Anaesthesia for Off-Pump Coronary Artery Surgery

Sanjula Virmani, DA, DNB, Deepak K. Tempe, MD
Department of Anaesthesiology & Intensive Care, G.B. Pant Hospital, New Delhi

Off-pump coronary artery bypass (OPCAB) is a technique of performing coronary anastomosis on a beating heart without instituting cardiopulmonary bypass (CPB). Coronary stabilizers (CS) are used for local cardiac wall immobilization and access to the heart can be achieved by a lateral, anterolateral, subxyphoidal or midsternal incision. With median sternotomy and use of CS, all sides of the heart can be reached, thus enabling triple vessel revascularization on the beating heart. Therefore, techniques such as minimally invasive direct coronary artery bypass grafting (MIDCAB), which allows only single or two vessel surgery have slowly phased out.

The current era is of evidence based medicine and OPCAB has now become an established procedure. This has been mainly due to avoidance of complications related to CPB, including systemic inflammatory response, coagulopathies, platelet dysfunction, fibrinolysis, consumption of clotting factors, neurological injury, renal impairment, and atrial fibrillation.[1-9] In addition, evidence from randomized controlled trials suggests that, compared to conventional coronary artery bypass grafting (CABG), OPCAB has similar graft patency as well as measure of quality of life,[1] and also appears to produce better results than conventional surgery in high risk patient population, elderly patients and those with compromised cardiac function or coagulation disorders.[10]

Operation Technique

The development of CS has been the key to the success of OPCAB. This allows effective local cardiac wall stabilisation to permit suturing at the anastomotic site. The Octopus stabilisation system (Medtronic Inc, Minneapolis, USA, Figure 1) is one of the commonly used CSs. It consists of two paddles with suction domes that are placed at the anastomotic site. Due to suction, the operating site is lifted and immobilized. For accessing the lateral wall, a suction cup or starfish is used that lifts the apex by applying suction. A saline and/ or carbondioxide irrigation system is also used to maintain a clear surgical field i.e. to blow away the blood from the anastomotic site.

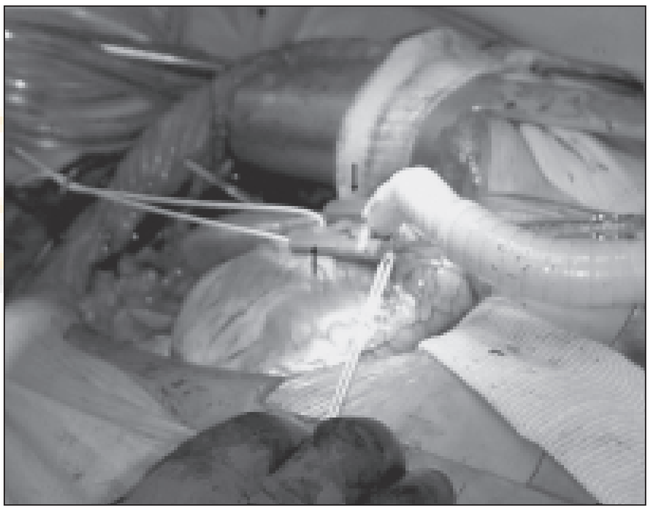


Fig. 1. Intraoperative photograph showing octopus tissue stabiliser (Medtronic Inc, Minneapolis, USA) placed over left anterior descending artery. Arrows showing the two paddles with suction domes immobilising the anastomotic site.

Bleeding from the arteriotomy site during anastomosis is prevented by the use of intracoronary shunts. These maintain coronary perfusion, minimize ischaemia and reduce bleeding during suturing. A double limb shunt is placed after arteriotomy into proximal and distal ends of the open coronary artery. The use of shunts has eliminated an earlier technique of occluding the coronary artery proximal to the arteriotomy site during suturing. Alternatively, the technique of ischaemic preconditioning can be used. A brief period of coronary occlusion (2, 3 or 5 min)

Address for correspondence: Dr. Deepak K. Tempe, Director-Professor and Head, Department of Anaesthesiology & Intensive Care G.B. Pant Hospital, New Delhi – 110 002, INDIA.
Phone/Fax: 91-11-23232877
E-mail: tempedeepak@hotmail.com

Annals of Cardiac Anaesthesia 2007; 10: 65-71

Key words: OPCAB, Anaesthesia, Coronary artery disease

followed by a similar time for reperfusion in the target vessel is carried out. However, use of shunts is a more elegant technique and use of ischaemic preconditioning is on the decline.

