Change in right ventricular function during off-pump coronary artery bypass graft surgery[☆]

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Abstract

Objectives: Hemodynamic derangement during displacement of beating heart in off-pump coronary artery bypass graft (OPCAB) surgery might be related with right ventricular (RV) dysfunction. We evaluated RV function and hemodynamic alterations using a thermodilution pulmonary artery catheter. **Methods**: The study included 30 patients undergoing OPCAB, using single pericardial suture and tissue stabilizer. A thermodilution pulmonary artery catheter for continuous monitoring of the cardiac output (CO), right ventricular ejection fraction (RVEF) and RV volume was inserted before anesthesia. The hemodynamic variables were measured after the induction of anesthesia, 5 min after the heart was positioned for each coronary anastomosis and after the sternum was closed. **Results**: There was no significant change in the RVEF and cardiac index during anastomosis of the left anterior descending artery and right coronary artery. However, the significantly reduced RVEF accompanied by an increase in RV afterload and decrease in the CO was observed during anastomosis of the obtuse marginal (OM) artery. RV volumes did not significantly change during anastomoses, though the right atrial pressure increased during anastomoses of all coronary arteries. **Conclusions**: The displacement of beating heart for positioning during anastomosis of the graft to OM artery caused significant derangement of RV function and decrease in CO. A thermodilution catheter continuously measuring the CO and RVEF was useful to monitor the change in RV function and volume during OPCAB.
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Keywords: Off-pump coronary artery bypass grafting; Right ventricular ejection fraction; Thermodilution pulmonary artery catheter; Right heart function

1. Introduction

Recently, the portion of coronary artery bypass grafting on the beating heart without the use of cardiopulmonary bypass (CPB) has been expanded in cardiac surgery as a result of awareness of the damaging effect of CPB [1,2] and improvements in surgical equipment and techniques [3]. However, serious hemodynamic changes and subsequent myocardial ischemia and decrease in left ventricular (LV) performance can be still induced in the process of displacing the beating heart and restricting the cardiac motion to expose the planned anastomosis site during off-pump coronary bypass grafting (OPCAB) [4–7]. A few studies on hemodynamic alternations associated with OPCAB reported that reduced functions of both ventricles during coronary artery anastomosis are the main mechanism of hemodynamic derangements and especially, impaired diastolic function of the right ventricle (RV) plays an important role [4,5,7]. However, clinical studies evaluating the change in RV function in patients with ischemic heart disease are very rare. Mathison et al. [4] reported that the major cause of hemodynamic changes during OPCAB was disturbed diastolic filling of the RV through the measurement of chamber pressures or monitoring of echocardiography. Consequently, the current study was designed to examine changes in RV volume and ejection fraction during coronary artery anastomosis, using a thermodilution pulmonary artery catheter, and concomitant changes in hemodynamic variables in the patients undergoing OPCAB.

2. Patients and methods

2.1. Patients preparation

With the approval of Institutional Review Board and patient's consent, this study was prospectively performed in 31 patients who were to undergo elective OPCAB. No patient with unfavorable coronary anatomy, clinical instability, atrial fibrillation, any evidence of valvular heart disease (greater than grade I), ventricular aneurysm or emergent operation was included. In the final data analysis, we excluded the results from one patient who was converted to conventional coronary artery bypass grafting (CABG) emergently.

All patients were premedicated with the intramuscular 0.05–0.1 mg/kg of morphine 1 h before anesthesia. Five-ECG leads were attached and leads II and V_5 with ST-segment trend analysis were simultaneously monitored once patients arrived in the operating room. A 20-gauge catheter was inserted into the right radial artery for direct arterial pressure monitoring and blood gas analysis. A thermodilution pulmonary artery catheter (Swan–Ganz CCOmbo V Model 774HF75®, Baxter healthcare, USA; CCOmbo V catheter) was introduced through the right internal jugular vein. After advancing the CCOmbo V catheter until the pressure curve of the proximal port revealed RV pressure, it was retrieved 2–3 cm backward to the area where right atrial pressure (RAP) was obtained. The CCOmbo V catheter was connected to the continuous cardiac output (CO)/oxymetry/volumetric monitors (Vigilance monitor®, Baxter healthcare, USA). ECG slave cable's phone plug was connected to the ECG monitor input rear panel of Vigilance unit, and the other end of the slave cable was connected to the patient's bedside monitor's ECG signal output. After induction of anesthesia, in vivo calibration for mixed venous oxygen saturation (SvO_2) with mixed venous blood gas analysis was performed and SvO_2 value was set up.

