Seminars in Cardiothoracic and Vascular Anesthesia
2015, Vol. 19(2) 163–168

DOI: 10.1177/1089253215584919
scv.sagepub.com
SAGE

Early Extubation and Fast-Track Management of Off-Pump Cardiac Patients in the Intensive Care Unit

Daniel Bainbridge, MD, FRCPC[1] and Davy C. Cheng, MD, MSc, FRCPC[1]

Abstract

Off-pump surgery was the original approach to treating patients with cardiac disease in the era before cardiopulmonary bypass. With the advent and refinement of cardiopulmonary bypass, the use of this technique fell out of favor and was quickly surpassed by on-pump techniques. However, the limitations of bypass surgery, especially for coronary artery bypass procedures, was still significant, leading to renewed interest in this technique. Postoperative care for off-pump coronary artery bypass (OPCAB) surgery presents both a challenge and opportunity to the intensivist. OPCAB patients can be treated in a fast-track manner allowing rapid recovery and early extubation and discharge from the intensive care unit. This is supported through the use of protocols that help standardize care and set expectations for the post–cardiac care team. Importantly, complications that may delay recovery including hypothermia, hypotension, and bleeding must be recognized early and treated aggressively to prevent unwanted complications and intensive care delays. Finally, care of these patients has shifted to the post-anesthesia recovery room, making knowledge of the care of these patients in the early postoperative period essential for cardiac anesthesiologists. This article will discuss the care of OPCAB patients following surgery and include approaches to managing patients who return both intubated and extubated.

Keywords

off-pump coronary artery bypass, anesthesia, surgical intensive care, off pump, OPCAB

Introduction

Beating heart surgery was originally developed, prior to the advent of cardiopulmonary bypass (CPB) surgery, to provide treatment for patients suffering from cardiac disease. It was later resurrected from obscurity when concerns over the injurious effects of CPB were postulated. Off-pump coronary artery bypass (OPCAB) surgery was seen to be less invasive, without cross-clamping the aorta and exposure to the CPB circuit, with the potential to provide better patient outcomes. It was also felt that this less-invasive approach could allow for even more rapid recovery than conventional cardiac surgery, thus reducing intensive care unit (ICU) and hospital length of stay and ultimately reducing the costs associated with cardiac surgery care.[1-4] While many of these assumptions remain to be definitively proven, fast-track surgery has shown that recovering patients with the aim to reducing length of stay can indeed reduce the cost associated with postoperative care.[5-7] Patients who have undergone OPCAB surgery are ideal candidates for fast-track recovery programs involving early extubation and early transfer to low-intensity care (in most cases floor beds). This may involve short stays in a general surgical recovery area, a dedicated cardiac recovery area, or an ICU. An ultrafast track program in which OPCAB patients are extubated immediately after the surgical procedure, within the operating room (OR), is also possible.[8-10]

This article will focus on the care of cardiac patients following OPCAB surgery, with an emphasis on the uncomplicated care pathway, which may be standardized to provide high-quality patient-focused care with the dual goals of improving patient outcomes while reducing costs. In addition, common complications associated with OPCAB surgery will be reviewed focusing on early recognition and management to reduce its adverse impact on patients' recovery.

Routine Care

The main goal when a patients returns from surgery is to ensure efficient transfer of care, which includes a thorough

[1]Department of Anesthesia & Perioperative Medicine, Western University, London, Ontario, Canada

Corresponding Author:
Davy C. Cheng, London Health Sciences Centre—University Hospital, 339 Windermere Road, Room C3-128, London, Ontario, Canada N6A 5A5.
Email: davy.cheng@lhsc.on.ca

assessment to ensure the patient is stable and has no serious complications that will affect recovery. Handover of care from the anesthesia and surgical teams should occur, preferably in a standardized manner, involving all team members highlighting and reviewing key perioperative issues that will have an impact on patient care.[11,12] Blood work should be drawn as with conventional cardiac surgery. Results will direct ventilator settings, possible need for packed red cells or thrombostatic agents, as well as the need to treat electrolyte imbalances, which may delay awakening or lead to arrhythmias.

