Pro: Continuous Cardiac Output and SvO_2 Monitoring Should Be Routine During Off-Pump Coronary Artery Bypass Graft Surgery

Ronit Lavi, MD, and Davy Cheng, MD, MSc, FRCPC, FCAHS

OFF-PUMP CORONARY ARTERY bypass surgery (OPCAB) has gained popularity in recent years as a technique of surgical myocardial revascularization. In the United States, about 20% to 25% of coronary artery bypass graft (CABG) surgeries are performed off-pump.[1] The clinical advantages of OPCAB are the avoidance of the cross-clamping of the aorta and the reduced systemic inflammatory effects of cardiopulmonary bypass (CPB), which have been shown to reduce postoperative morbidity in low-risk and high-risk patients as well as in comparison with patients who underwent percutaneous coronary intervention.[2-4] Nevertheless, abrupt manipulations of the heart during OPCAB surgery presents unique challenges to the cardiac anesthesiologist.[5]

The main anesthetic goal during an OPCAB procedure is to maintain cardiac output, which might be compromised by anesthesia and by surgical manipulations including restraint, compression, and displacement of the heart as well as by myocardial ischemia and reperfusion injury. Hence, these procedures mandate scrupulous hemodynamic monitoring both during and after the surgical procedure.[6] Investigators have tried to develop the ideal monitor of cardiac output (CO) measurement. Such a monitor would be minimally invasive, accurate, and reproducible and would compare favorably with CO values derived from thermodilution (TDCO) with a pulmonary artery catheter (PAC), which is considered the "gold standard" when other devices are compared. Furthermore, such a monitor would also need to be reliable under many different physiologic and pathophysiologic conditions when dynamic changes in intravascular volume status and peripheral resistance are occurring. The ideal CO monitor would need to provide continuous monitoring, to have the ability to assess the efficacy of therapeutic interventions such as hemodynamic response to administration of fluids and vasopressor drugs, and to provide accurate CO measurement in a timely manner. At present, no device meets all of these criteria. However, partial carbon dioxide rebreathing systems, pulse contour analysis, thoracic electrical bioimpedance, esophageal Doppler, and indicator dilution methods (lithium dilution) are being evaluated for this purpose.[7]

HEMODYNAMIC CHANGES DURING OPCAB SURGERY

During OPCAB surgery, optimal hemodynamic stability should be maintained during surgical manipulations, stabilization of the heart, coronary artery clamping, and anastomosis. This implies promptly detecting and treating systemic hypotension, arrhythmias, myocardial ischemia, abrupt compression of the heart walls, and especially low CO, which may lead to end-organ injury such as renal failure and neurologic deficits.[8]

During beating-heart surgery, the surgeon obtains adequate exposure of the anastomosis site with restrained cardiac motion. For this purpose, the heart will be displaced and the ventricular wall compressed. Thus, the anesthesiologist must be prepared to handle severe hemodynamic alterations, transient deterioration of cardiac pump function, and acute intraoperative myocardial ischemia. Furthermore, the team must be prepared for conversion to CPB in case of sustained ventricular fibrillation or cardiovascular collapse.[9] By using suction to take hold of a relatively small epicardial area, the stabilization system facilitates coronary artery surgery on the beating heart. This suction fixation method helps to expose all sides of the heart and may be used through any access point.[10]

Despite the availability of cardiac stabilizers, the continuous motion of the heart and the potential for associated hemodynamic derangements during manipulation and elevation of the heart continue to be concerns.[11] The largest hemodynamic changes appear during the positioning of the heart and the stabilizer.[12]

Surgical access to the left anterior descending coronary artery is feasible through a median sternotomy. However, the positioning for the left anterior descending artery causes increases of the right atrial pressure and right ventricular end-diastolic pressure. Although left atrial pressure and left ventricular end-diastolic pressures are also elevated, the pressures from the right heart are much more increased probably because of right ventricular compression. When the stabilizer is placed

From the Department of Anesthesia and Perioperative Medicine, London Health Science Centre, University of Western Ontario, London, Ontario, Canada.

Address reprint requests to Davy Cheng, MD, MSc, FRCPC, FCAHS, Department of Anesthesia and Perioperative Medicine, London Health Sciences Centre and St Joseph Health Care, University of Western Ontario, University Hospital-LHSC, 339 Windermere Road, C3-172, London, ON N6A 5A5, Canada. E-mail: davy.cheng@lhsc.on.ca

1053-0770/2606-0027$36.00/0

http://dx.doi.org/10.1053/j.jvca.2009.06.014

Key words: cardiac output monitoring, off-pump coronary artery bypass surgery, SvO_2 monitoring

on the left ventricle, it is compressed directly, whereas the right ventricle is more affected by the compression because its wall is thinner, its pressure is relatively low, and it is pressed against the pericardial cradle. Therefore, even though the left ventricle is compressed, the effect on the right ventricle is greater than that on the left.[13]