Cardiac displacement permits exposure of posterior, lateral and inferior coronary arteries. This necessitates frequent and multiple manipulation of the heart in order to obtain optimum exposure of the targeted vessel.

Anaesthetic Technique

The anaesthesiologist is integral to the success of OPCAB surgery. He is required to maintain stable haemodynamics and rhythm in an environment that changes rapidly because of regional ischaemia and cardiac manipulation. He should be aware of when the heart is being displaced, when a coronary artery is occluded and when a shunt has been inserted or removed. Also, he should keep a close vigil on ST segment or rhythm disturbances and judiciously use inotropes or vasopressors.

The anaesthetic goals of management of OPCAB surgery include:

1. The primary goal, like any other coronary artery surgery, is to provide safe induction and maintenance of anaesthesia using a technique that minimises myocardial ischaemia.
2. The maintenance of haemodynamic stability throughout surgery, but especially during cardiac manipulation.
3. Appropriate plan for postoperative care, which generally includes early extubation and ambulation along with excellent postoperative analgesia.

Conventional techniques using opioids (morphine, fentanyl, sufentanil) in association with a combination of volatile agents and propofol are frequently used. However, some institutions prefer to use general anaesthesia combined with intrathecal or thoracic epidural techniques. It has been shown that thoracic epidural anaesthesia dilates epicardial arteries and decreases myocardial oxygen demand as well as provides good postoperative analgesia.[11] However, studies have not shown improved outcome in terms of myocardial performance using epidural techniques.[12] Anaesthetic techniques achieving extubation in the operating room have not demonstrated any additional benefit or to be cost effective.[13]

Cardiac manipulation, intraoperative myocardial ischaemia and resultant changes in haemodynamics

First, to obtain an adequate exposure of the anastomotic site with restrained cardiac motion, the heart is displaced, sometimes lifted out of the pericardial cradle i.e. enucleated by pericardial stitches, using gauze pads and /or suction stabilizer devices.[10] This may lead to significant increase in the atrial size and pressures, as the atria are then situated below the corresponding ventricles.[14] This can cause a marked decrease in the cardiac output (CO) and mixed venous oxygen saturation (SVO_2). The atrial filling pressures are increased much more than the corresponding ventricular end-diastolic pressures[14] and must be maintained at a higher than normal level to maintain the cardiac filling.[15] At times the right ventricle (RV) may be squeezed between the pericardium and the bulky left ventricle (LV) and compressed under the right hemisternum resulting in severe haemodynamic compromise.

