion score index (WMSI) significantly increased during CX grafting, as was demonstrated by higher WMSI values than for the RCA, diagonal, and LAD grafts. The ejection fraction was decreased significantly during CX and RCA anastomoses compared with baseline levels. The hemodynamic changes were in accord with these findings. The greatest hemodynamic compromise was seen during CX anastomosis.

Conclusion. Positional mitral regurgitation occurs frequently and is a major contributor to hemodynamic instability during posterior- and lateral-wall revascularization during the OPCAB procedure.

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INTRODUCTION

Coronary artery bypass grafting (CABG) on the beating heart has become a widely used alternative to the standard on-pump technique [Parolari 2005; El-Hamamsy 2006; Panesar 2006]. The potential advantages of off-pump CABG (OPCAB) are reduced systemic inflammation (such as no activation of proteolytic and inflammatory systems and no depression of the immune system), reduced coagulopathy, and reduced dysfunction of respiratory and other end organs [Parolari 2005; Chakravarthy 2007]. Potential economic benefits include decreased costs arising from reductions in postoperative patient instability and faster recovery rates with a reduced need for blood products [Panesar 2006; Chakravarthy 2007]. Several clinical results have shown that OPCAB is a safe and effective method in selected cases and is more cost-effective [Chassot 2004; Hirose 2005; Gurbuz 2007].

The main disadvantage of OPCAB is the risk of acute hemodynamic instability requiring immediate conversion to cardiopulmonary bypass (CPB) [Chassot 2004; Hirose 2005; Parolari 2005; Chakravarthy 2007]. The performance of OPCAB has been limited by the ability of the heart to maintain adequate function throughout patient positioning, patient stabilization, and interruption of coronary blood flow during the procedure. Disastrous hemodynamic compromise may occur with retraction and stabilization of the heart [Hirose 2005; El-Hamamsy 2006; Chakravarthy 2007]. Thus, the fact that complete revascularization may not be achievable in every patient with OPCAB is related to the hemodynamic instability that can occur during positioning and stabilization of the heart and during snare occlusion of the coronary artery. Intravenous fluids, Trendelenberg positioning, inotropes, and vasopressors have been used to support the blood pressure and cardiac output [Chassot 2004; Chakravarthy 2007; Gurbuz 2007]. Nevertheless, conversion to CPB is inevitable in some cases.

Animal and clinical studies that have investigated the hemodynamic changes that occur when the heart is positioned for access to the coronary arteries have indicated that such displacement has its deleterious effects primarily on the right heart [Lee 2006; Gurbuz 2007]. On the other hand, mitral valve functions may be altered during this displacement, which may trigger intraoperative hemodynamic instability [Nakamura 2005; Omae 2005]. Nevertheless, the precise mechanisms that cause altered hemodynamics have not been clarified.

The aims of this study were to elucidate the hemodynamic changes that occur during OPCAB grafting for the left anterior descending artery (LAD), the obtuse marginal branch of the left circumflex artery (LCX), the right coronary artery (RCA), and the diagonal artery to evaluate the relationships of these changes with ventricular function and possible mitral valve regurgitation caused by positioning.

MATERIALS AND METHODS

Included in this study were 60 consecutive patients (46 men, 14 women) who underwent CABG on the beating heart between January 2005 and June 2006. Patients undergoing nonelective procedures and those with a poor left ventricular function (ejection fraction <40%), concomitant mitral regurgitation, or other valvular or systemic disease were not included in the study.

All of the patients underwent operation by the same surgical team. Our routine OPCAB protocol was applied to all patients. A Swan-Ganz catheter was introduced through the right internal jugular vein, and a 20-gauge catheter was inserted into the radial artery for monitoring of blood pressure and blood gases. Right atrial and right ventricular end-diastolic pressures and mixed venous oxygen-saturation measurements were obtained through the Swan-Ganz catheter.