Many ICUs have developed handover checklists to aid in communication during the transfer of care from the anesthesiologist to the intensivist. In addition to the routine information normally given to all patients, which includes a brief history, conduct of the surgery, and any complications encountered in the OR, specific emphasis should be placed on the reason for the OPCAB approach (calcified aorta, for example); any complications occurring during anastomosis, specifically, ischemia, hypotension, or arrhythmia; the completeness of the revascularization; and the patient's temperature at the end of the procedure (as hypothermia is common following OPCAB procedures).

Routine blood work on admission is the same as for conventional heart surgery: a complete blood count and electrolyte panel (sodium, potassium, bicarbonate, urea, creatinine, magnesium, and calcium). A set of arterial blood gases should be drawn with focus on the pH, partial pressure of arterial carbon dioxide ($PaCO_2$), partial pressure of arterial oxygen (PaO_2), and lactate levels. A chest X-ray and 12-lead electrocardiogram should also be performed at this time, although the value of routine chest X-ray in stable patients may be limited.[12]

A complete physical exam should be performed following OPCAB surgery, similar to conventional bypass techniques. The aim should be to assess the patient's neurologic status and rule out focal deficits, all to aid the decision whether to rapidly awaken and wean the patient. Cardiopulmonary exam should ensure bilateral air entry and include a review of the chest tubes to ensure minimal drainage. Abdominal exam is needed to ensure the abdomen is soft. Finally, careful attention to the placement of all lines or attempted lines along with the assessment of peripheral perfusion is required. Patients may be arousable or awake on admission and may be breathing spontaneously, which are indications that rapid weaning is possible.

Weaning: Sedation and Extubation

For the routine patient who returns following OPCAB surgery, it should be expected that the patient received a low-dose narcotic regimen during the procedure and returns on a propofol infusion or similar short-acting agent and has received intermittent doses of longer acting narcotics like morphine or hydromorphone for analgesia.[13-16] Over the next 2 to 4 hours the goal is to have the patient awake and following commands (which will aid in analgesia administration). They may be breathing spontaneously or ventilated. It should be noted that lung function following OPCAB is usually better than following conventional bypass surgery, because the lungs are continually ventilated during OPCAB surgery and there is no exposure to the bypass pump, which may contribute to acute lung injury.

The same criteria are used for extubating OPCAB patients as for conventional bypass patients[17,18]: the patient must be awake and responding to commands and must be hemodynamically stable with reasonable chest tube losses (less than 150 cc/h). Inspired oxygen (FiO_2) should be less than 50%. Usually, a measure of muscle strength such as vital capacity >25 mL/kg is used; however, if the patient has reasonable tidal volumes and has been intubated for a short period of time this may be omitted. Amnestic agents are weaned prior to extubation and converted to narcotic-based sedation titrated to patient pain. The patient must be initiating breaths but usually have a respiratory acidosis owing to the use of narcotic analgesics. Arterial carbon dioxide levels in the high 40 mm Hg to low 50 mm Hg are usually well tolerated. However, care must be taken when extubating patients with a concomitant metabolic acidosis as this puts additional workload on the patient's respiratory system and may contribute to early respiratory failure.

The weaning of patients can be performed using one of many different methods; our practice is to wean from assist control (A/C) to pressure support (PS) 15 cm H_2O and then reduce pressure support every hour to the target of PS 5 cm H_2O at which point the patient is extubated. This approach is very conservative, and given the lack of CPB and modest doses of narcotics it is not unusual to either extubate the patient from PS 10 mm H_2O or speed up the weaning process to periods of 20 minutes between adjustments to PS. There is debate whether a protocolized approach to weaning results in decreased ventilation times.[19] However, a consistent approach aids in setting expectations for rapid recovery and extubation among all caregivers within the ICU.

Following extubation, the patient is usually placed on oxygen by facemask, which is adjusted based on saturations. An arterial blood gas may be drawn if there is concern about the patient's respiratory status, especially CO_2 retention, although frequently the patient's level of consciousness is used as a surrogate for high CO_2 levels.