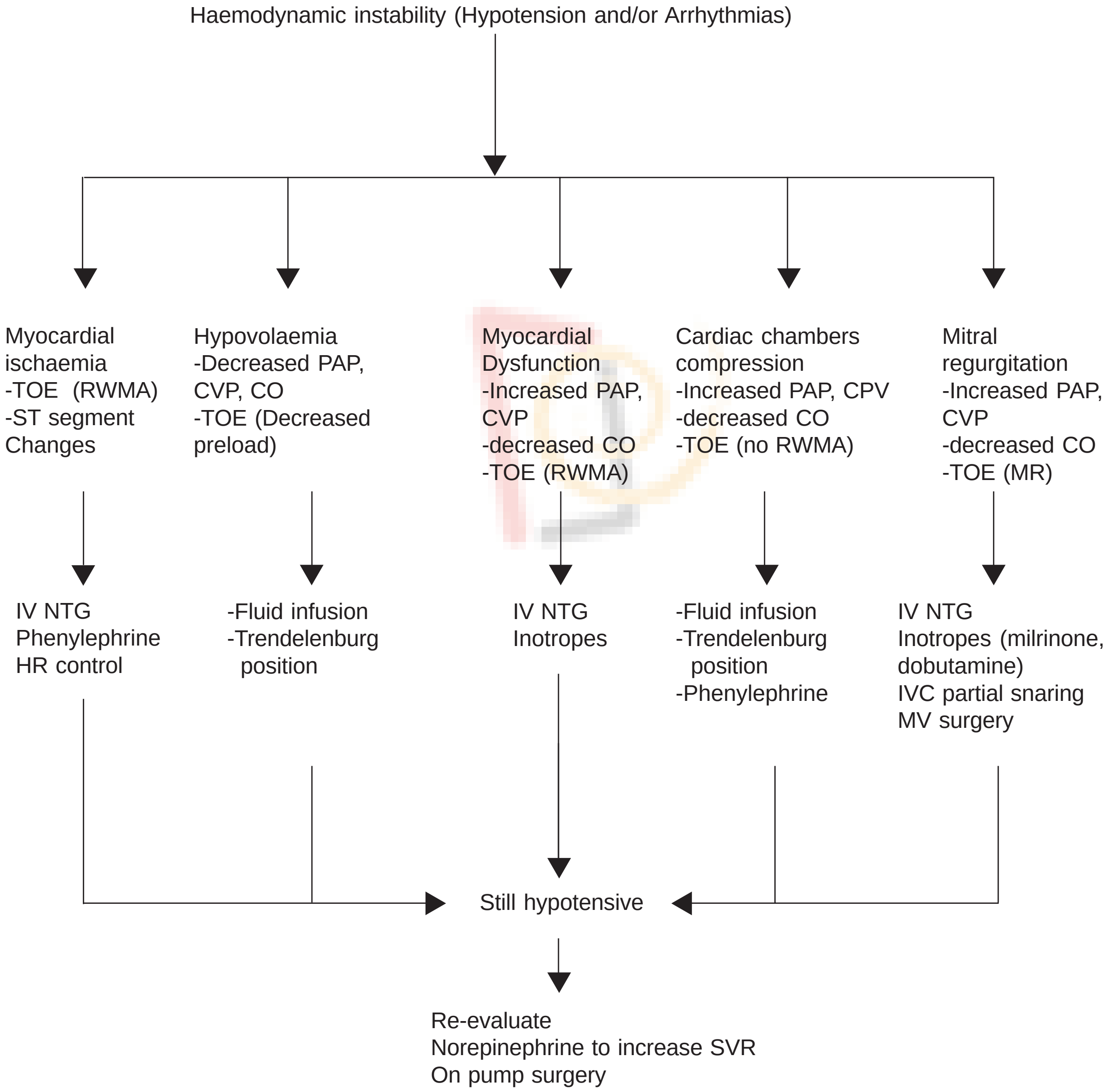
Second, the CS is used to immobilise the area of anastomosis. It restricts the local motion and decreases ventricular dimensions.[10] Compression on the anterior and lateral walls has more serious haemodynamic consequences than compression on the posterior wall because the anterior and lateral walls have wider displacement in systole and diastole than the septal and postero-inferior walls.

Third, the vertical position of the heart produces distortion of the mitral and tricuspid annuli and significant regurgitation may occur.[10] The sudden appearance of large 'v' waves (>30 mm Hg) on the pulmonary artery catheter (PAC) readings without signs of LV failure illustrates the same mechanism. Abnormal valves become more distorted.

Intraoperative myocardial ischaemia may result during anastomosis. Although, use of intracoronary shunt is expected to maintain distal coronary flow, this may be compromised due to presence of narrowing of the native coronary artery as well as associated haemodynamic compromise. The ischaemia may manifest as ST elevation and new regional wall motion abnormality (RWMA). Occlusion of highly collateralised vessels produces less ischaemia than occlusion of terminal vessels.[16] Severe ischaemia during clamping of a non-occlusive right coronary artery (RCA) can result in dangerous arrhythmias such as complete atrioventricular (AV) block resulting from interruption of blood flow to the AV node artery.