For grafting of the circumflex artery and posterior descending artery branches through a sternotomy, an anterior displacement of the beating heart needs to occur. In order to explore the posterior and lateral walls, the heart must be lifted and tilted out of the pericardium.[14] During this time, all pressures in the 4 chambers (right and left atrial pressures and right and left ventricular end-diastolic pressures) are elevated, whereas mean arterial pressure, cardiac output, and stroke volume are decreased. When the stabilizer is placed for circumflex anastomosis, the left ventricle and even more the right ventricle are compressed and impair diastolic distention. Displacement of the heart to a vertical position for anastomosis to the posterior descending and marginal branches of the right coronary artery causes the greatest hemodynamic compromise and distorts the annuluses of the mitral and tricuspid valves as the intracardiac structures are kinked at the atrioventricular groove. This could result in significant modification of these valve annuluses and significant valvular regurgitation.[13]

INTRAOPERATIVE MYOCARDIAL ISCHEMIA

During OPCAB surgery, coronary artery cross-clamping is performed to ensure bloodless anastomotic conditions. This results in brief periods of myocardial ischemia that may manifest by ST-segment elevation or depression and new regional wall motion abnormalities (RWMAs) on echocardiographic imaging.[15] Severe ischemia during clamping of a nonocclusive right coronary artery can result in dangerous arrhythmias such as complete atrioventricular block attributable to the interruption of the blood flow to the atrioventricular node artery.[16] In order to reduce the consequences of coronary blood flow interruption during OPCAB surgery, several pharmacologic techniques to improve myocardial oxygen balance and perfusion pressures are applied. Other options are ischemic and pharmacologic preconditioning, pharmacologic prophylaxis, and surgical shunting.[9] Hence, meticulous continuous CO monitoring during an OPCAB procedure is recommended to manage the constant changes in heart function and myocardial ischemia during the revascularization procedure. Emergent conversion of OPCAB to CPB carries major morbidity and mortality. The indicators for CPB conversion during OPCAB surgery include persistence of the following >15 min: cardiac index (CI) <1.5 L/min/m^2, SvO^2 <60%, mean arterial pressure <50 mmHg, ST elevation >2 mV, significant new RWMA, and sustained malignant arrhythmias.[17] Continuous CO monitoring could improve the timing and refine the criteria for CPB conversion with better sensitivity in monitoring critical myocardial oxygen supply and demand during OPCAB surgery.

CONTINUOUS CO AND SvO_2 MONITORING: VALIDITY

PAC intermittent TDCO currently is considered the gold standard for CO measurement in the operating room. However, because of the rapid hemodynamic changes occurring in OPCAB procedure, cardiovascular monitoring and accurate CO/CI measurements are advisable during this procedure and intermittent TDCO may not detect rapid and transient hemodynamic changes. Hence, myocardial oxygen imbalance and deterioration may not be detected early enough. This makes CI measured with the pulmonary artery catheter incomplete for OPCAB surgery. Continuous CO and SvO_2 monitoring would be ideal to assess cardiac performance and to guide medical interventions during an OPCAB procedure.[12]

Mixed Venous Oxygen Saturation Monitoring and Cardiac Surgery

SvO_2 is a commonly used surrogate monitor of CO in this clinical setting. SvO_2 commonly is monitored during OPCAB surgery and changes may correlate with the changes in CO. However, previous studies have found that SvO_2 readings may be delayed by several minutes and may only weakly correlate with decreased CO and increased mean pulmonary artery pressure in this patient population.[18] A pulmonary artery catheter equipped with fiberoptic oximetry can be used to monitor continuous SvO_2 in adult patients during and after cardiac surgery.[19] A current version of the continuous central venous mixed oxygen saturation assessment, the CeVOX device (Pulsion Medical Systems, Munich, Germany), might not be the tool to replace mixed venous oxygen saturation determined by co-oximetry. Although sensitivity and specificity of saturation measured by the CeVOX device to predict substantial changes in SvO_2 were acceptable during surgery, they failed to do so in the immediate postoperative period during the stay in the intensive care unit.[20]

Continuous monitoring of CI and SvO_2 can be performed with one monitoring device (PAC, Swan-Ganz CCOmbo CCO/SvO_2; Edwards Lifesciences LLC, Irvine, CA). This device includes a PAC that is inserted through the right internal jugular vein and connected to a dedicated analysis system (Vigilance, Edwards Lifesciences LLC).[21] Although this monitor may be promising to evaluate CO and SvO_2 during OPCAB surgery, it needs further validation in view of the fact that continuous and bolus CO determinations were not found to be interchangeable in the first 6 hours after CPB.[22]

Continuous CO can be monitored by another device that is inserted using a right internal jugular approach ([CCO]/SvO_2/CEDV-VIP, Edwards CCOmbo Catheter; Baxter Healthcare, Deerfield, IL). When studying this device, the changes in SvO_2 correlated with the changes in TDCO, but SvO_2 was not a completely accurate, real-time indicator of the changes in TDCO in the setting of cardiac manipulation and stabilization during OPCAB surgery.[5]

Continuous CO Monitoring and Cardiac Surgery

Several methods have been evaluated over the years for the accuracy of CO measurement. Pulmonary artery TDCO is the clinical gold standard for CO determination, and newer developed CO monitoring techniques are compared with it for accuracy.[23-25]

Other techniques under investigation for continuous CO measurement are lithium indicator dilution, pulse contour analysis, indocyanine green indicator dilution, partial CO_2 rebreathing systems, Doppler ultrasound, TEE, and impedance cardi-