

Hemodynamic Changes during Off-Pump Coronary Artery Bypass Graft Surgery: Experience Using Pericardial Bands for Target Stabilization

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Received November 4, 2013; revised December 4, 2013; accepted December 10, 2013

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ABSTRACT

Background: The off-pump coronary artery bypass graft surgery (OPCAB) may produce significant hemodynamic instability necessitating conversion to on-pump surgery. This study evaluated the hemodynamic parameters in patients undergoing OPCAB using pericardial bands for stabilization of the coronary target sites. **Methods:** In 250 patients undergoing OPCAB the hemodynamic parameters including continuous cardiac output and systemic venous oxygen saturation (SvO₂) were recorded at baseline after pericardiotomy, during each coronary artery anastomosis at 3, 5, 10, 15 min, and after release of the pericardial bands used for target stabilization. Vasopressors were used to maintain mean arterial pressure (MAP) > 60 mmHg. **Results:** SvO₂ and cardiac index (CI) decreased significantly after target stabilization and during all coronary anastomoses with greater decreases noted during obtuse marginal branch of left circumflex (OM) anastomosis. The MAP and heart rate were maintained without significant change but central venous pressure increased significantly during all coronary anastomoses. The significant increase in pulmonary capillary wedge pressure and mean pulmonary artery pressure were noted only during anastomosis of the left anterior descending artery. The highest dose of vasopressor was used during OM anastomosis. **Conclusions:** During OPCAB surgery using pericardial bands for coronary target stabilization, MAP was maintained constantly, but SvO₂ and CI decreased immediately after target stabilization and reduced further during all coronary artery anastomoses. During OM anastomosis SvO₂ and CI were significantly lower as compared to that of LAD and right coronary artery. Careful monitoring and management of hemodynamic variables are warranted to avoid conversion to on-pump technique.

Keywords: Circulatory Hemodynamics; CABG; New Technology; Off-Pump Surgery

1. Introduction

The off-pump coronary artery bypass graft surgery (OPCAB) is being expanded in recent years because of the advantage of avoiding cardiopulmonary bypass (CPB) and its attendant complications, improvements in techniques as well as recent introduction of instruments to optimally stabilize the coronary targets on a beating heart. [1-5]. The introduction of mechanical stabilizers such as CTS pressure mechanical stabilizers, epicardial fixation by suction devices and the Medtronic-Utrecht Octopus system, (Medtronic Inc, Minneapolis, MN), produced adequate cardiac immobilization of the coronary target

site for performance of a safe anastomosis [6]. However, the hemodynamic instability that occurs during positioning of the heart and stabilization of the coronary targets with interruption of coronary blood flow are important factors limiting the safe performance of OPCAB. Several studies have been performed noting the changes in hemodynamic parameters and management of hemodynamic instability during OPCAB using mechanical stabilizers for coronary target stabilization and hemodynamic variables measured in most of these studies were either sparse or were measured only once during procedure without noting the progress of hemodynamic change dur-

ing coronary artery anastomosis [7,8]. This study evaluated the use of pericardial bands for coronary target stabilization, noting serial hemodynamic parameters recorded during coronary artery anastomoses.

2. Material and Methods

During a three year period 250 patients with coronary artery disease participated in this prospective study and all were planned to undergo OPCAB. Patients with significant preoperative hepatic or renal dysfunction, bleeding disorder or uncontrolled arrhythmia were excluded. The characteristics of this patient group are shown in **Table 1**. This study was approved by the institutional review board and ethics committee of the NRBIMC and informed consent was obtained from all patients.

2.1. Surgical Technique

All preoperative cardiac medications were continued till the morning of surgery, but digoxin was withheld. Morphine sulphate 0.05 mg/kg IM was given an hour before the surgery as premedication. In the operating room, EKG leads II and V5 were monitored and the radial artery was cannulated for continuous monitoring of arterial blood pressure and blood gas analysis. Anesthetic induction was done with 2.0 - 3.0 mg of midazolam, 1.0 - 3.0 µg/kg of sufentanil, and 50 mg of rocuronium. Anaesthesia was maintained with 0.2 - 0.5 vol% of isoflurane and

continuous intravenous infusion of 0.5 - 1.5 µg/kg/min of sufentanil and vecuronium. Ventilation was controlled with oxygen-air mixture (FiO₂ 0.6) to maintain end-tidal CO₂ in 35 - 38 mmHg. After anaesthetic induction isosorbide dinitrate infusion at 0.5 µg/kg/min and diltiazem infusion at 1mcg/kg/min were started and the Swan-Ganz catheter (Swan-Ganz, Baxter Healthcare Co., Irvine, CA, USA) was inserted through the right internal jugular vein into the main pulmonary artery. The temperature of the operating room was kept above 25°C and all the fluid (infusions and irrigations) was warmed to prevent hypothermia. Warm humidifier was connected to the breathing circuit. Patients were also warmed with warm mattress and after the venous harvest, the lower limbs were wrapped with ace bandage and covered with a warm blanket.