2.2. Anesthetic techniques

After the induction of anesthesia using intravenous midazolam 2.0–3.0 mg, fentanyl 10–15 μg/kg and vecuronium 8 mg, trachea was intubated. Anesthesia was maintained with the inhalation of medical oxygen–air–isoflurane (under 0.5 MAC) and continuous infusion of fentanyl, 2–4 μg/kg per h. Breathing was controlled so that carbon dioxide partial pressure in arterial blood was maintained at 30–35 mmHg. After the central vein catheter was placed for fluid and drug injection, the infusion of isosorbide dinitrate, 0.5–1.0 μg/kg per min was maintained during operation. A transesophageal echocardiographic (TEE) probe was inserted to monitor wall motion of both the ventricles on the transgastric short-axis view at the mid-papillary level. The two, four, or five chamber view was used to monitor when TEE images were difficult to obtain while the heart was being displaced for anastomosis.

To maintain body temperature during the operation, the temperature in the operation room was maintained at $> 21\,°C$, and fluids were warmed, and a humidifier was attached to the inspiratory limb of anesthesia circuit. Warm blanket was also applied after the veins were harvested. An average of 1000–1500 ml fluid was introduced intravenously to maintain preload during the harvesting of graft vessels which were used for the bypass grafts.

2.3. OPCAB techniques

Intravenous heparin 1 mg/kg was administered after dissecting the internal mammary artery to maintain the activated clotting time > 250 s during anastomosis. Pericardial suture was placed in the posterior aspect of pericardial reflection between the left and right pulmonary veins [8]. After the suture was placed, suture thread was passed through a folded 2 cm width tape for effective elevation of cardiac apex and exposing the lateral wall. Using the tape, the heart was displaced in various directions and angles along the vessel for grafting to expose the coronary territories and tissue stabilizer (Octopus Tissue Stabilization System®, Medtronic, USA) was applied. Coronary anastomosis was performed in order of the left anterior descending artery (LAD), obtuse marginal branch (OM), and right coronary artery (RCA) continuously without repositioning the heart in neutral position in all patients included in this study.

During displacement of beating heart, the patients were placed in a 10–20° head-down tilt and norepinephrine 0.03–0.05 μg/kg per min was infused intermittently if mean systemic arterial pressure (MAP) decreased below 60–65 mmHg. Intracoronary shunt (Shunt Florester®, Bio-Vascular, USA) was inserted in case of LAD and proximal RCA anastomosis, but other coronary branches were snared during anastomosis.

Emergent conversion to CPB was done when the MAP was maintained at < 50 mmHg despite volume loading and drug treatment, the ST segment change of > 4 mm continued during coronary artery anastomosis, the ventricular fibrillation did not respond to cardioversion, or newly developing abnormal wall motion suggestive of ischemia on TEE continued.

2.4. Data collection

Hemodynamic variables were measured after the induction of anesthesia (control value, T1), 5 min after the heart was positioned for the LAD, OM and RCA anastomosis (T2, T3 and T4, respectively) and after the sternum was closed (T5). The variables measured were the CO, heart rates (HR), MAP, mean pulmonary artery pressure (MPAP), RAP, pulmonary capillary wedge pressure (PCWP), SvO_2, right ventricular ejection fraction (RVEF) and right ventricle end-diastolic and end-systolic volume (RVEDV and RVESV, respectively). Using these

Table 1
Patient characteristics

Age (years)	63.5 ± 7.3
Sex (M/F)	27/3
Left ventricular ejection fraction (%)	61.1 ± 9.2
Segmental wall motion abnormality	
Hypokinesia	10
Akinesia	1
Preoperative medications	
β-Receptor blockers	19
Calcium channel antagonists	19
Angiotensin converting enzyme inhibitors	8
Diuretics	1
Comorbid risk factors	
Hypertension	9
Diabetes mellitus	5
Previous myocardial infarction	2
Transient ischemic accident	2

Values are the number of patients or mean ± SD.

variables, the cardiac index (CI), systemic and pulmonary vascular resistance index (SVRI and PVRI, respectively), and stroke volume index (SVI) right ventricular end-diastolic and end-systolic volume index (RVEDVI and RVESVI, respectively) were calculated. ST segment change and the amount of norepinephrine infused during anastomosis of each coronary artery were recorded.