Patients were anesthetized by means of a general anesthesia technique. A standard midsternotomy approach was used, and the chest wall was retracted.

We recorded several hemodynamic variables (systolic arterial pressure, mean arterial pressure, the right atrial pressure, pulmonary capillary wedge pressure [PCWP], and heart rate) at baseline and after each anastomosis. Transesophageal echocardiography (TEE) was used routinely after sternotomy, during each anastomosis, and after completion of the operation. Valvular functions, the ejection fraction, and the wall motion systolic index were recorded during each TEE evaluation.

The heart was retracted and stabilized with the Octopus3 stabilizer and the Starfish apical retractor (Medtronic, Minneapolis, MN, USA). A single surgeon performed all of the operations.

A deep pericardial suture was employed to retract the pericardium, and the patient was placed in various degrees of the Trendelenburg position and lateral rotations to help with heart displacement. No intracoronary shunts were used for any of the grafts. The sequence of grafting was to perform grafts to the LAD territory first, followed by sequential anastomoses to circumflex territories and then RCA territories.

The heart was positioned, and the coronary stabilizer was applied to obtain an optimal view for distal anastomoses. The operating table was always tilted in the head-down position (Trendelenburg maneuver) for anastomoses to circumflex and posterior descending arteries. Each time the operating table was repositioned, the zero levels for measurements were corrected. All pressure measurements were taken at the end-inspiration phase during mechanical ventilation.

The left internal mammary artery (LIMA) was the preferred graft for the LAD. The greater saphenous vein was the choice for the other coronary arteries. The proximal anastomosis was performed under the side clamp before the distal anastomosis.

After completion of the bypass procedure and measurements were made, the patient was admitted to the intensive care unit.

Echocardiography Measurements

A multiplane transesophageal transducer (MPT7-4, 5-MHz phased array; ATL/Phillips Medical Systems, Bothell, WA, USA) was placed following induction of anesthesia, and the patient was monitored continuously during the operation with the ATL Ultrasound HDI 3500 CV (ATL/Phillips Medical Systems).

We conducted a baseline examination prior to surgical manipulation of the heart to assess the following: global left ventricular function; regional left ventricular functions; mitral regurgitation; right ventricular function; tricuspid valve regurgitation; the aortic valve for regurgitation, stenosis, and calcification; and the thoracic aorta.

Imaging evaluations were repeated for each coronary anastomosis at the 10th minute of occlusion and at the end of surgery. To study left ventricular wall motion, we divided the left ventricle into 16 segments per the recommendations of the American Society of Echocardiography. We analyzed endocardial motion and wall thickening and graded each segment as follows: normokinesis, 1; mild hypokinesis, 2; severe hypokinesis, 3; akinesis, 4; and dyskinesis, 5. We calculated a regional wall motion score index (WMSI) for each time point by dividing the sum of the 10 segmental wall motion scores by 10. Thus, a WMSI of 1 corresponds to completely normal wall motion, whereas we defined a regional wall-motion worsening of grade ≥2 lasting >1 minute as a TEE episode suggestive of ischemia.

Statistical Analysis

SPSS 10.0 software (SPSS, Chicago, IL, USA) was used for statistical analyses. Data are expressed as the mean ± SD. A *P* value <.05 was considered to indicate statistical significance. The data obtained at baseline, at the 10-min anastomotic time, and at the end of the operation were compared within groups by means of 1-way repeated measures analysis of variance (RM ANOVA) and post hoc Tukey tests for multiple comparisons. We used the Pearson chi-square test to estimate the relative risk and the odds ratio of mitral insufficiency for each anastomosis.

RESULTS

Included in this study were 60 consecutive patients (46 men, 14 women; mean age, 66.23 ± 8.84 years) who underwent CABG on the beating heart between January 2005 and June 2006. All of the patients underwent complete revascularization, and we carried out 132 consecutive OPCAB anastomoses in the 60 patients (60 LAD, 20 RCA, 45 LCX, and 7 diagonal grafts). All patients underwent LIMA-to-LAD anastomoses. None of the patients required conversion to on-pump CABG.

