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Anesthesia for Robotic Heart Surgery: An Overview

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INTRODUCTION

An innovative approach to coronary revascularization, robotically-assisted vision-enhanced coronary artery bypass (RAVECAB), is performed by means of a small anterior minithoracotomy or ministernotomy on a beating heart without the aid of cardiopulmonary bypass. Components of this technique include thoracoscopic video-assisted harvesting of the internal mammary artery (IMA), robotic telemanipulation, and prolonged one-lung ventilation (OLV).

With the absence of cardioplegia, myocardial protection during normothermic beating heart surgery poses a challenge. Patient selection is important to avoid intraoperative and postoperative complications. Prolonged one-lung ventilation, incomplete revascularization in hybrid procedures, and limited access for rapid intervention pose challenges for patient management. Conversion to sternotomy may be required in 3-5% of patients, and extension of portals over several dermatomal segments requires a versatile analgesic technique.

The use of regional anesthesia as general anesthesia adjuvant allows lighter levels of general anesthesia during surgery, with minimal intraoperative hemodynamic changes and a smooth transition to postoperative analgesia. Although a number of regional techniques may be used to achieve this goal, continuous percutaneous paravertebral block (PVB) offers specific, potent analgesia and advantages associated with cardiac sympathectomy.

MATERIALS AND METHODS

Surgical Approach:

The primary surgical approach employed for RAVECAB involves use of port access lateral thoracostomy incisions [Boyd 2000]. Endoscopic harvesting of the right or left IMA is completed prior to the main surgical exposure for anastomosis [Kiaii 2000]. Thoracoscopic harvesting of the IMA requires ports for the camera, telemanipulator harmonic scalpel, and CO_2 insufflator that are inserted at different intercostal spaces, usually via the third to sixth intercostals. Occasionally, radial artery or saphenous vein grafts may be required to extend the length of the IMA [Diegeler 1999].

The ipsilateral lung is collapsed both during dissection of the IMA and during coronary anastomosis to facilitate access and to avoid movement induced by respiratory excursions. An active pneumothorax (PTX) is induced with CO_2 insufflation to facilitate IMA dissection. This procedure requires a high level of communication between the surgeon and the anesthesiologist because it has the potential for significant hemodynamic compromise. Since PTX is maintained throughout the surgical procedure, in some cases we monitor intrapleural pressure directly via an 18-gauge IV cannula and pressure transducer to avoid excessive pressure generation.

Performance of the distal anastomosis involves the use of a myocardial stabilizer designed to isolate a small segment of myocardium with the relevant coronary artery, and proximal and distal silastic sutures to control back-bleeding. Intracoronary shunts are often used to facilitate anastomosis and maintain distal perfusion, particularly since robotic distal anastomosis on the beating heart requires up to 30 minutes to complete. A variety of stabilizers are used [Cremer 1997, Grundeman 1997] that provide a relatively motionless field to perform the anastomosis on a beating heart, but a steady heart rate without myocardial irritability facilitates surgical conditions.

Graft patency is usually evaluated intraoperatively using direct measurement of flow by means of a Doppler flow meter (Transonics, Ithaca, NY). The flow measured is thus dependent on systemic blood pressure and distal coronary run-off. Intraoperative coronary angiograms are still undergoing evaluation, but most patients are given coronary angiograms in the immediate postoperative period both to evaluate patency and to anticipate additional procedures such as angioplasty/stent insertion that might be required for patients undergoing hybrid procedures.

Conversion to sternotomy is required in 3-5% of patients [Subramanian 1997, Diegeler 1999]. This is often due to poor visualization of the IMA due to fat and or abnormal coronary anatomy such as an intramyocardial course of the left anterior descending artery (LAD), injury to the IMA, or an extensively calcified LAD requiring coronary endarterectomy [Subramanian 1997].