2.5. Statistical analysis

All data were expressed as the number of patients or mean ± SD. One-way analysis of variances was used to compare the hemodynamic variables measured at each coronary anastomosis and the amount of norepinephrine infused during each coronary anastomosis. Multiple comparisons were performed using the Bonferroni procedure. Independent t-test was also used to compare control with values after sternal closure. A P-value < 0.05 was considered statistically significant.

3. Results

At the beginning, 31 patients were included in the study. However, emergent conversion to CPB was performed in one patient during OPCAB due to hypotension following global hypokinesia and distension of LV on TEE when the heart was elevated to place the pericardial suture, and the patient was converted to conventional CABG and excluded from data. Six patients had the history of myocardial infarction in the anterior wall, and five of them showed the evidence of akinesia in the anterior wall preoperatively. The average LV ejection fraction measured with echocardiography preoperatively was 58.4 ± 12.0%, regional wall motion abnormalities were seen in 66% of the patients, and 80% of the patients were taking β-blockers and calcium channel antagonists preoperatively. In all patients LV ejection fraction measured with TEE before OPCAB in the operating room was $> 40\%$, and no patient was diagnosed with LV or RV failure. A total of 80 vessels at an average of 2.7 ± 0.4 bypass vessels per patient were anastomosed in 30 patients (Table 1).

During the LAD and OM anastomosis, the MPAP, PCWP, RAP and PVRI significantly increased and the SvO_2 significantly decreased compared with values at T1. The SVRI at T3 was also higher than that at T1 and T2. During the RCA anastomosis, the HR and RAP significantly increased and the SvO_2 significantly decreased compared with the values at T1. The HR at T4 significantly increased compared with T2 and T3. The MPAP and PVRI at T4 significantly decreased compared with the value at T2. After sternal closure, the HR significantly increased using cardiac pacing in 11 patients with accompanied bradycardia and the SvO_2 significantly decreased compared with T1 (Table 2). The CI at T3 significantly decreased compared with values at T1, T2 and T4 (Fig. 1). The SVI significantly decreased at T3 and T4 compared with values at T1 and T2 (Fig. 2). The RVEF at T3 significantly decreased compared with the value at T1 (Fig. 3). There was no significant change in the RVEDVI and RVESVI
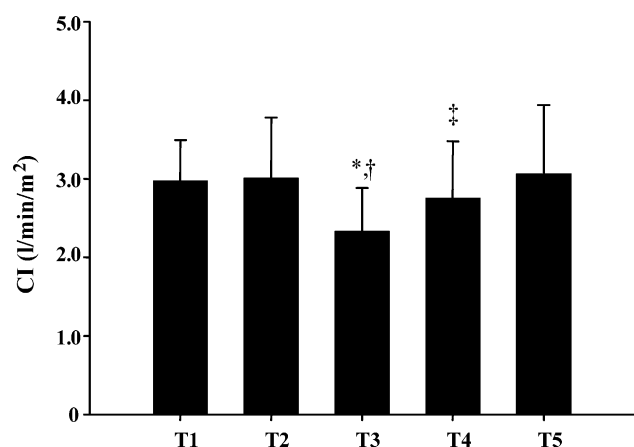
Table 2
Change of hemodynamic values during coronary anastomosis-1

	T1	T2	T3	T4	T5
HR	60 ± 8	61 ± 8	59 ± 9	66 ± 8*[†,‡]	71 ± 9
MAP	79 ± 9	78 ± 11	80 ± 9	78 ± 10	80 ± 10
MPAP	18 ± 4	24 ± 5*	22 ± 4*	21 ± 4[†]	19 ± 4
PCWP	14 ± 4	17 ± 3*	16 ± 3*	15 ± 3	14 ± 3
RAP	9 ± 3	12 ± 3*	11 ± 4*	12 ± 3*	10 ± 3
SVRI	1957 ± 504	1831 ± 420	2531 ± 862*[†]	2087 ± 740[‡]	1981 ± 629
PVRI	140 ± 64	204 ± 78*	245 ± 125*	172 ± 108[†]	133 ± 67
SvO_2	84 ± 2	77 ± 4*	73 ± 6*	71 ± 4*	78 ± 4*

