Review Article

Anesthetic challenges in minimally invasive cardiac surgery: Are we moving in a right direction?

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ABSTRACT

Continuously growing patient's demand, technological innovation, and surgical expertise have led to the widespread popularity of minimally invasive cardiac surgery (MICS). Patient's demand is being driven by less surgical trauma, reduced scarring, lesser pain, substantially lesser duration of hospital stay, and early return to normal activity. In addition, MICS decreases the incidence of postoperative respiratory dysfunction, chronic pain, chest instability, deep sternal wound infection, bleeding, and atrial fibrillation. Widespread media coverage, competition among surgeons and hospitals, and their associated brand values have further contributed in raising awareness among patients. In this process, surgeons and anesthesiologist have moved from the comfort of traditional wide incision surgeries to more challenging and intensively skilled MICS. A wide variety of cardiac lesions, techniques, and approaches coupled with a significant learning curve have made the anesthesiologist's job a challenging one. Anesthesiologists facilitate in providing optimal surgical settings beginning with lung isolation, confirmation of diagnosis, cannula placement, and cardioplegia delivery. However, the concern remains and it mainly relates to patient safety, prolonged intraoperative duration, and reduced surgical exposure leading to suboptimal treatment. The risk of neurological complications, aortic injury, phrenic nerve palsy, and peripheral vascular thromboembolism can be reduced by proper preoperative evaluation and patient selection. Nevertheless, advancement in surgical instruments, perfusion practices, increasing use of transesophageal echocardiography, and accumulating experience of surgeons and anesthesiologist have somewhat helped in amelioration of these valid concerns. A patient-centric approach and clear communication between the surgeon, anesthesiologist, and perfusionist are vital for the success of MICS.

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INTRODUCTION

Increasing use of laparoscopy in general surgical population prompted Cosgrove to venture into minimally invasive cardiac surgery (MICS) in 1996.[1] MICS generally comprises of a wide variety of cardiac surgical procedures performed through a limited surgical access or by a reduced surgical intervention. However, the consensus definition of MICS still eludes us.[2] It can be performed with or without cardiopulmonary bypass (CPB). Vanermen enumerated four type of less invasive cardiac surgery, namely direct coronary artery surgery on the beating heart, limited or modified approaches using traditional technique and instruments with either conventional CPB or endovascular CPB system, minimally invasive direct coronary artery bypass (MIDCAB) on the beating heart through a parasternal or a small left lateral thoracotomy, and true port access surgery,

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in which all surgical acts are performed through ports.[3] Anesthetic approaches to these surgeries is based on the nature of surgery ([coronary artery bypass grafting (CABG), valve procedures or congenital heart lesions]), surgical incision (sternotomy, ministernotomy, parasternal, thoracotomy, or port access), surgical approaches (video assisted, robotic technology, or direct vision), and perfusion practices (beating or nonbeating heart, cannulation techniques, cardioplegia delivery, aortic clamping, and venting). Anesthesia practices are continually evolving with the advancement and innovations in MICS. The cardiac anesthesiologist is becoming more accustomed and experienced in managing these types of surgeries. In this review, we will discuss the anesthetic challenges associated with MICS and the issues ranging from preanesthetic evaluation, premedication, monitoring, vascular access, perfusion techniques, intraoperative, and postoperative care.