There were no postoperative deaths or major morbidity following the procedures. There were no perioperative myocardial infarctions (ie, new ST changes on electrocardiograms or increases in cardiac enzymes). None of the patients required high-dose inotropic support during the operation, and dopamine, dobutamine, or ephedrine was used for volume loading or vasopressor support to treat minor hemodynamic aberrations that occurred during grafting procedures. The cardiac rhythm was controlled when needed with atropine or intravenous β_1-blockers.

Hemodynamic Parameters

The heart rate did not vary significantly during each anastomosis.

The percent saturation of mixed venous oxygen before surgery, during LAD, RCA, LCX, and diagonal artery grafting, and at the end of the operation did not change significantly (prestabilization, 73.4%; during anastomosis to the LAD, 69.7%; during anastomosis to the RCA, 67.7%; during anastomosis to the LCX, 63.3%; during anastomosis to the diagonal artery, 68.4%; at the end of the operation, 73.2%; $P > .05$).

We measured the changes in systemic arterial pressures, left and right atrial pressures, and PCWPs during each anastomosis and compared the preoperative values with those obtained between each anastomosis. We observed an increase in the central venous pressure (CVP) during all anastomoses except for the LAD anastomoses. The most significant increases compared with baseline levels were seen during CX anastomoses (Figure 1).

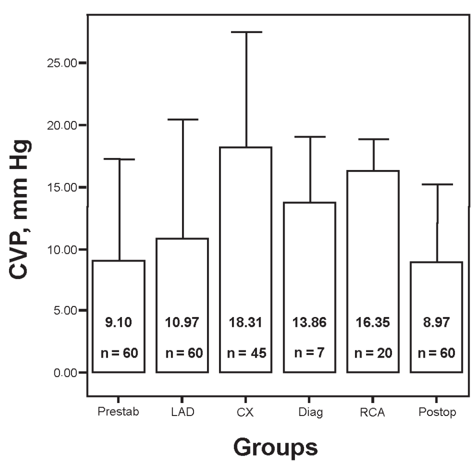

Figure 1. Changes in central venous pressure (CVP) indicated from CVP measurements taken before stabilization of the heart for anastomosis (Prestab), during each anastomosis, and at the end of the operation (Postop). Histogram data are presented as the mean ± 2 SDs. LAD indicates left anterior descending coronary artery; CX, circumflex coronary artery; Diag, diagonal coronary artery; RCA, right coronary artery.

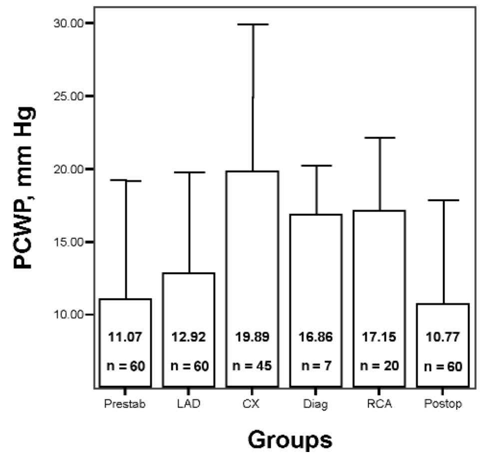

Figure 2. Changes in pulmonary capillary wedge pressure (PCWP) indicated from PCWP measurements taken before stabilization of the heart for anastomosis (Prestab), during each anastomosis, and at the end of the operation (Postop). Histogram data are presented as the mean ± 2 SDs. LAD indicates left anterior descending coronary artery; CX, circumflex coronary artery; Diag, diagonal coronary artery; RCA, right coronary artery.

Similarly, changes in the PCWP were seen during all RCA, diagonal, and CX anastomoses, but not for LAD anastomoses. The most significant increases were seen during CX anastomoses (prestabilization, 11.07 ± 4.09 mm Hg; during the anastomosis, 19.88 ± 5.05 mm Hg; postoperative, 10.77 ± 3.54 mm Hg; $P < .05$) (Figure 2).