Values are mean ± SD. T1, after induction of anesthesia; T2, during left anterior descending artery anastomosis; T3, during obtuse marginal artery anastomosis; T4, during right coronary anastomosis; T5, after sternal closure; HR, heart rate (beats/min); MAP, mean systemic arterial pressure (mmHg); MPAP, mean pulmonary arterial pressure (mmHg); PCWP, pulmonary capillary wedge pressure (mmHg); RAP, right atrial pressure (mmHg); SVRI, systemic vascular resistance index (dyn·s·cm^{-5}·m^{-2}); PVRI, pulmonary vascular resistance index (dyn·s·cm^{-5}·m^{-2}); SvO_2, mixed venous oxygen saturation (%). *$P < 0.05$ compared with T1; [†]$P < 0.05$ compared with T2; [‡]$P < 0.05$ compared with T3.

Fig. 1. Change of the cardiac index (CI) during and after coronary artery anastomosis. Abbreviations are the same as defined in Table 2. *$P < 0.05$ compared with T1; [†]$P < 0.05$ compared with T2; [‡]$P < 0.05$ compared with T3.

during coronary artery anastomoses and the RVEDVI significantly decreased but the RVESVI did not significantly change at T5 compared with values at T1 (Fig. 4).

No inotropic agent was used during the operation. Norepinephrine was continuously administered in 45% of the patients during the anastomosis of the OM to maintain the MAP and the amount of norepinephrine infused was significantly greater in OM ($0.3 \pm 0.4 \mu$g/kg per min, $P = 0.008$) than in other coronary artery. Five patients (17%, $17.8 \pm 0.4 \mu$g/kg per min) were supported with norepinephrine to maintain adequate hemodynamics for 12 h postoperatively. No significant change was seen in ST segment or cardiac rhythm in all coronary arteries. Preoperative regional wall motion abnormality was improved after anastomosis in most cases, and no new case of regional wall motion abnormality was observed during operation except in one patient who underwent emergent conversion to CPB and excluded from the results. Postoperative creatinine kinase myocardial band (CK–MB)
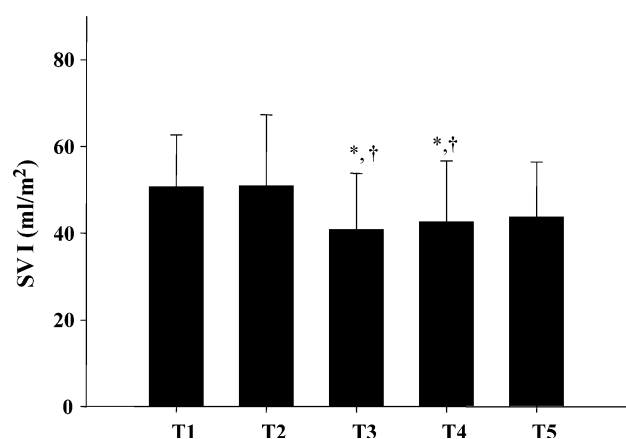
increased to >50 IU/l in three patients (10%) 1 day after operation, but no new Q wave nor ST segment elevation was seen on ECG during hospital stay. The CI was maintained at >2.0 l/min per m^2 in all patients during intensive care unit stay and no patients showed other neurological or gastrointestinal complications, or decrease in renal function during hospital stay.

4. Discussion

In the current study, we evaluated concomitant change in hemodynamic variables and RV function using a CCOmbo V catheter during OPCAB and found that significant decrease in RVEF and hemodynamic derangements developed concomitantly during anastomosis in the OM. In contrast, there was no significant change in RV function measured with CCOmbo V catheter during the LAD and RCA anastomoses.
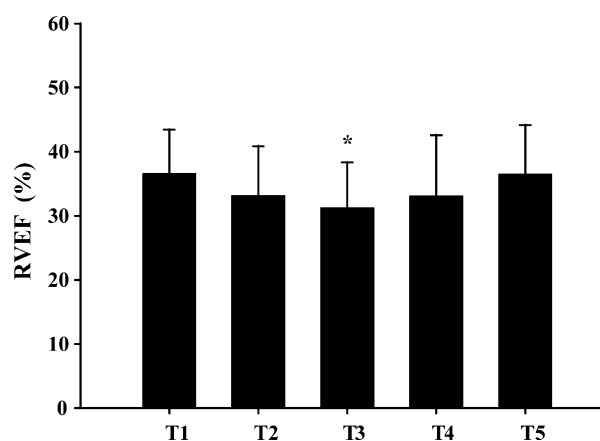

Fig. 3. Change of the right ventricular ejection fraction (RVEF) during and after coronary artery anastomosis. Abbreviations are the same as defined in Table 2. *$P < 0.05$ compared with T1.