PREANESTHETIC EVALUATION

A focused history, relevant physical examination, and laboratory investigation are an integral part of preanesthetic evaluation. The role of the cardiac anesthesiologist in surgical decision making, patient's preferences interpretation, and prognosis deliberation is rapidly increasing. However, it is still unevenly spread across the globe. Traditionally, anesthesiologist generally relies on the surgical decision already made by the surgeons. However, the involvement of the anesthesiologist in shared decision making from the beginning of patient evaluation appears reasonable to avoid the unnecessary change in plan or cancellation of surgery at the last stage. The presence of risk factors which would alter the plan of MICS should be sought at the earliest, these include peripheral vascular disease, aortic atheroma, congestive cardiac failure, chronic lung disease, chest irradiation, obesity, pulmonary hypertension, and previous cardiac surgery.[4,5] A detailed systemic inquiry should be done to exclude the presence of esophageal and gastric disease such as hiatal hernia, esophageal web, and varices, which would preclude the use of transesophageal echocardiography (TEE). In addition, cerebrovascular disease, neuromuscular disease, and orthopedic abnormality should be sought to avoid the complications associated with the patient's position. History of peripheral vascular disease requires aortogram with a distal run off, venogram, and echocardiographic assessment of ascending and thoracic aorta.[6] The requirement of single-lung ventilation in the majority of MICS procedures mandates an evaluation of pulmonary function. Baseline arterial blood gas parameters give a reasonable assessment of lung parenchymal function and can predict the oxygenation status during single-lung ventilation. Single-lung ventilation is not recommended in patients with resting hypercarbia ($PaCO_2$ >50 mmHg), hypoxia (PaO_2 <65 mmHg on room air), significantly lower forced vital capacity, and forced expiratory volume in 1 s.[7,8] A detailed external and internal oropharyngeal examination become necessary to find predictors of difficult ventilation and tracheal intubation, especially if the patient requires lung isolation. In addition, cervical mobility and condition of dentition should be looked into.

PREANESTHETIC MEDICATION AND MONITORING

Patients who prefer MICS are generally of younger, middle-aged male and female. They tend to be more anxious and require adequate anxiolytic a day before and on the day of surgery. An addition of mild sedation is of great help in these patients. Essential monitoring required for minimally invasive is similar to that of open cardiac surgery that includes an electrocardiogram, capnograph, invasive blood pressure, central venous pressure, oxygen saturation, core temperature, and urine output. In addition, transesophageal echocardiographic probe and external defibrillator pads are mandatory in these procedures. Proper placement of defibrillator pads is essential so that current delivery should be optimized to restore the sinus rhythm. The position of electrocardiogram lead may vary depending on the position of patient, site of the incision, and approaches to surgery. The altered lead position coupled with associated pneumothorax may hinder the interpretation of myocardial ischemia, amplitude, and electrical axis. Balloon cardioplegia delivery requires placement of both left and right radial arterial catheter. We should be careful while interpreting the invasive mean blood pressure reading, especially if differences are there between the two radial line pressures. It could be due to pressure exerted on limb arisen because of patient position. One groin should be spared for placement of arterial and venous cannula. No attempt should be made to do puncture on both sides of the groin to place venous and arterial catheter for monitoring purposes. If the surgeon opts for superior vena cava (SVC) cannulation, then it would be ideal to place a central venous catheter in the left internal jugular vein and the right internal jugular vein should be used for SVC cannulation to avoid infection and to prevent inadvertent pulling out of central venous catheter during removal of SVC cannula. In the event of coronary sinus cardioplegia delivery and SVC cannulation, the left femoral central venous catheter should be preferred. Placement of oxygen saturation probe should be determined by patient position during surgery, site of arterial catheter, and accessibility.