The pulmonary arterial pressure (PAP) before, during, and after LAD, RCA, and diagonal artery anastomoses did not vary significantly, but the PAP was increased significantly during CX anastomoses (prestabilization, 25.13 ± 8.85 mm Hg; during anastomosis to the CX, 33.18 ± 7.6 mm Hg; at the end of the operation, 24.08 ± 5.78 mm Hg; $P < .05$, 1-way RM ANOVA), compared with the other grafts (Figure 3).

Measurements of the ejection fraction decreased significantly during CX and RCA anastomoses compared with baseline levels. On the other hand, no significant changes were seen during LAD and diagonal artery anastomoses (Figure 4).

The changes in systemic blood pressure are summarized in Figures 5 and 6. CX anastomosis caused a significant decrease in diastolic blood pressure. The changes in systolic and diastolic blood pressures were insignificant during LAD anastomoses. The decrease in systolic blood pressure was most apparent during CX and RCA anastomoses.

Wall Motion Score Index

The WMSI was significantly increased (1-way RM ANOVA) during CX grafting, compared with RCA, diagonal artery, and LAD grafting (2.97 ± 0.62, 2.35 ± 0.48, 2.28 ± 0.48, and 1.51 ± 0.7, respectively; Figure 7). This significant decline in systolic wall thickening during CX grafting, however, returned to baseline at the end of the operation (1.25 ± 0.47). This result indicates a reversible regional systolic dysfunction during CX grafting that we did not see during LAD grafting.

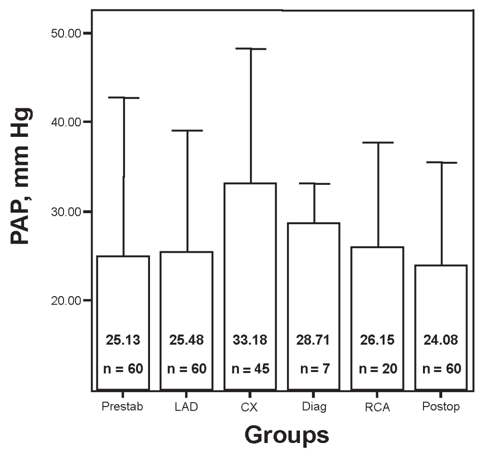

Figure 3. Changes in pulmonary arterial pressure (PAP) indicated from PAP measurements taken before stabilization of the heart for anastomosis (Prestab), during each anastomosis, and at the end of the operation (Postop). Histogram data are presented as the mean ± 2 SDs. LAD indicates left anterior descending coronary artery; CX, circumflex coronary artery; Diag, diagonal coronary artery; RCA, right coronary artery.

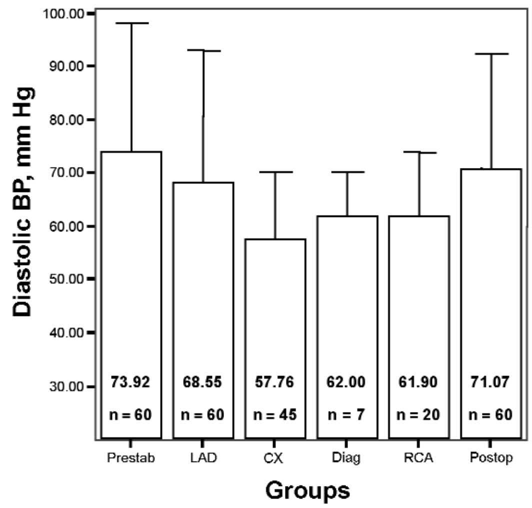

Figure 5. Changes in systemic diastolic blood pressure (BP) indicated from diastolic BP measurements taken before stabilization of the heart for anastomosis (Prestab), during each anastomosis, and at the end of the operation (Postop). Histogram data are presented as the mean ± 2 SDs. LAD indicates left anterior descending coronary artery; CX, circumflex coronary artery; Diag, diagonal coronary artery; RCA, right coronary artery.