Fig. 2. Change of the stroke volume index (SVI) during and after coronary artery anastomosis. Abbreviations are the same as defined in Table 2. *$P < 0.05$ compared with T1; [†]$P < 0.05$ compared with T2.
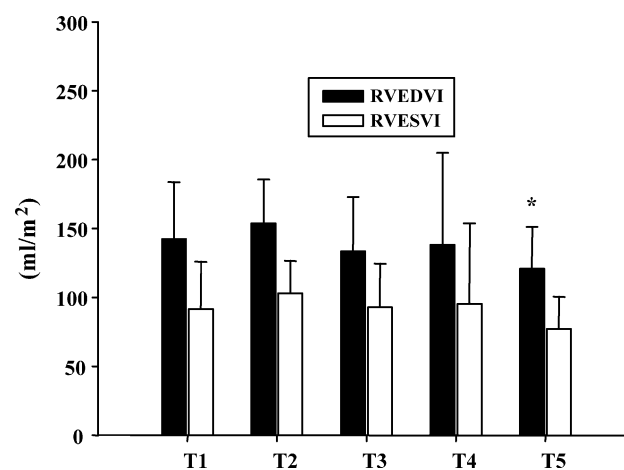

Fig. 4. Change of the right ventricular end diastolic and systolic volume index (RVEDVI and RVESVI, respectively) during and after coronary artery anastomosis. Abbreviations are the same as defined in Table 2. *$P < 0.05$ compared with T1.

It is generally accepted that hemodynamic derangement during OPCAB is induced due to the effect of the displacement of the heart and inevitable pressure applied to the heart affecting both ventricular functions and coronary artery flow [7,9–11]. Also there are some reports about the important role of RV function on hemodynamic deterioration during OPCAB [4,5,12]. Porat and colleagues [5] reported that dysfunction in right heart probably induced hemodynamic abnormalities, and they examined that the CO and systemic blood pressure decreased with a concomitant increase in the central venous pressure (CVP) and right ventricular end-diastolic pressure (RVEDP) whereas LV pressure did not change during displacement of the heart in animal study. They also found that the use of an RV assist device to augment pulmonary blood flow induced decrease in the CVP and RVEDP with concomitant increase in the CO and systemic blood pressure. Furthermore, Mathison and colleagues [4] reported that RV dysfunction induced by direct ventricular compression is the main cause of hemodynamic instability when the heart was observed with TEE. In their study, when the heart was displaced and stabilized for anastomosis, the degree of compression pressures to the right heart was much more severe than that applied to the LV and the degree of increase in RV wall tension was greater than that in the LV. They proposed that the RV was more affected by compression compared with the LV because the RV has thinner wall and lower pressure and it is easy to be sandwiched between the thicker LV wall and pericardium when the heart is displaced.

Although hemodynamic derangement during anastomosis is attributable to RV dysfunction, there are a few methods available to comparatively evaluate RV function during operation. TEE is the most valuable monitor for the concomitant monitoring of the RV as well as LV function and detection of myocardial ischemia during OPCAB. However, its use has limitations during the positioning of the heart for anastomosis and in intensive care unit after operation. And measuring RV contractility with TEE is difficult because of the complex shape of the RV. Previous studies for the hemodynamic changes during OPCAB were to observe RV function using TEE or to measure RVEDP directly [4,5,13] and this is the first study to observe the change in RV function with the thermodilution catheter. RV function with the change in RVEF and RV volume could be evaluated with the thermodilution technique in this study. As reported in the previous studies, the RVEF measured by the thermodilution catheter has high reproducibility and good correlation with other measurement methods [14,15] and CCOmobo V catheter used in this study is an advanced thermodilution catheter. This catheter can continuously measure the change in RVEF and RV preload. It also concomitantly measures the CI, SvO$_2$, RAP, PAP and PCWP which are important hemodynamic variables reflecting ventricular function. Another advantage of CCOmbo V catheter is that it can be used during all