The main goal of extubation is to allow the patient to have deep breath, cough, and mobilize, as these maneuvers reduce complications associated with cardiac surgery (such as atelectasis, pneumonia). So these goals must be

reinforced to the patient by nursing/physiotherapy, and the patient should be encouraged to mobilize out of bed as soon as possible.

The Extubated OPCAB Patient

Some patients may return from the OR already extubated. This is common especially in patients who have undergone limited bypass grafting off pump (typically the *left internal mammary artery* to *left anterior descending* artery). The process of handover remains the same as does the admission blood work. The need to wean the patient from sedatives is not an issue in the extubated patient, but additional opioids may be needed for pain control. Blood gases usually demonstrate a respiratory acidosis with carbon dioxide levels in the 45 to 55 mm Hg range. The 2 concerns in any extubated patient are (*a*) that the patient avoids respiratory failure and (*b*) that another complication does not occur that may necessitate reintubation, specifically postoperative bleeding.

Respiratory failure following extubation has many potential causes, and the differential can be simplified into central causes and peripheral causes. Central causes include narcosis, stroke, encephalopathy, and residual anesthetics. Central causes are usually associated with a decreased level of consciousness (LOC), but this may be complicated by the decreased LOC often associated with severe respiratory failure and acidosis. Peripheral causes are more diverse and include muscle weakness/residual paralysis, lung collapse/atelectasis, pneumothorax/hemothorax, aspiration, bronchospasm, and upper airway obstruction.

Management includes identifying a cause through the use of a focused history and physical exam looking for patient's LOC, focal neurologic deficits, air entry, and hand grip strength. An arterial blood gas should be done and may be repeated to follow the patient's pH and $PaCO_2$. A chest X-ray is useful to rule out a pneumothorax, atelectasis, and alveolar lung disease (pneumonia). Management can be directed toward the underlying cause. A chest tube may be required if a pneumothorax or hemothorax is suspected or visible on chest X-ray. The use of naloxone (0.04 mg every 3-5 minutes) is warranted if excess narcotic administration is felt to be the cause. However, the dose given should be small and repeated frequently to avoid rapid reversal leading to pain, tachycardia, or pulmonary edema. A reversal dose of muscle relaxant may be required if no reversal was given at the end of the procedure or the patient is felt to be weak. If no specific cause is found, then the patient will need ventilatory support. An intermediate step would be to try noninvasive respiratory support such as continuous positive airway pressure (CPAP) or bi-level positive airway pressure (BiPAP).[20] These modes work well for patients with peripheral causes of respiratory failure but should be avoided in patients with central depression or a decreased LOC. Patients on BiPAP or CPAP for respiratory failure should be carefully monitored. Both clinical indicators (respiratory rate, use of accessory muscles, agitation) and laboratory values (reduced PaO_2, elevated $PaCO_2$) should be used to gauge the success of the noninvasive ventilation. If the patient continues to deteriorate then the key to management is early intervention to reintubate the patient prior to their LOC becoming profoundly depressed and their respiratory acidosis resulting in severe hypotension.

Pain Control in OPCAB Surgery

The avoidance of CPB coupled with the use of lower doses of heparin often permits the use of other pain control strategies besides intravenous narcotics. This is especially true of patients who may have undergone robotic OPCAB surgery through a mini-thoracotomy. Options include the use of intrathecal narcotics, which may provide up to 24 hours of pain relief, use of thoracic epidural anesthesia, or paravertebral anesthesia (bilateral for sternotomy and unilateral for mini-thoracotomy).[21-24] The use of continuous catheters may aid in extubation and pain control following OPCAB surgery; however, the management of the regional anesthesia catheters must be coordinated with the pain team, who will follow the patients on the floor. Intravenous narcotic doses need to be reduced or eliminated from the pain protocol, and the weaning of sedation needs to include an assessment of how well the catheter is working, as during the weaning process in the ICU it frequently becomes apparent that the catheter alone is insufficient to treat the patient's pain. Intrathecal narcotics spread throughout the spinal dermatomes; however, thoracic epidural or paravertebral catheters may miss the pain caused by the chest tubes, irritating the thoracic pleura, and patients may require supplemental narcotics until the chest tubes are removed.