Mitral Regurgitation during Anastomosis

None of the patients revealed any mitral regurgitation at the baseline TEE evaluation. No mild to moderate changes in mitral valve functions were seen during LAD and diagonal artery anastomoses. Eight of the 20 patients who underwent RCA anastomosis (RCA main branch, 10 patients; RCA posterior descending branch, 10 patients) developed moderate mitral regurgitation; the graft was anastomosed to the posterior descending branch of the RCA in 6 of these 8 patients. During CX anastomosis, 38 (84.4%) of 45 patients developed moderate mitral regurgitation. A Pearson chi-square test revealed the risk of mitral regurgitation during CX anastomosis to be 15.1 times greater than with other anastomoses (odds ratio for CX, 15.1; 95% confidence interval, 5.9-38.5; $P < .001$).

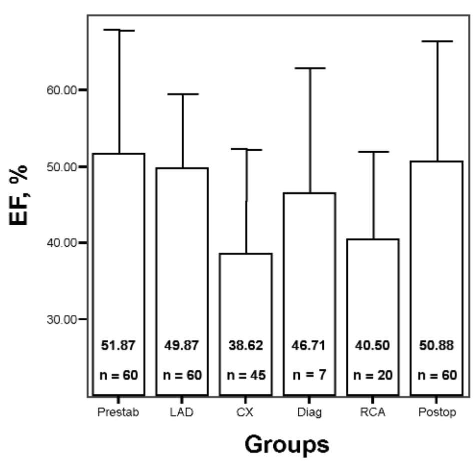

Figure 4. Changes in ejection fraction (EF) indicated from EF measurements taken before stabilization of the heart for anastomosis (Prestab), during each anastomosis, and at the end of the operation (Postop). Histogram data are presented as the mean ± 2 SDs. LAD indicates left anterior descending coronary artery; CX, circumflex coronary artery; Diag, diagonal coronary artery; RCA, right coronary artery.

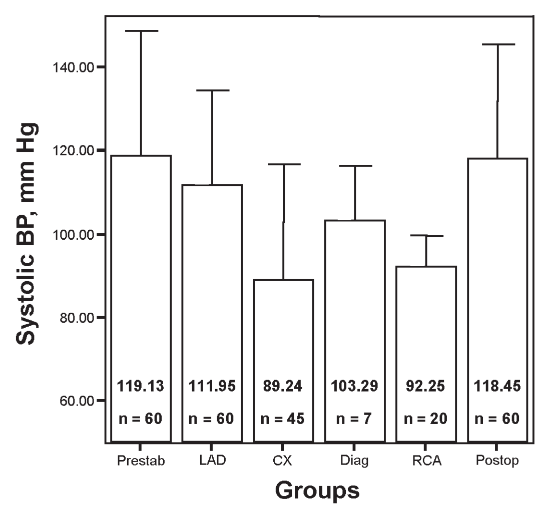

Figure 6. Changes in systemic systolic blood pressure (BP) indicated from systolic BP measurements taken before stabilization of the heart for anastomosis (Prestab), during each anastomosis, and at the end of the operation (Postop). Histogram data are presented as the mean ± 2 SDs. LAD indicates left anterior descending coronary artery; CX, circumflex coronary artery; Diag, diagonal coronary artery; RCA, right coronary artery.