the perioperative period, not just during operation. However, the pulmonary artery catheter is a non-specific tool to assess RV function and the most important disadvantage of this catheter is that RVEF is a load-dependent variable and the RV volume is calculated based on RVEF. The change in RVEF reflects the change in RV function but does not mean the change in intrinsic RV contractility. Another limitation of this catheter is that it dose not provide real-time information regarding changes in RVEF and RV volume. In this study, recording of variables during anastomosis was performed at 5 min after application of tissue stabilizer and several results (CI, SVI, RVEF, RVEDVI, RVESVI) were average value displayed on monitor. Therefore, the reported values might not correspond to the hemodynamic status at that time when measured. Time regarded for one coronary anastomosis was varied between 5 and 15 min according to the position and patients, therefore measurement at 5 min after application of stabilizer was selected to include all the cases. Until the completion of application of stabilizer, about 5 min were needed for the positioning of the heart and preparation of a vessel for anastomosis. Therefore, considering this time interval, time to measurement took about 10 min from beginning of heart positioning. Measurements at 5 min might be corresponding more closely to the average hemodynamic status during displacement, compression and anastomosis for each coronary artery considering average values displayed in the Vigilance monitor® of measurement during the past 6–9 min. The other limitation of this catheter is that tricuspid regurgitation and rhythm disturbance reduce the accuracy of measured variables. In all patients recruited for this study, TEE was observed throughout the entire procedure and significant TR, which was newly developed or aggravated, was hardly observed in this investigation. Rhythm disturbance lasting >1 min did not develop.

In the current study, we observed that RVEF decreased significantly during the OM anastomosis whereas it decreased insignificantly during the LAD and RCA anastomosis and there was no significant change in the RVEDVI during all coronary anastomoses. Considering the fact that when stabilizer was placed for the OM anastomosis, although the LV was compressed, the RV was more compressed, thus causing a disturbance in diastolic expansion [4], there was a possibility that decrease in RVEF was not attributed to impaired contractility or ischemia, but is secondary to direct compression with reduced stroke volume. However, the development of ischemia during coronary anastomosis, especially during OM anastomosis, which was performed without the use of intracoronary shunt, could not be completely excluded. The ischemia could be detected by TEE and ECG in practice. Indeed, TEE and ECG with ST-segment analysis were continuously monitored throughout the entire procedures and newly developed significant wall motion abnormalities or progressive ST changes were not observed. There might be, if

any, less significant effects of ischemia on the results of this study than that of mechanical compression and distortion. In this study, the RAP significantly increased compared to the control but preload of the RV (RVEDVI) maintained constant values at the time of OM anastomosis. The afterload of RV, PAP and PVRI significantly increased during OM anastomosis and it seemed to contribute to the decrease in RVEF. And also, decrease in the CI during OM anastomosis compared to control, the LAD and RCA anastomosis might also affect RV function [16–20] during OM anastomosis. However, we were unable to distinguish whether the initial decrease in RV function affected hemodynamic changes or a decrease in the CI caused RV dysfunction. During the LAD anastomosis, the CI was maintained and the RVEF did not decrease in spite of increase in the PAP and PVRI. Although the MAP and HR were maintained with Trendelenburg position, volume loading and vasopressor during anastomosis, those measures were not guaranteed to protect RV function during anastomosis, especially in the OM. Further study on whether the RV function during OM anastomosis can be maintained at the reliable value when the CI is maintained with another pharmacological or mechanical assistance, is needed. Although increase in the RAP and PAP are in accordance with other studies, these hemodynamic variables have a close relationship with the patient's position, which varies according to the surgical procedures. The degree of head down and side tilting during anastomosis were not tightly controlled, and the changes of these variables might not correctly reflect the change in the patient's hemodynamic status, which was a limitation of this study. And also, the number of patients included in this study was relatively small and it might substantially influence on the result.

In conclusion, when RV function was evaluated with CCOmbo V catheter, reduced RVEF with concomitant increase in afterload and decrease in CO were observed during anastomosis of the OM, though coronary artery anastomosis could be performed without serious derangement of vital signs in patients undergoing OPCAB. Thus, appropriate monitoring the RV in addition to LV function and efforts to maintain the CO are needed for the management of patients during OPCAB.

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