After median sternotomy, adequate amount of fluid (1.5 - 2.0 liters) was administered to keep the CVP around 10 mm-Hg. After dissection of left internal mammary artery (LIMA), and harvesting 3 pericardial bands intravenous heparin was injected (1 mg/kg) and activated clotting time was maintained over 250 s during the coronary anastomoses. To expose the left lateral side of the heart and to elevate the apex, four deep pericardial stay sutures were placed at aorto-pericardial reflection, left superior and inferior pulmonary veins and between left inferior pulmonary veins and inferior vena cava [9]. Traction on these stay sutures positioned the heart to expose the coronary artery target, and then appropriate pericardial bands were snared for stabilization of the coronary targets for anastomosis. The technique of harvesting the pericardial bands and coronary target stabilization using pericardial bands was as described earlier [10]. Briefly, this technique involved fashioning 3 pericardial bands of 2.5 cm wide and 8 to 10 cm long from the body of the anterior pericardium after median sternotomy incision was completed. Two pericardial bands are positioned one above and one below the coronary target and the distal ends of the bands were snared to the pericardial well for stabilization of the anastomotic site. Trendelenburg position was often employed during anastomosis. In case of hypotension, nor-epinephrine was given to maintain mean systemic arterial pressure (MAP) above 60 mmHg. In this study (250 patients) an average of 2.8 ± 0.7 coronary arteries were bypassed in a patient. The time for performing three coronary artery anastomoses was 48 ± 12 min (mean). The time required to anastomose each coronary artery are following: 17.6 ± 3.4 min for LAD, 17.6 ± 1.8 min for obtuse marginal branch of LCX and 17.9 ± 1.8 min for RCA.

2.2. Hemodynamic Monitoring

The hemodynamic variables recorded were heart rate (HR), central venous right atrial pressure (CVP), systemic mean

Table 1. Patient Demographics.

Variable	Number	Percentage (%)
Age (years)	56 ± 9*	
Sex (M/F)	200/50	80/20
Co-morbidity:		
Diabetes mellitus	88	35
Hypertension	75	30
Prior myocardial infarction	50	20
Prior stroke/TIA	38	15
Preoperative medications:		
ACE inhibitors	120	48
Beta blockers	225	90
Calcium channel blockers	212	85
Coronary artery disease		
Left main and 2 or 3 vessel	25	10
3 Vessel disease	207	82
2 vessel disease	18	7
Echocardiography:		
Wall motion abnormalities:		
Regional akinesia	56	22
Regional hypokinesia	225	90
Ejection fraction	57.3 ± 11.4*	

*Mean value and ± SD (standard deviation), TIA = transient ischemic event.

arterial pressure (MAP), pulmonary artery pressure (PAP), pulmonary capillary wedge pressure (PCWP), cardiac output (CO), and systemic venous oxygen saturation (SvO₂). The cardiac index (CI), stroke volume index (SVI), left ventricular stroke work index (LVSWI), and systemic and pulmonary vascular resistances were calculated according to standard formulas. Hemodynamic measurements were recorded after pericardiotomy for baseline value, then 3, 5, 10, and 15 min after snaring the pericardial bands for coronary artery target stabilization during each coronary artery anastomosis, after the removal of the bands and after sternal closure. The amount of nor-epinephrine used to maintain MAP for each anastomosis was also recorded.

2.3. Statistical Analysis

All hemodynamic variables were expressed as the mean value \pm SD. Hemodynamic changes for each coronary graft anastomosis were compared to baseline values using repeated measures of analysis of variance (ANOVA). The comparisons of variables between coronary arteries were analyzed with one-way ANOVA. Percent changes of CI and SvO₂ for baseline values in each coronary artery were analyzed with linear regression. A P value of <0.05 was considered as statistically significant. Data were analyzed with SPSS for Windows, release 10.0 (SPSS Inc., Chicago, IL, USA).