Manoeuvres to manage haemodynamic changes (Figure 2)

Speed of heart positioning has a more dramatic effect than the displacement itself. Therefore, the positioning should be progressive with rigorous adjustment.[15] The severity of haemodynamic



TOE: transoesophageal echocardiography, NTG: nitroglycerin, PAP: pulmonary artery pressure, CVP: central venous pressure, CO: cardiac output, RWMA: regional wall motion abnormality, MR: mitral regurgitation, MV: mitral valve, IVC: inferior vena cava, SVR: systemic vascular resistance, HR: heart rate

Fig. 2. Schematic diagram of haemodynamic management during Off-pump coronary artery bypass surgery.

changes is linked to the site of anastomosis, being more pronounced during circumflex artery grafting when compared to the RCA or left anterior descending (LAD) artery. This is because the lateral wall contraction contributes more to stroke volume than does the posterior wall and also because tilting is more accentuated than for LAD grafting.[14, 17] To improve surgical access to the lateral and posterior walls, the operating table can be tilted to the right or given the Trendelenburg position respectively. The patient frequently becomes hypotensive when the heart is tilted into a new position. Myocardial preload can be increased by leg elevation and by administration of fluids. Ringer's lactate and colloid can be transfused as and when needed. Also, Trendelenburg manoeuvre assists in re-establishing the circulatory status and coronary blood flow at the expense of a further increase in the RV and LV preload, and increased heart rate (HR).[18] Alternatively, leg elevation improves preload more efficiently resulting in improved CO. Furthermore, it is recommended to start the sequential anastomosis with the most severely stenotic or occluded vessel, as highly collateralized vessels produce less ischaemia on cross clamping.[16, 19] Some other methods that are used include, opening the right pleura when the RV is seen to be squeezed between the LV and right hemisternum, and placing the distal anastomosis of RCA beyond its bifurcation to avoid complete AV block. The anaesthesiologist must collaborate with the surgeon to allow the patient adequate time to recover in between grafts. It may be necessary in a few sick patients to insert intra-aortic balloon pump catheter preoperatively so that the patient can better tolerate the OPCAB procedure.

Managing myocardial ischaemia (Table 1)

To reduce the myocardial ischaemia, it is imperative to improve myocardial oxygen balance by reducing the oxygen consumption through a decrease in HR and contractility as well as decreasing the occurrence of arrhythmias. The following pharmacological prophylaxis can be used:

I. Perioperative use of β-blocking agents such as esmolol or metoprolol has been shown to be the most effective measure.[20]

II. Calcium antagonists such as diltiazem can be administered as infusion at 0.1 mg/Kg/hour. In addition to reducing AV conduction and HR, calcium antagonists also induce vasodilatation in arterial conduits.[21]

III. Magnesium ions up to 20 mmol/L in the form of chloride or sulfate produce arterial vasodilatation and also decrease the incidence of atrial tachycardia.[22]

IV. The K^+ concentration in blood should be maintained at > 4.5 meq/L

Table 1. Showing methods of decreasing myocardial ischaemia

1. Increase oxygen delivery
Nitrates
Adequate MAP
Intra-coronary shunts
2. Decrease oxygen consumption
Decrease HR and contractility
β-blockers
Calcium blockers
3. Increase tolerance to ischaemia (preconditioning)
Mechanical
Pharmacological
Isoflurane
Sevoflurane
4. Monitoring
ECG: ST segment
Invasive arterial pressure
Pulmonary artery pressure
Transoesophageal echocardiography

MAP: mean arterial pressure, HR: heart rate

The anaesthesiologist should be aware that tachycardia in the context of coronary artery occlusion is often a manifestation of ischaemia itself and the response to a low CO. In such a situation, decreasing the HR will only further decrease the CO and may lead to haemodynamic instability and / or organ injury. With the use of CS, a low HR (< 50 beats/min) is no longer advocated and a HR of 70-80 beats/min is accepted.[11]

Myocardial oxygen supply can be increased by nitrates, maintaining an adequate coronary perfusion pressure and intracoronary shunts. Nitroglycerin (NTG) has been used to reduce pulmonary arterial pressure,[23] to treat active ischaemia[24] or as a hypothetical prophylactic measure. However, the NTG induced decrease in preload can be detrimental, when higher filling pressures are needed to ensure optimal ventricular filling.