Finally, the use of nonsteroidal anti-inflammatory drugs (NSAIDs) may be beneficial in younger patients who have undergone OPCAB surgery. They provide excellent pain control without the risk of respiratory depression.[25,26] However, care must be taken when administering NSAIDs or avoided in patients with low urine output or elevated creatinine levels.

Common Complications in the OPCAB Patient That May Delay Recovery and Transfer to the Floor

The goal of OPCAB surgery is to provide patients with reduced complications and rapid recovery, allowing early transfer out of the ICU and discharge from the hospital. The aim therefore is to anticipate potential complications and prevent or minimize their impact on the routine course

of recovery.[18] The aim of the remainder of the article will be to address several common issues associated with OPCAB surgery and suggest ways to prevent these complications from occurring and treatment strategies if they do occur.

Hypothermia

While avoiding CPB may have many potential advantages, a distinct disadvantage is the inability to efficiently maintain the patient's body temperature during the procedure. Ideally, forced air warmers and fluid warmers would be employed during the OPCAB procedure; however, unexpected blood loss or prolonged chest closure may result in hypothermia in the patient. Hypothermia may cause respiratory depression, cardiac depression, and coagulopathy, so it should be aggressively treated once recognized. The use of forced air warmers is the most efficient and in the ICU has the advantage of being applied across the entire body. Fluid warmers should also be used if the patient is actively bleeding or hemodynamically unstable, with the expectation that large volumes of fluid will be administered. Certainly, patients who are otherwise stable but hypothermic should not generally be extubated if their body temperature is below 36°C (96.8°F). In addition, the vasodilation associated with rewarming frequently results in hypotension, which will require treatment with volume or vasoconstrictors. It may also be advisable to maintain sedation during rewarming in order to reduce patient shivering, which may increase oxygen consumption.

Hypotension

Hypotension following OPCAB surgery has similar causes to conventional bypass surgery. However, post bypass myocardial ischemia and stunning may be more common following OPCAB surgery due to need to occlude the proximal coronary vessels during coronary revascularization. In addition, the patient's volume status may be decreased compared to on-pump surgery as OPCAB surgery omits the pump prime solution. This may result in less total inoperative volume administered compared to conventional bypass surgery. Finally, the salvage of blood through a cell saver is less efficient than mediastinal salvage through a CPB machine as the plasma is lost during washing. If the hypotension is not associated with signs of poor perfusion, such as peripheral vasoconstriction, decreased urine output, or elevated serial arterial lactate levels, then treatment with volume infusions (500 mL crystalloid) or low-dose vasoconstrictors (phenylephrine 20-40 μg/min or Levophed 2-4 μg/min) is warranted. As the sedation is weaned or when the patient is fully rewarmed, the hypotension usually resolves. If the hypotension is associated with signs of reduced tissue perfusion, then a cause must be sought. Initial management will be the same as noted above but may entail more aggressive volume boluses (1000 mL crystalloid or 250-500 mL colloid) and vasoconstrictors (norepinephrine or epinephrine 3-7 μg/min). Hemoglobin level should be reviewed, and if low (<70 or <80 in the unstable patient) packed red blood cells should be transfused. If the patient is intubated then transesophageal echocardiography is often helpful to rule out tamponade, poor left ventricular (LV)/right ventricular (RV) function, regional wall motion dysfunction, or reduced filling volumes. If the patient is extubated then bedside transthoracic echocardiography can be performed. In patients who are extubated, poor pulmonary function may exacerbate pulmonary hypertension and contribute to RV failure, so this must be careful evaluated. Treatment is based on findings and may consist of further crystalloid, colloid, or blood products administration, inotropes, vassopressors, or chest exploration in the OR for cardiac tamponade.