3. Results

During RCA anastomosis, the HR was significantly in-

creased throughout the procedure (T3 to T15 and at sterna closure) compared to the baseline value, but MAP decreased only initially at T3. The MPAP and PCWP did not show significant change compared with baseline, except a brief elevation of PCWP at T3. The CVP at T3 to T15 significantly increased and the CI, SvO₂, SVI and LVSWI at T3 to T15 significantly decreased compared with baseline. The SVRI did not change compared with baseline except increase at T10.

During obtuse marginal branch of LCX anastomosis, the HR at T3 to T10 and at sternal closure (Ts), significantly increased, but without any change in MAP. The CVP at T3 to T15 and PCWP at T10 to T15 significantly increased compared with baseline values. The cardiac index (CI), SvO₂, SVI, and LVSWI showed significant decrease at T3 to T15 compared with baseline. The SVRI at T3 to T15, significantly increased compared with baseline values.

During LAD anastomosis, the HR was significantly increased only at sternal closure without a change in MAP. The CVP, MPAP, PCWP significantly increased from T3 to T15 compared with the baseline values. The CI, SvO₂, SVI, and LVSWI were significantly decreased from T3 through T15 and SVRI was significantly increased at T15 compared with baseline values. Hemodynamic data during coronary artery bypass graft anastomoses are shown in **Tables 2 and 3**.

On comparing variables between the 3 coronary artery anastomoses, no differences were noted in HR, MAP and CVP during entire period of surgery (B to Ts). MPAP was significantly lower in OM at T3, and in RCA at T3

Table 2. Hemodynamic data during coronary artery bypass graft anastomosis. (Mean \pm SD).

Var	Art	B	T3	T5	T10	T15	Tr	Tst
HR	RC	61 \pm 10	69 \pm 10*	68 \pm 10*	68 \pm 11*	67 \pm 10*	68 \pm 10*	69 \pm 12*
	OM	61 \pm 10	66 \pm 14*	65 \pm 14*	65 \pm 13*	63 \pm 12	64 \pm 11	70 \pm 12*
	LA	61 \pm 10	64 \pm 12	63 \pm 12	63 \pm 13	62 \pm 12	62 \pm 10	70 \pm 12*
CVP	RC	6 \pm 5	12 \pm 4*	11 \pm 4*	11 \pm 3*	11 \pm 4*	9 \pm 3	9 \pm 3
	OM	6 \pm 4	11 \pm 4*	11 \pm 4*	11 \pm 4*	11 \pm 5*	9 \pm 3	8 \pm 3
	LA	6 \pm 4	11 \pm 4*	11 \pm 4*	11 \pm 4*	11 \pm 5*	9 \pm 3	9 \pm 3
MAP	RC	85 \pm 12	76 \pm 8*	80 \pm 9	80 \pm 10	82 \pm 9	79 \pm 13	84 \pm 13
	OM	85 \pm 12	83 \pm 9	81 \pm 9	80 \pm 10	80 \pm 12	83 \pm 13	84 \pm 13
	LA	85 \pm 12	84 \pm 12	81 \pm 11	80 \pm 12	81 \pm 10	82 \pm 11	84 \pm 13
MPAP	RC	16 \pm 7	21 \pm 7	21 \pm 5**	21 \pm 7	20 \pm 6**	20 \pm 6	20 \pm 4
	OM	16 \pm 6	20 \pm 7**	22 \pm 6	22 \pm 7	22 \pm 7	21 \pm 7	20 \pm 5
	LA	16 \pm 6	24 \pm 7*	25 \pm 7*	24 \pm 7*	24 \pm 7*	22 \pm 6	20 \pm 5
PCWP	RC	10 \pm 4	15 \pm 4*	14 \pm 4	14 \pm 4	14 \pm 4	14 \pm 4	14 \pm 4
	OM	10 \pm 4	14 \pm 4	14 \pm 4	15 \pm 4*	15 \pm 5*	14 \pm 5	14 \pm 5
	LA	9 \pm 5	16 \pm 4*	17 \pm 5*	17 \pm 5*	17 \pm 5*	15 \pm 4*	14 \pm 5
SvO ₂	RC	83 \pm 5	73 \pm 9*	70 \pm 9*	70 \pm 9*	70 \pm 10*	72 \pm 11*	76 \pm 7*
	OM	83 \pm 5	72 \pm 9*	68 \pm 9**	68 \pm 9	67 \pm 10**	70 \pm 11	76 \pm 7*
	LA	83 \pm 5	76 \pm 8*	73 \pm 10*	74 \pm 11*	73 \pm 11*	74 \pm 8*	76 \pm 7*