Aortic diastolic pressure is the driving force for coronary perfusion and clinically its closest measurement is mean arterial pressure (MAP) measured in radial or femoral artery.[25,26] Maintaining an adequate MAP is the most important manoeuvre as far as decreasing myocardial ischaemia is concerned. The literature suggests that an accepted minimal MAP ranges from 60 mm Hg[27,7,15] to 80 mm Hg.[24] A MAP of ≥70 mm Hg is safe and may be achieved with the help of positioning, fluids, vasopressors like phenylephrine or norepinephrine and inotropes such as milrinone and dobutamine.

Intracoronary shunts: The surgeon can insert a small shunt into the coronary artery to provide distal perfusion, a bloodless field and a guide for the placement of anastomotic sutures.[28]

During positioning, CO is often decreased to low levels but, is generally accepted as long as it meets the demand of the organs as shown by a SVO_2 >60%, the MAP is 70 mm Hg, and without LV dilatation as monitored by transoesophageal echocardiography (TOE).

Ischaemic preconditioning though on the decline, can also produce improvement in the tolerance to ischaemia and can be used as a technique of myocardial protection.[29] In addition to coronary occlusion followed by a period of reperfusion, preconditioning may also be induced pharmacologically using isoflurane or sevoflurane, which act by activation of a preconditioning like mechanism when administered at 2 minimum alveolar concentration at least 30 minutes before ischaemic insult.[30]

Monitoring:

a. Five Lead surface electrocardiography (ECG) with ST-segment analysis is routine. However, manipulation of the heart modifies the relationship to the surface electrodes,[15] thereby the shape of tracing and amplitude of the signal gets altered. Therefore, the accuracy of ECG monitoring may be reduced.
b. Invasive arterial pressure monitoring is mandatory.
c. Pulmonary artery catheter: Right atrial and pulmonary artery wedge pressures must be interpreted taking into account the changes produced due to heart manipulation. SVO_2 is useful to evaluate global tissue oxygenation and a decrease below 50% has been associated with the development of bowel ischaemia.[31] It is essential that the tip of the PAC be in the mainstream of a large pulmonary artery, as it may advance during handling of the heart.
d. TOE: The performance of TOE may be limited considerably because of air surrounding the heart, use of pericardial stitches and swabs during manipulation. However, it is still a very useful device for evaluation of ventricular function, diagnosing new RWMA and post-anastomosis regional contractility.
e. Monitoring nasopharyngeal temperature is necessary in order to detect and correct hypothermia.

Summary of the anaesthetic technique:

In comparison with conventional CPB, changes in the anaesthetic technique with OPCAB are as follows.

- The trend towards shorter ICU and hospital length of stay has led to the adaptation of fast track management with early extubation (i.e. between 1 and 4 hours after operation). This is easily possible with OPCAB, as one of the major reasons for extended postoperative ventilation, i.e. CPB, is avoided. Therefore, the dosage of opioids should be appropriately reduced. For instance, induction dose of morphine can be decreased to 0.3 to 0.5 mg/Kg and that of fentanyl to 5 to 10 μg/Kg.
- CPB pump is set-up but not primed. However, the perfusion team remains immediately available.
- Hypothermia is avoided by all possible means such as administering warm fluids, using a heat exchanger on the fresh gas flow, warming mattress, maintaining the ambient temperature of 24°C.[11,19]
- General anaesthesia may be combined with intrathecal (sufentanil-morphine or bupivacaine),[32] or thoracic epidural (bupivacaine) analgesia.[11]
- Beating heart surgery requires less

heparinization (ACT is maintained at 250-300 seconds, with 1.5 mg/Kg body weight of heparin).