Bleeding

Blood loss following OPCAB surgery is in general less than conventional surgery owing to the lack of CPB and reduced heparin doses during the procedure. In fact, concern has been raised that patients are more hypercoagulable following OPCAB surgery; however, this concern does not appear to be valid,[27] and the goal should be to ensure a normal activated clotting time (ACT) in the ICU.[28] Some OPCAB patients, however, may be at increased risk of bleeding. As previously mentioned, hypothermia may contribute to coagulopathy and increase postoperative blood loss. Increased intraoperative blood loss is usually treated with a cell salvage device that, while preserving red blood cells, does result in the loss of fresh frozen plasma (FFP) and platelets. This may result in postoperative coagulopathy. Management of bleeding should focus on treating the underlying cause, correcting coagulopathy, and if bleeding is brisk (usually >400 cc/h) return to the OR for re-exploration similar to conventional bypass cases.

Finally, OPCAB surgery may be performed on patients with a contraindication to heparin (HITT) or in patients who have received antiplatelet agents (clopidogrel) prior to emergency surgery. In the case of patients with a contraindication to heparin, commonly the anticoagulant bivalirudin (0.75 mg/kg bolus, 1.75 mg/kg/h infusion) is used.[29,30] While the half-life of bivalirudin is short (30 minutes), it still may be present in therapeutic concentrations in the ICU. No direct inhibitor is available and treatment is symptomatic and may include transfusions of FFP, platelets, and cryoprecipitate to replace chest tube drainage. Usually the bleeding is self-limited and the anticoagulation effect of bivalirudin should wear off after several hours.

The use of antiplatelet agents poses a greater bleeding problem. Many agents can last 12 hours or more and all

lack a reliable means of reversal. The platelet count is usually normal; however, platelet function is impaired. Use of bedside platelet function tests may serve as a guide to the degree of platelet dysfunction as few core labs provide routine platelet function assays. Management is usually a combination of administration of FFP, cryoprecipitate, and of course platelets to treat the coagulopathy.

Management of OPCAB Patients in the Recovery Room: The Ultrafast Track Recovery Approach

While the theme of this article is management of the patients in the ICU, we will conclude the article with a look at ultrafast track recovery of OPCAB patients in the post-anesthesia care unit (PACU). It is usually the cardiac anesthesiologist attending the patient in the OR who is ultimately responsible in managing the ultrafast-track recovery of the patient in the PACU. This eliminates the transfer of care from physician to physician but still mandates an appropriate handover to the recovery room nurse.

Patients most suitable for ultrafast track recovery are those who are younger and have had short OPCAB surgical procedures with no intraoperative complications. Patients with dementia or cognitive impairments, history of severe pulmonary disease (including morbid obesity), and those with poor LV function may be particularly challenging to manage in an ultrafast track recovery protocol. In addition, patients who pose an increased risk of postoperative bleeding may also not be ideal candidates.

Patients should be brought to the recovery room extubated, awake, and following commands. Longer acting opioids should be initiated in the OR to begin the transition from anesthesia to analgesic regimens. The use of regional techniques maybe helpful for this transition but are not always necessary. Postoperative blood work is similar for the patient admitted to the ICU and includes a complete blood count, electrolytes, coagulation panel, and magnesium and calcium. A chest X-ray is always performed to confirm line placement and rule out the presence of a hemothorax or pneumothorax. The patient's hemodynamic status should be stable, which does not preclude use of low-dose vasopressors. The need for ongoing vasopressor support does, however, preclude transfer to the ward. If hypotension persists a cause must be sought while supportive treatment is ongoing. Blood loss should be minimal (<100 cc/h), and it is important to monitor chest tube drainage closely in the recovery room, as this frequently determines the success of ultrafast track recovery. Such a protocol may include q30min chest tube drainage monitoring for the first 4 hours with drainage greater than 80 cc in any 30-minute period necessitating a repeat coagulation profile. Administering protamine boluses (25-50 mg intravenous over 5-10 minutes) or infusions empirically (25 mg/h over 4 hours) or in response to an elevated partial thromboplastin time (PTT) early after blood loss increases may prevent further bleeding.

Patients typically stay 3 to 4 hours in the recovery area, and criteria for discharge are similar for other noncardiac patients. Consideration should be given to starting an intravenous patient control analgesia (PCA) for postoperative pain control.[31] In addition, the use of NSAIDs may reduce the adverse events associated with narcotics, which may be of special concern given the limited monitoring for floor patients.