Hr, heart rate (beats/minute); CVP, central venous pressure (mm·Hg); MAP, mean systemic arterial pressure (mm·Hg); MPAP, mean pulmonary arterial pressure (mm·Hg); PCWP, pulmonary capillary wedge pressure (mm·Hg); SvO₂, systemic mixed venous oxygen saturation(%); LA, left anterior descending coronary artery; OM, obtuse marginal branch of left circumflex coronary artery; RC, right coronary artery or posterior descending coronary artery; Var, variable; Art, artery; B, baseline; T3, 3 minutes; T5, 5 minutes; T10, 10 minutes; T15, 15 minutes after application of pericardial bands for coronary target stabilization, Tr, after release of pericardial bands used for coronary target stabilization. T st, after sternal closure. *p < 0.05 compared to baseline value. **p < 0.05 compared to LAD branch.

Table 3. Calculated hemodynamic data during coronary artery bypass graft anastomosis. (Mean \pm SD).

Var	Ar	B	T3	T5	T10	T15	Tr	Tst
CI	Rc	2.8 \pm 0.6	2.4 \pm 0.6*	2.1 \pm 0.6*	2.1 \pm 0.6	2.2 \pm 0.5*	2.2 \pm 0.6*	2.9 \pm 0.6
	Om	2.8 \pm 0.6	2.0 \pm 0.6*	1.9 \pm 0.5**	1.9 \pm 0.5**	1.9 \pm 0.4	2.0 \pm 0.5	2.9 \pm 0.6
	La	2.8 \pm 0.6	2.3 \pm 0.7*	2.3 \pm 0.5*	2.3 \pm 0.5*	2.2 \pm 0.5*	2.1 \pm 0.4*	2.8 \pm 0.6
SWI	Rc	46 \pm 9	34 \pm 9*	32 \pm 9*	32 \pm 9*	33 \pm 7*	34 \pm 11*	42 \pm 8*
	Om	46 \pm 9	31 \pm 9***	30 \pm 10***	31 \pm 10***	30 \pm 8*	32 \pm 10*	42 \pm 8*
	La	46 \pm 11	39 \pm 10*	39 \pm 11*	38 \pm 9*	36 \pm 8*	36 \pm 8*	42 \pm 8*
LVSWI	Rc	43 \pm 10	31 \pm 9*	28 \pm 8*	27 \pm 8*	30 \pm 6*	30 \pm 10*	39 \pm 9
	Om	43 \pm 10	30 \pm 8*	27 \pm 10*	27 \pm 9*	27 \pm 7*	29 \pm 10*	39 \pm 9
	La	43 \pm 10	34 \pm 9	31 \pm 8*	32 \pm 9*	30 \pm 9*	31 \pm 9*	39 \pm 9
SVRI			Rc	Om		La		
B			2295 \pm 615	2295 \pm 615		2295 \pm 615		
T3			2735 \pm 762	3102 \pm 960**		2514 \pm 729		
T5			2729 \pm 672	3179 \pm 932**		2529 \pm 572		
T10			2853 \pm 612*	3194 \pm 979**		2534 \pm 512		
T15			2769 \pm 672	3144 \pm 872**		2592 \pm 482*		
Tr			2722 \pm 812	3232 \pm 992**		2652 \pm 622*		
Tst			2185 \pm 612	2185 \pm 612		2185 \pm 612		

CI, cardiac index (liters/min²); SWI, stroke work index (ml/beat/m²); LVSWI, left ventricular stroke work index (gm/m²); SVRI, systemic vascular resistance index, (dynes cm⁻⁵/m²); La, left anterior descending coronary artery; Om, obtuse marginal branch of left circumflex coronary artery; Rc, right coronary artery or posterior descending coronary artery; T3, 3 minutes; T5, 5 minutes; T10, 10 minutes; T15, 15 minutes after application of pericardial bands for coronary target stabilization, Tr, after release of pericardial bands used for coronary target stabilization. T st, after sternal closure. *p < 0.05 compared to baseline value, **p < 0.05 compared to LAD branch, ***p < 0.05 compared to both baseline and LAD.