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Patient Selection and Preparation:

Patient selection is crucial because of such factors as the need for multiple small incisions that extend over several dermatomal segments, induced tension pneumothorax, prolonged OLV, postoperative pain management, and the potential for incomplete revascularization. Ideally, the patients should be seen in the preoperative anesthesia clinic by a cardiac anesthesiologist familiar with MIDCAB/RAVECAB. The primary difference associated with RAVECAB is the requirement for a longer duration of one-lung ventilation.

Coagulation parameters, the condition of the thoracic spine, and the skin overlying the T1-T5 area should be examined to determine suitability for neuraxial techniques for intra/postoperative analgesia. Airway and chest anatomy should be suitable for insertion of a double lumen tube to facilitate OLV. Thus, a patient having documented difficulty with intubation, major scoliosis, or emphysematous chest may be identified in the preoperative clinic as unsuitable for this type of surgery. Patients with severe chronic obstructive pulmonary disease (COPD) or asthma will also be poor candidates for prolonged OLV.

Pulmonary function values have been reported not to correlate with or predict postoperative ventilatory failure; nevertheless, spirometry with and without bronchodilators, arterial blood gases, and chest x-rays may provide information about patients who cannot tolerate prolonged OLV. Patients with resting hypercarbia (>50 mmHg) and hypoxia (PaO_2 <65 mmHg on room air), active bronchospasm, and major emphysematous bullae will not be able to tolerate the hypercarbia, potential hypoxia, and barotrauma resulting from OLV and carbon dioxide insufflation. In patients with mild COPD, pulmonary function should be optimized with the aid of bronchodilators, steroids, and physiotherapy. Patients who smoke should be encouraged to stop smoking at least two weeks before surgery.

The potential for hypoxia, incomplete revascularization, and hemodynamic changes poses significantly increased risk to patients with diffuse multivessel coronary artery disease, congestive heart failure, poor left ventricular function, and major valvular lesions. Patients with unstable angina or recent myocardial infarction have the potential for myocardial irritability and dysfunction associated with recent ischemia/injury. Such patients are generally better managed with median sternotomy and other beating heart surgery techniques, such as off-pump coronary artery bypass (OPCAB), because enhanced exposure enables cardiopulmonary bypass (CPB) to be initiated relatively quickly if required.

Preoperative medications, particularly beta-blockers, should be continued throughout the perioperative period to decrease myocardial irritability and maintain a slow heart rate. However, caution should be exercised in elderly patients who are significantly beta-blocked, as they may not tolerate the additional sympathetic blockade from thoracic epidural anesthesia (TEA). Aspirin and other antiplatelet agents should not be taken for at least five days prior to surgery, particularly if neuraxial block is planned. Oral anticoagulants such as coumadin should be discontinued in adequate time. Patients with unstable angina requiring ongoing anticoagulation with heparin will not be suitable for neuraxial blocks. Coagulation parameters should be checked preoperatively and should be normal before initiation of neuraxial blocks. Electrolytes such as potassium and magnesium should be within normal range prior to anesthesia.

Anesthesia:

Because the duration of significant pain following RAVECAB/MIDCAB is about 48 hours [Ganapathy 1999a], a continuous catheter anesthesia technique is indicated. Use of regional anesthetic techniques as analgesic components of balanced anesthesia make transition to postoperative analgesia smooth.

For the majority of RAVECAB procedures, our technique of choice is a combination of thoracic PVB and light general anesthesia. We have employed this technique in over 40 patients and find it is easy to initiate before surgery, requiring on average less than 15 minutes. In our practice, anesthesia is initiated prior to surgery with the patient awake and sitting upright. Pre-induction placement reduces intraoperative anesthetic requirements and can provide cardiac sympathectomy. A posterior approach to the paravertebral space is used to block the intercostal nerves as they exit the intervertebral foramina. The epidural needle is walked above or under the transverse process to puncture the superior costal rib transverse ligament to lie in the paravertebral "gutter." This technique has been used extensively following a variety of surgical procedures [Richardson 1998]. The sympathetic chain is very close to the somatic nerves in the paravertebral space, and bilateral sympathetic block is known to occur with paravertebral blocks [Tenicela 1990]. The success rate of this block in a teaching center with inexperienced hands is >90%. We have recently reported on the use of this technique [Ganapathy 1999b].