If any significant complications persist (bleeding, hypotension) or the patient does not meet criteria for transfer out of the recovery room, the patient should be transferred to an ICU and the ultrafast track pathway abandoned.

Conclusion

Care of patients following off-pump beating heart surgery is in many ways similar to care of patients during conventional CPB procedures. With a concerted intraoperative and postoperative team management plan, a patient's recovery can be fast tracked considerably with no reductions in the quality of care or an increase in the risks of morbidity. A fast-track and ultrafast track care can often be protocolized in general and individualized when needed to ensure high standards of care delivery and more uniformity in both treatments provided and outcomes observed. With all other things being equal, faster throughput permits more access to care for a given amount of finite resource utilization with benefits to the patient, institution, and society in general.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

References

1. Bainbridge D, Cheng D, Martin J, Novick R. Does off-pump or minimally invasive coronary artery bypass reduce mortality, morbidity, and resource utilization when compared with percutaneous coronary intervention? A meta-analysis of randomized trials. *J Thorac Cardiovasc Surg*. 2007;133:623-631.
2. Puskas J, Cheng D, Knight J, et al. Off-pump versus conventional coronary artery bypass grafting: a meta-analysis and consensus statement from the 2004 ISMICS Consensus Conference. *Innovations (Phila)*. 2005;1:3-27.