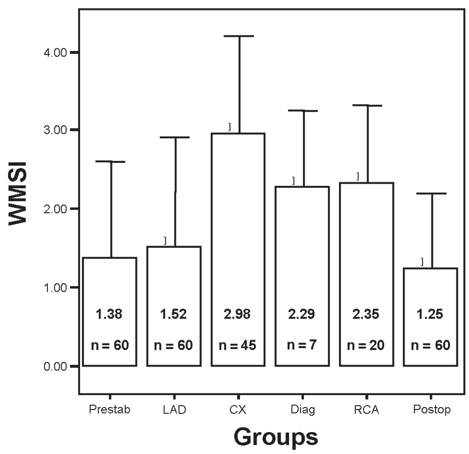

Figure 7. Changes in wall motion score index (WMSI) indicated from WMSI measurements taken before stabilization of the heart for anastomosis (Prestab), during each anastomosis, and at the end of the operation (Postop). Histogram data are presented as the mean ± 2 SDs. LAD indicates left anterior descending coronary artery; CX, circumflex coronary artery; Diag, diagonal coronary artery; RCA, right coronary artery.

DISCUSSION

OPCAB has generally been performed for the purpose of avoiding CPB-related complications in patients with high-risk factors, such as old age, cerebrovascular disease, ventricular failure, and renal failure [Suzuki 2003; Murphy 2004]. Hemodynamic deterioration during coronary anastomosis is the main problem with the OPCAB operation, and several studies have reported changes in hemodynamic variables during anastomoses and have documented their recovery following the anastomosis by measuring hemodynamic variables before and after the anastomosis [Cartier 1999; Suzuki 2003; Chassot 2004; Gurbuz 2007].

Anesthesia management of OPCAB is challenging because of hemodynamic deterioration during anastomoses, and the hemodynamic dysfunction that occurs during OPCAB has been postulated to be induced by the effect of the displacement of the heart and the unavoidable pressure applied to the heart, which affect both ventricular functions and coronary artery flow [Mathison 2000; Vassiliades 2002; Chassot 2004; Gurbuz 2007].

Anastomosis to the anterior wall (the LAD and diagonal arteries) causes relatively less hemodynamic compromise, but an anastomosis on the posterior wall (RCA and CX arteries) may cause severe deterioration in hemodynamic variables [Cartier 1999; Suzuki 2003]. Although volume loading, vasopressors, and Trendelenburg positioning may correct hemodynamic instability, conversion to on-pump surgery may still be necessary in some cases [Cartier 1999; Mathison 2000; Nierich 2000; Omae 2005].

Access to the different coronary arteries during CABG surgery requires displacement of the heart. Retraction of the heart for anastomosis to the LAD or to the diagonal artery causes insignificant hemodynamic changes, and beating-heart surgery for these vessels has been practiced for several years. The effects of cardiac positioning and stabilization for the right (RCA) and LCX coronary grafts have not been evaluated fully [Mathison 2000; Nierich 2000; Chang 2004; Omae 2005].

Revascularization of the posterior territory often results in hemodynamic compromise. In particular, exposure of the CX coronary artery and its marginal branches is more challenging during OPCAB, requiring elevation of the cardiac apex and medial rotation of the heart [Cartier 1999; Mathison 2000; Nierich 2000; Couture 2002; Suzuki 2003].

In the present study, we did not find any significant deterioration that required conversion to on-pump surgery. The mean arterial pressure, the right-side and left-side pressures, and the ejection fraction remained within safe and acceptable limits. Overall, the hemodynamic data showed no clinically important deterioration in the hemodynamic function of the global circulation, and no ischemic impairment in cardiac function was apparent during the OPCAB procedure. Ischemia was also not significant during the anastomosis period. We observed no major decrease in contractility, as would be reflected in unstable hemodynamics. Conversion because of hemodynamic instability or the use of a shunt was not necessary in any of the patients.

Displacement of the heart vertically for anastomosis to the posterior descending and marginal branches of the RCA causes the greatest hemodynamic compromise [Burfeind 1998; Couture 2002]. In our study, such a change was reflected as decreases in the PAP, blood pressures, and the ejection fraction. Monitoring by TEE during this period revealed moderate mitral regurgitation and an increase in the WMSI.