When PVB has been established, the general anesthesia is induced with a small dose of narcotic (fentanyl 3-5 mg/kg) and of propofol (0.5-1 mg/kg) and rocuronium (1 mg/kg). Because the RAVECAB procedure currently requires four to six hours, an infusion of rocuronium and low dose propofol (50 mg/kg/min.) is maintained throughout surgery. It is crucial to ensure absolute patient immobility from the time the myocardial stabilizer is placed until after completion of anastomosis and confirmation of flow adequacy, since any untoward motion at this time can result in myocardial perforation, graft avulsion, or other serious mishap. Profound neuromuscular blockade is thus mandatory throughout this stage.

Specific Considerations:

Patient positioning and monitoring:

Patients are positioned in the lateral tilt position with the left arm suspended from a support at the level of the head. If the arm is not carefully positioned, brachial plexus injury may result [Martin 1992]. Patients undergoing RAVECAB may additionally have their left arm free-draped to facilitate instrumentation, and additional care should then be taken to avoid neurological injury. Patients are draped with the thorax, abdomen, both groins, and one lower limb exposed for surgical access. This leaves only the right arm for arterial pressure monitoring and intravenous access.

Cardiovascular system:

External defibrillator pads are applied before induction of anesthesia. Because there is limited access to the heart for direct defibrillation, provision for external transthoracic defibrillation is essential. Infusion of nitroglycerin is used to control ST segment changes or elevations of pulmonary capillary wedge pressure. Bolus doses of intravenous lidocaine and magnesium (2-4 gm) are used before initiation of anastomosis to reduce ventricular irritability. Because of improved stabilizer design, however, we currently maintain a heart rate between 50-80 bpm.

Anterior surgical incision in the fourth or fifth intercostal space and ports in the midaxillary line preclude optimal positioning of the lateral chest ECG leads such as V5 and V6, potentially confounding ischemia monitoring. The pneumothorax induces changes in ECG axis and waveform amplitude, further confounding the monitoring of ischemia and arrhythmia. It is thus important to monitor ECG and ST segments in at least two leads simultaneously, e.g., lead II and a lateral chest lead. In addition, we routinely employ an oxymetric pulmonary artery (PA) catheter. Continuous mixed venous saturation monitoring using oxymetric PA catheters can provide information about peripheral oxygen delivery in the presence of acute hemodynamic and respiratory system changes. Decreases in myocardial compliance resulting from ischemia can be detected as increases in pulmonary capillary wedge pressure, thus permitting earlier detection and treatment of ischemia. Transesophageal echocardiography (TEE) has been used to identify intraoperative ischemia, but there are drawbacks to using this method of monitoring MIDCAB patients induced by pneumothorax that should be taken into consideration [Mehta 1999].

Respiratory system:

Either a left-sided double lumen tube or a single lumen tube with a bronchial blocker such as the Univent® tube is used for facilitating one-lung ventilation. Usually, continuous positive airway pressure (CPAP) of 5 cm is applied on the collapsed lung to improve oxygenation and reduce shunt fraction. One-lung ventilation and induction of an active pneumothorax with carbon dioxide insufflation is required during virtually the entire surgical procedure. One-lung ventilation can reduce cardiac output, increase pulmonary artery pressure and pulmonary vascular resistance [Sessler 1992], and produce hypoxia and hypercarbia. These effects may be exaggerated in the subset of patients who are obese and/or chronic smokers. Prolonged OLV can cause significant atelectasis, edema, and ventilation perfusion mismatch resulting in hypoxemia well into the postoperative period. The mean duration of OLV in our series of 48 patients was 196.8+/–67 minutes [Ganapathy 1999a]. Pneumothorax, which is induced to facilitate dissection of IMA, can become a tension pneumothorax intermittently if the insufflation pressures are not carefully monitored. This can produce significant reduction in venous return and hypotension, which requires frequent adjustments in insufflation pressure and active communication between the anesthesiologist and the surgeon. Continual vigilance and monitoring of insufflation pressure, airway pressure, expired tidal volume, and central venous pressure is essential. Hypoxia and hypercarbia can elevate pulmonary artery pressure and pulmonary vascular resistance as well as reduce cardiac output [Sessler 1992].