3. Cheng DC, Bainbridge D, Martin JE, Novick RJ. Does off-pump coronary artery bypass reduce mortality, morbidity, and resource utilization when compared with conventional coronary artery bypass? A meta-analysis of randomized trials. *Anesthesiology*. 2005;102:188-203.
4. Hadjinikolaou L, Cohen A, Glenville B, Stanbridge RD. The effect of a 'fast-track' unit on the performance of a cardiothoracic department. *Ann R Coll Surg Engl*. 2000;82:53-58.
5. Cheng DC, Barash PG. Is fast-track intensive care unit management still on the express track? *Crit Care Med*. 2006;34:1826-1828.
6. Cheng DC. Fast track cardiac surgery pathways: early extubation, process of care, and cost containment. *Anesthesiology*. 1998;88:1429-1433.
7. Cheng DC, Karski J, Peniston C, et al. Early tracheal extubation after coronary artery bypass graft surgery reduces costs and improves resource use. A prospective, randomized, controlled trial. *Anesthesiology*. 1996;85:1300-1310.
8. Borracci RA, Dayan R, Rubio M, Axelrud G, Ochoa G, Rodriguez LD. Operating room extubation (ultra fast-track anesthesia) in patients undergoing on-pump and off-pump cardiac surgery. *Arch Cardiol Mex*. 2006;76:383-389.
9. Straka Z, Brucek P, Vanek T, Votava J, Widimsky P. Routine immediate extubation for off-pump coronary artery bypass grafting without thoracic epidural analgesia. *Ann Thorac Surg*. 2002;74:1544-1547.
10. Djaiani GN, Ali M, Heinrich L, et al. Ultra-fast-track anesthetic technique facilitates operating room extubation in patients undergoing off-pump coronary revascularization surgery. *J Cardiothorac Vasc Anesth*. 2001;15:152-157.
11. Segall N, Bonifacio AS, Schroeder RA, et al. Can we make postoperative patient handovers safer? A systematic review of the literature. *Anesth Analg*. 2012;115:102-115.
12. Moller TP, Madsen MD, Fuhrmann L, Ostergaard D. Postoperative handover: characteristics and considerations on improvement: a systematic review. *Eur J Anaesthesiol*. 2013;30:229-242.
13. Brown MM. Implementation strategy: one-stop recovery for cardiac surgical patients. *AACN Clin Issues*. 2000;11:412-423.
14. Engoren M, Luther G, Fenn-Buderer N. A comparison of fentanyl, sufentanil, and remifentanil for fast-track cardiac anesthesia. *Anesth Analg*. 2001;93:859-864.
15. Myles PS, Daly DJ, Djaiani G, Lee A, Cheng DC. A systematic review of the safety and effectiveness of fast-track cardiac anesthesia. *Anesthesiology*. 2003;99:982-987.
16. London MJ, Grunwald GK, Shroyer AL, Grover FL. Association of fast-track cardiac management and low-dose to moderate-dose glucocorticoid administration with perioperative hyperglycemia. *J Cardiothorac Vasc Anesth*. 2000;14:631-638.
17. Cheng DC, Karski J, Peniston C, et al. Morbidity outcome in early versus conventional tracheal extubation after coronary artery bypass grafting: a prospective randomized controlled trial. *J Thorac Cardiovasc Surg*. 1996;112:755-764.
18. Wong DT, Cheng DC, Kustra R, et al. Risk factors of delayed extubation, prolonged length of stay in the intensive care unit, and mortality in patients undergoing coronary artery bypass graft with fast-track cardiac anesthesia: a new cardiac risk score. *Anesthesiology*. 1999;91:936-944.
19. Blackwood B, Alderdice F, Burns K, Cardwell C, Lavery G, O'Halloran P. Use of weaning protocols for reducing duration of mechanical ventilation in critically ill adult patients: Cochrane systematic review and meta-analysis. *BMJ*. 2011;342:c7237.
20. Suzuki T, Kurazumi T, Toyonaga S, et al. Evaluation of noninvasive positive pressure ventilation after extubation from moderate positive end-expiratory pressure level in patients undergoing cardiovascular surgery: a prospective observational study. *J Intensive Care*. 2014;2:5.
21. Rosen DA, Hawkinberry DW 2nd, Rosen KR, Gustafson RA, Hogg JP, Broadman LM. An epidural hematoma in an adolescent patient after cardiac surgery. *Anesth Analg*. 2004;98:966-969.
22. Caputo M, Alwair H, Rogers CA, et al. Thoracic epidural anesthesia improves early outcomes in patients undergoing off-pump coronary artery bypass surgery: a prospective, randomized, controlled trial. *Anesthesiology*. 2011;114:380-390.
23. Mehta Y, Vats M, Sharma M, Arora R, Trehan N. Thoracic epidural analgesia for off-pump coronary artery bypass surgery in patients with chronic obstructive pulmonary disease. *Ann Card Anaesth*. 2010;13:224-230.
24. Suryaprakash S, Chakravarthy M, Gautam M, et al. Effect of thoracic epidural anesthesia on oxygen delivery and utilization in cardiac surgical patients scheduled to undergo off-pump coronary artery bypass surgery: a prospective study. *Ann Card Anaesth*. 2011;14:192-196.
25. Bainbridge D, Cheng DC, Martin JE, Novick R. NSAID-analgesia, pain control and morbidity in cardiothoracic surgery. *Can J Anaesth*. 2006;53:46-59.
26. Hynninen MS, Cheng DC, Hossain I, et al. Non-steroidal anti-inflammatory drugs in treatment of postoperative pain after cardiac surgery. *Can J Anaesth*. 2000;47:1182-1187.
27. Tanaka KA, Thourani VH, Williams WH, et al. Heparin anticoagulation in patients undergoing off-pump and on-pump coronary bypass surgery. *J Anesth*. 2007;21:297-303.
28. Gatti G, Pugliese P. Heparin reversal in off-pump coronary artery bypass surgery: complete, partial, or no reversal? *Cardiovasc Surg*. 2002;10:245-250.
29. Merry AF, Raudkivi PJ, Middleton NG, et al. Bivalirudin versus heparin and protamine in off-pump coronary artery bypass surgery. *Ann Thorac Surg*. 2004;77:925-931.
30. Smedira NG, Dyke CM, Koster A, et al. Anticoagulation with bivalirudin for off-pump coronary artery bypass grafting: the results of the EVOLUTION-OFF study. *J Thorac Cardiovasc Surg*. 2006;131:686-692.
31. Bainbridge D, Martin JE, Cheng DC. Patient-controlled versus nurse-controlled analgesia after cardiac surgery—a meta-analysis. *Can J Anaesth*. 2006;53:492-499.