and T10 as compared to LAD. The CI and SvO₂ from T3 to T15 were significantly lower in OM as compared to LAD. The SVI was significantly lower in OM than in LAD from T3 to T10. The LVSWI of LAD at T3 was higher than that of OM and RCA. The SVRI was significantly higher in OM from T3 to Tr compared to LAD. The changes of CI and SvO₂ of each coronary artery were compared. The decrease in CI was greater in OM compared to that of LAD (**Figure 1**). Similarly the decrease in SvO₂ was greater in OM compared to that of LAD (**Figure 2**). Noticeably, the change of CI in LAD showed linear decrease with time though the change of CI in OM and RCA did not show the same pattern. The total doses of nor-epinephrine used to maintain MAP over 60 mmHg during performance of anastomoses were 87.1 \pm 106.4, 74.0 \pm 60.9 and 216.9 \pm 282.6 μ g for LAD, RCA, and OM vessels respectively. The amount of nor-epinephrine used was significantly larger in OM than in other two arteries.

4. Comment

Though during earlier years, the OPCAB surgery was performed in patients with good ventricular function and a single or two-vessel disease, this has been recently performed in patients with calcified and atheromatous ascending aorta, renal failure, cerebrovascular disease, or in patients with poor ventricular function or advanced heart failure for avoiding CPB-related complications [11]. The hemodynamic deterioration occurring during coronary anastomosis is an important concern of OPCAB pro-

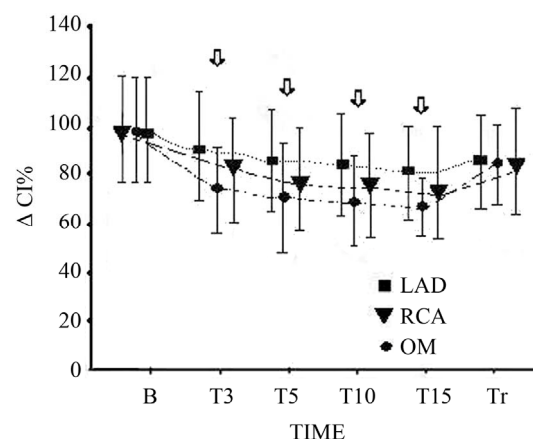


Figure 1. The changes in cardiac index during each coronary graft anastomosis. Δ CI% = (cardiac index for each period/baseline cardiac index) \times 100. The vertical bars represent standard deviation. B = baseline after pericardiotomy, T3 = 3 minutes after stabilization of a coronary target, T5 = 5 minutes after stabilization of a coronary target, T10 = 10 minutes after stabilization of a coronary target, T15 = 15 minutes after stabilization of a coronary target, Tr = after release of pericardial bands used for stabilization of a coronary target and post grafting period. LAD = left anterior descending coronary artery, RCA = right coronary artery, OM = obtuse marginal branch of left circumflex coronary artery, the white arrows indicate p < 0.05 compared to LAD.

cedure. This study evaluated the hemodynamic variables during coronary artery anastomoses using deep pericardial stay sutures and pericardial bands for coronary artery target stabilization and all hemodynamic variables were

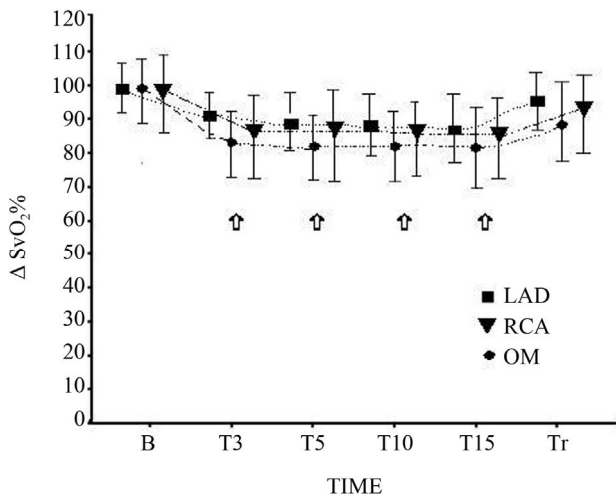


Figure 2. The changes in mixed venous oxygen saturation ($\Delta \text{SvO}_2\%$) during each coronary graft anastomosis. $\Delta \text{SvO}_2\% = (\text{SvO}_2 \text{ for each period/baseline SvO}_2) \times 100$. The vertical bars represent standard deviation. B = baseline after pericardiotomy, T3 = 3 minutes after stabilization of a coronary target, T5 = 5 minutes after stabilization of a coronary target, T10 = 10 minutes after stabilization of a coronary target, T15 = 15 minutes after stabilization of a coronary target and post grafting period. LAD = left anterior descending coronary artery, RCA = right coronary artery, OM = obtuse marginal branch of left circumflex coronary artery. The white arrows indicate $p < 0.05$ compared to LAD.

recorded as a function of time during each coronary artery anastomosis. After the initial hemodynamic change induced by the heart positioning and snaring the pericardial bands to the pericardial well, no further significant hemodynamic deterioration or improvement were noticed. There was no case that could not perform planned anastomosis or convert to CPB due to hemodynamic instability. Though incidence of emergency conversion during OPCAB has decreased with increasing surgical experience, outcomes in these patients continued to be worse than those in non-converted patients. Therefore, careful monitoring of hemodynamic changes and safer bail out strategies are still warranted [12].