- Volatile anaesthetics such as isoflurane[33] and sevoflurane[34] and opioids[35] have been shown to induce significant pharmacological preconditioning. Therefore, these should be a part of anaesthetic technique.
- Sometimes, there can be substantial blood loss during the distal anastomosis. The blood conservation methods include, acute normovolaemic haemodilution, retransfusion of blood collected from the operative field using filters or cell washing devices or a combination of these.
- Heparin reversal with protamine is optional.
- OPCAB should be converted to conventional CABG with CPB, if there is difficulty in maintaining a MAP of > 50 mm Hg, sustained malignant arrhythmias and ST elevation (>2 mV).
- Heparin reversal with protamine is optional.

References

1. Raja SG. Pump or no pump for coronary artery bypass. Current best available evidence. *Texas Heart Institute J* 2005, 32: 489-501
2. Larmann J, Theilmeier G.I. Inflammatory response to cardiac surgery: cardiopulmonary response versus non-cardiopulmonary bypass surgery. *Bes Pract Res Clin Anaesthesiol* 2004; 18: 425-38
3. Ascione R, Williams S, Lloyd CT, et al. Reduced postoperative blood loss and transfusion requirement after beating-heart coronary operations: a prospective randomized study. *J Thorac Cardiovasc Surg* 2001; 121; 689-96
4. Ereth MH, Nuttal GA, Oliver WC Jr., et al. Temperature and duration of cardiopulmonary bypass influence transfusion requirements. *J Clin Anesth* 1998; 10: 588-92
5. Murkin JM. Attenuation of neurologic injury during cardiac surgery. *Ann Thorac Surg* 2001; 72: S1 838-44
6. Taggart DP, Westaby S. Neurological and cognitive disorder after coronary artery bypass grafting. *Curr Opin Cardiol*; 2001; 16: 271-76
7. Loef BG, Epema AH, Navis G, et al. Off-pump coronary revascularization attenuates renal damage compared with on-pump revascularization. *Chest* 2002; 121: 1190-4
8. Hashimoto K, Miyamoto H, Suzuki K, et al. Evidence of organ damage after cardiopulmonary bypass. The role of elastase and vasoactive mediators. *J Thorac Cardiovasc Surg* 1992; 104: 666-73
9. Angelini GD, Taylor FC, Reeves BC, et al. Early and midterm outcome after off-pump and on-pump surgery in Beating Heart Against Cardioplegic Arrest Studies (BHACAS 1 and 2): a pooled analysis of two randomized controlled trials. *Lancet* 2002; 359: 1194-99
10. Chassot PG, vander Linden, Zaugg M, et al. Off-pump coronary artery bypass surgery: physiology and anaesthetic management. *Br J Anaesth* 2004; 92: 400-13
11. Nierich AP, Diephuis J, Jansen EW, et al. Embracing the heart: perioperative management of patients undergoing off-pump coronary artery bypass grafting using the octopus tissue stabilizer. *J Cardiothorac Vasc Anesth* 2002; 16: 139-43
12. Scott NB, Turfrey DJ, Ray DA, et al. A prospective randomized study of the potential benefits of thoracic epidural anesthesia and analgesia in patients undergoing coronary artery bypass grafting. *Anesth Analg* 2001; 93: 528-35
13. Montes FR, Sanchez SI, Giraldo JG, et al. The lack of benefit of tracheal extubation in the operating room after coronary artery bypass surgery. *Anesth Analg* 2000; 91: 776-80
14. Mathison M, Edgerton JR, Horswell JL, et al. Analysis of hemodynamic changes during beating heart surgical procedures. *Ann Thorac Surg* 2000; 70: 1355-60
15. Nierich AP, Diephuis J, Jansen EW, et al. Heart displacement during off-pump CABG: how well is it tolerated? *Ann Thorac Surg* 2000; 70: 466-472
16. Koh TW, Carr-White GS, DeSouza AC, et al. Effect of coronary occlusion on left ventricular function with and without collateral supply during beating heart coronary artery surgery. *Heart* 1999; 81: 285-91
17. Mueller XM, Chassot PG, Zhou J, et al. Hemodynamics optimization during off-pump coronary artery bypass: the 'no compression' technique. *Eur J Cardiothorac Surg* 2002; 22: 249-54
18. Grundeman PF, Borst C, van Herwaarclen JA, et al. Vertical displacement of the beating heart by the octopus tissue stabilizer: influence on coronary flow. *Ann Thorac Surg* 1998; 65: 1348-52
19. Cartier R, Brann S, Dagenais F, et al. Systematic off-pump coronary artery revascularization in multivessel disease: experience of three hundred cases. *J Thorac Cardiovasc Surg* 2000; 119: 221-29
20. Ferguson TB Jr, Coombs LP, Peterson ED. Preoperative β blocker use and mortality and morbidity following CABG surgery in North America. *JAMA* 2002; 287: 2221-27
21. Seitelberger R, Hannes W, Gleichauf M, et al. Effects of diltiazem on perioperative ischemia, arrhythmias and myocardial function in patients undergoing elective coronary bypass grafting. *J Thorac Cardiovasc Surg* 1994; 107: 811-21
22. Maslow AD, Regan MM, Heindle S, et al. Postoperative atrial tachyarrhythmias in patients undergoing coronary artery bypass graft surgery without cardiopulmonary bypass: a role for intraoperative magnesium supplementation. *J Cardiothorac Vasc Anesth* 2000; 14: 524-30