The differential diagnosis for the major cause of hemodynamic instability during CX and RCA anastomoses requires evaluation for the presence of myocardial ischemia [Couture 2002]. ST analysis showed no abnormality in any of our patients. The similarity in baseline and postoperative enzyme levels revealed in follow-up analyses of cardiac enzymes provides support for this statement. The cause for the hemodynamic instability could be hypovolemia, but the elevated PAP and CVP levels observed during the anastomoses were not compatible with a hypovolemic state. The other potential factors for instability are myocardial dysfunction, compression of the cardiac chambers, and mitral regurgitation. Increased PAP and CVP values are compatible with all 3 of these factors. TEE findings may help decide which of these factors is the major cause, thus allowing for the development of treatments for achieving hemodynamic stabilization [Couture 2002; Chassot 2004; Gurbuz 2007].

The TEE findings in our study showed a decrease in the ejection fraction and an increase in the WMSI, but the findings did not show any significant myocardial dysfunction associated with regional wall motion abnormalities caused by cardiac compression except during CX anastomoses. The WMSI increased significantly during CX grafting, compared with grafting to the RCA, the diagonal artery, and the LAD. This finding indicates a reversible regional systolic dysfunction during CX grafting that we did not see during the other anastomoses. Mitral regurgitation of a moderate degree was seen during 84% of CX anastomoses and during 80% of all anastomoses to the posterior wall (posterior descending branch of the RCA and the CX). These patients were the most hemodynamically unstable. Mitral regurgitation seemed unlikely to be related to ischemia but rather to the positioning of the heart.

In these cases, significant acute mitral valve dysfunction precipitated hemodynamic instability following heart positioning. In our clinical experience, the patients who are at greatest risk for developing severe mitral valve regurgitation are those who have preexisting myocardial dysfunction or mild to moderate mitral regurgitation; however, we included in our study only patients with a good ejection fraction and no mitral regurgitation. Thus, the mitral regurgitation that developed during anastomoses was not severe and did not precipitate any severe hemodynamic instability that would have prompted conversion to on-pump surgery.

The main causes of hemodynamic disturbance that occur during positioning are thought to be decreased filling of the right ventricle and, to a lesser extent, decreased left ventricular filling that occur via direct ventricular compression [Burfeind 1998; Couture 2002]. Volume loading, the Trendelenburg position, and vasopressor infusion usually correct these disturbances. TEE is indicated in patients who are not responsive to such treatment and helps to differentiate between cardiac dysfunction and extracardiac compression [Burfeind 1998; Jurmann 1998]. Acute position-related mitral regurgitation may be the concomitant factor precipitating hemodynamic deterioration. When increases in the PAP and the CVP are observed, a TEE examination of the mitral valve can be very helpful in the diagnosis [Couture 2002; Chassot 2004; Omae 2005; Gurbuz 2007]. In such cases, we administer nitroglycerin and inotropic agents intravenously. Clamping of the inferior vena cava has been used to control an acute increase in the PAP that is unresponsive to the usual treatment [Dagenais 1999]. None of the patients in this study required clamping of the inferior vena cava.

Refinements in the mechanical stabilizer have provided a very stable surgical field with minimal hemodynamic change. In addition, the deep pericardial suture technique is very effective for accessing the lateral and posterior walls of the heart [Chang 2004; Shinn 2004]. Nevertheless, the heart is very prone to developing significant mitral regurgitation, especially during CX anastomosis [Suzuki 2003; Chang 2004]. Increases in the CVP, the PAP, the PCWP, and the WMSI, along with decreases in the diastolic and systolic blood pressures and in the ejection fraction, may be a reflection of positional mitral regurgitation, which can lead to hemodynamic instability. This regurgitation may worsen if not addressed, and so its medical management is crucial [Stamou 2000; Couture 2002].

Positional mitral regurgitation is frequently observed and is a major factor of the hemodynamic instability that occurs during posterior- and lateral-wall revascularization during the OPCAB procedure.

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