In our experience, 20 percent of patients require short-term postoperative ventilation because of hypothermia and or excessive sedation [Ganapathy 1999b]. Use of double lumen tubes for one-lung ventilation will necessitate change to a single lumen tube, requiring a deeper level of anesthesia and profound neuromuscular blockade at the end of surgery. We currently use an endotracheal tube with a removable bronchial blocker (Univent® tube) intraoperatively, as this facilitates short-term postoperative ventilation without requiring change of the endotracheal tube.

Anticoagulation:

Unlike patients undergoing conventional CABG, RAVECAB patients receive a smaller dose of heparin (10,000-20,000 IU), with activated clotting time aimed at >300 seconds [Subramanian 1997, Diegeler 1999]. Coagulation function is better maintained at the end of surgery because CPB has been avoided. Although this degree of coagulation disturbance is similar to what occurs in major vascular surgery, such as the repair of an abdominal aortic aneurysm, where safety of neuraxial blockade has been documented, patients receiving neuraxial blocks should be given adequate postoperative neurological monitoring to identify any evolving neuraxial hematoma.

Fluid and Temperature Management:

Unless specifically guarded against, progressive hypothermia may occur during MIDCAB, delaying extubation or causing shivering in the postoperative period that may increase oxygen requirements significantly. Ambient air warmers may be used to maintain normothermia [Sessler 1992]. Unlike regular CABG with CPB, MIDCAB does not involve local cooling of the heart, and therefore the core temperature can be reliably monitored using the PA catheter blood temperature. Patients should not be extubated unless the core temperature is above 36°C. Unlike many centers, our facility has found that it is not necessary to maintain an elevated operating room temperature. Use of a warm air blower (Bare Hugger") positioned around the patient's head only, along with use of an IV fluid warmer, is more than sufficient to maintain body temperature at 36°C without risk of cerebral hyperthermia.

Careful attention should be paid to fluid balance. Adequate intravascular volume status is important for hemodynamic stability and organ perfusion. In general, we attempt to titrate fluid therapy to maintain pulmonary capillary wedge pressure (PCWP) at patients' preoperative values, 12-15 mmHg. In the event that conversion to CPB is required after several hours, the addition of pump prime solution may result in significant crystalloid fluid overload. The perfusionist must be aware of this potential for fluid overload, with the possible requirement for ultrafiltration during rescue CPB in such stand-by cases.

Postoperative Management:

Postoperatively, RAVECAB patients need to be closely monitored for anastomotic patency, myocardial ischemia and infarction, arrhythmia, and postoperative bleeding. Optimal nurse/patient ratio is important to accomplish this monitoring. It is also important to establish nursing education both at the post-anesthesia care unit (PACU) and the ward level. A standardized protocol for determining which patients will be suitable, specific extubation criteria, how long patients will spend in the PACU, and specific criteria to determine their transfer to a ward bed should be clearly defined.

CONCLUSION

As we have previously demonstrated, heart surgery patients who are able to avoid CPB and aortic instrumentation, despite the considerably longer intraoperative duration associated with RAVECAB, have a significantly lower incidence of cognitive dysfunction after surgery than patients undergoing conventional CABG [Murkin 1999]. This benefit, along with the shorter duration of postoperative hospitalization, is one of the chief advantages of the RAVECAB/MIDCAB technique.

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