The CI and SvO_2 significantly decreased at the beginning of the anastomosis in all three coronary arteries although the MAP was constantly maintained throughout the procedure. In the OM and RCA, immediately after snaring the pericardial bands for stabilization CI and SvO_2 decreased abruptly, but further decrease did not occur. However, the cardiac index was decreased in linear fashion with time during LAD anastomosis. Compression of the left ventricular outflow tract and abnormal diastolic expansion secondary to direct deformation of the left ventricular geometry are proposed mechanisms for hemodynamic derangements with compression type

stabilizer. Coronary occlusion during the anastomosis can have additional effects on left ventricular function, depending on the status of collateral flow [8].

During anastomosis of anterior arteries such as LAD coronary artery target stabilization results in direct compression of the right ventricular outflow tract and the right ventricular end systolic and diastolic volumes increase. As a result, the left ventricular diastolic compliance is reduced through the interventricular relationship and the PAP and PCWP increase [13]. During LAD anastomosis, the obstruction of the right ventricular outflow tract may be the possible reason for the gradual decrease in CI, although reduction in blood supply to the large portion of left ventricular myocardium with impaired global ventricular function might have contributed, especially if intracoronary shunt was not used.

During OPCAB the sustained hemodynamic compromise may adversely affect major organ function, especially if the total time required for anastomosis is prolonged. The grafting of the posterior coronary branches (OM and posterior descending artery) through sternotomy requires anterior displacement of the beating heart and this often causes hemodynamic compromise [14,15]. The sustained decrease in CI ($< 2.0 \text{ l/min}$) and SvO_2 ($< 70\%$) during whole period of OM anastomosis should warn of impending major organ damage though none of patients, in this study, had developed neurologic complications or an evidence of organ damage. If high risk patients are subjected to OPCAB the sustained or repetitive low cardiac output status might have deleterious effect on organ function, therefore, it is increasingly necessary to adequately monitor and manage variables like CI, and SvO_2 . The SvO_2 represents both delivery and consumption of oxygen and changes earlier compared to the continuous cardiac output measurements. Though the changes in cardiac output might be too slow to monitor the cardiac status during the manipulation and tilting of the heart, it is still a useful variable as a trend during the entire surgical period.

The optimal management of patients undergoing OPCAB has been focused on the maintenance of stable hemodynamics such as MAP, HR and cardiac rhythm as well adequate tissue perfusion during coronary anastomosis [16-18]. The intravenous fluid loading and head down position were often used to compensate decreased MAP and CO while the use of inotropic drugs was relatively contraindicated [19]. The mechanical displacement and compression of the heart during anastomosis results in decrease in the CI and use of inotropic drugs may further increase myocardial oxygen consumption and induces myocardial ischemia [20-22]. In the study, it was found that the augmentation of preload with head down position and fluid loading was not adequate enough to compensate the reduced CO during anastomosis. There-

fore, management to maintain the CO and SvO₂ without subsequent adverse cardiac effects is essential and inotropic drugs that would not adversely increase chronotropism of the heart and myocardial oxygen consumption may be useful [22,23].

In conclusion, this study represents our experience using four deep pericardial stay sutures and pericardial bands for coronary artery target stabilization, recording serial hemodynamic changes occurred during OPCAB surgery. Other techniques using mechanical stabilizers, slings and tapes to expose and stabilize the coronary vessel may result in similar magnitude of hemodynamic changes which are largely dependent on the surgical technique and surgeon's skill. Though HR and MAP were maintained constantly throughout the procedure, SvO₂ and CI decreased significantly at the beginning of OM and RCA anastomosis, and maintained constantly throughout, while the CI and SvO₂ decreased further as a function of time during LAD anastomosis. Therefore, close monitoring with adequate interventions are necessary to prevent decreases in CI and SvO₂ and avoiding conversion to on-pump technique.

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