23. Bouchard D, Cartier R. Off-pump revascularization of multivessel coronary artery disease has a decreased myocardial infarction rate. *Eur J Cardiothorac Surg* 1998; 14: (Suppl 1): S 20-24
24. Do QB, Goyer C, Chavanon O, et al. Hemodynamic changes during of-pump CABG surgery. *Eur J Cardiothorac Surg* 2002; 2: 385-90
25. O'Rourke MF, Yaginuma T, Avolio AP. Physiological and pathophysiological implications of ventricular /vascular coupling. *Ann Biomed Eng* 1984; 12: 119-34
26. Rowell LB, Brengelmann GL, Blackmon JR, et al. Disparities between aortic and peripheral pulse pressures induced by upright exercise and vasomotor changes in man. *Circulation* 1968; 37: 954-64
27. Ascione R, Lloyd CT, Gomes WJ, et al. Beating versus arrested heart revascularization: evaluation of myocardial function in a prospective randomized study. *Eur J Cardiothorac Surg* 1999; 15: 685-90
28. Yeatman M, Caputo M, Narayan P, et al. Intracoronary shunts reduce transient intraoperative myocardial dysfunction during off-pump coronary operations. *Ann Thorac Surg* 2002; 73: 1411-17
29. Laurikka J, Wu ZK, Lisalo P, et al. Regional ischemic preconditioning enhances myocardial performance in off-pump coronary artery bypass grafting. *Chest* 2002; 121: 1183-89
30. Zaugg M, Lucchinetti E, Spahn DR, et al. Volatile anesthetics mimic cardiac preconditioning by priming the activation of mitochondrial K (ATP) channels via multiple signaling pathways. *Anesthesiology* 2002; 97: 4-14
31. Bams JL, Mariani MA, Groeneveld AB. Predicting outcome after cardiac surgery: comparison of global haemodynamic and tonometric variables. *Br J Anaesth* 1999; 82: 33-37
32. Bettex DA, Schmidlin D, Chassot PG, Schmid ERl. Intrathecal sufentanil-morphine shortens the duration of intubation and improves analgesia in fast track cardiac surgery. *Can J Anaesth* 2002; 9: 711-17
33. Belhomme D, Peynet J, Louzy M, et al. Evidence for preconditioning by isoflurane in coronary artery bypass graft surgery. *Circulation* 1999; 100: 11340-44
34. Julier K, daSilva R, Garcia C, et al. Preconditioning by sevoflurane decreases biochemical markers for myocardial and renal dysfunction in coronary artery bypass graft surgery: a double blinded, placebo controlled, multicentre study. *Anesthesiology* 2003; 98: 1315-27
35. De Hert SG. Anesthetic preconditioning: how important is it in today's cardiac anesthesia? *J Cardiothorac Vasc Anesth* 2006; 20: 473-76