INDUCTION AND MAINTENANCE

The variety of approaches and peculiarity of each cardiac lesion in MICS has many implications in intraoperative anesthetic management.[9-16] Physiologic behavior to cardiac manipulation is often unpredictable in CABG surgery. The anesthetic agent is tailored according to the number of target coronary arteries revascularized in MIDCAB, total endoscopic coronary artery bypass, or robotic-assisted CABG. Their uses are based on the desired cardiac grid of a particular cardiac lesion. In coronary artery disease and valvular stenotic lesion, tachycardia, fall in systemic vascular resistance and reduction in cardiac contractility, should be avoided. Cardiac manipulation results in decreased venous return, cardiac index, mean blood pressure, mixed venous oxygen saturation, and increased pulmonary occlusion pressure.[17] Trendelenburg maneuver partially restores the hemodynamic alterations toward baseline during manipulation and altered the cardiac position.[17] Off-pump coronary anastomosis requires quite cardiac motion and this could achieve by either pharmacologic manipulation and mechanical stabilizer or combination of both.[18] Mechanical stabilization provides better limitation of heart motion, better preservation of hemodynamic parameters, and improved anastomotic patency rates.[19-22] The available options for timely extubation include total intravenous anesthesia (propofol/fentanyl or remifentanil), inhalational anesthesia with supplemental short-acting opioids, and avoidance of long-acting vagolytic muscle relaxant (pancuronium).[23-27] Pharmacological stabilization can be achieved by beta-blockers (esmolol and metoprolol), verapamil, diltiazem, adenosine, and neostigmine.[28-33] Cardiac standstill may be required to control bleeding during coronary anastomosis and is produced by persantine and rapid intravenous adenosine or vagal stimulation.[34] Following this, if the sinus rhythm does not revert spontaneously, the epicardial pacing is required. A phenylephrine or noradrenaline or volume infusion becomes necessary to maintain mean arterial pressure and augment coronary perfusion during coronary anastomosis.[10,14] A sudden and severe reduction in mean arterial pressure may require insertion of an intraaortic balloon counterpulsation (IABP), use of femoral-femoral bypass or conventional CPB, or use of coronary infusion catheter.[35,36] Early recognition of myocardial ischemia by electrocardiography and echocardiography during target vessel anastomosis in altered cardiac position proves difficult to interpret. Pulmonary artery catheter and continuous cardiac output monitoring may help in early detection of hemodynamic instability.[37,38] Shorter durations (approximately 10 min) of target coronary vessel occlusion is generally well tolerated. Prophylactic anti-ischemic measures such as calcium channel blocker, beta-blocker, and nitrates with augmentation mean arterial pressure appears reasonable to prevent myocardial ischemia during target vessel occlusion. The valvular regurgitant lesions require a reduction in systemic vascular resistance, preservation of cardiac contractility, and avoidance of bradycardia. Systemic and pulmonary vascular resistance should be optimized to reduce the excessive pulmonary blood flow or to prevent the shunt reversal in left to right cardiac shunt lesions.

Preoxygenation, on-site airway assessment, fluid boluses, and preparation for double lumen tube placement should be ascertained before anesthetic drug administration and endotracheal or endobronchial intubation. Difficulty in endobronchial intubation with double lumen tube and inadequate lung isolation should be conveyed to the surgeon, and the alternate plan should be discussed with the surgeon and patient's relative. Difficulty with transesophageal echocardiographic probe placement and inability to place it usually preclude us from minimally invasive surgery. Anesthesia maintenance and drug administration are generally consistent with a cardiac grid of a particular cardiac lesion. The depth of anesthesia and adequate muscle relaxation should be maintained with the help of bispectral index and train of four to avoid inadvertent movement of the patient.[39] Patient position during these surgeries may predispose nerve compression and furthermore, instruments used for minimal access such as robotic arms may aggravate the compression by impinging upon the pressure points. Pressure points should be padded to prevent neuropathy. Warming devices and hot water mattress maintain normothermia and thus allows early extubation. One lung ventilation couple with carbon dioxide insufflation needs continuous monitoring with capnograph and airway peak and plateau pressure monitoring to avoid hypoxemia, hypercardia, and barotrauma. Management of arterial oxygen desaturation during one lung ventilation is challenging, especially in patients with mitral stenosis and mitral regurgitation.

The strategy in this scenario is to optimize fractional inspiration of oxygen, augmentation of cardiac output, and use of drugs that have minimal effect on hypoxic pulmonary vasoconstrictor response. Application of positive end expiratory pressure to the ventilated lung and application of continuous airway positive pressure may alleviate hypoxemia. Despite these efforts, if the patient still remains hypoxemia, an alternate plan for sternotomy and open cardiac surgery should be made with the resumption of double-lung ventilation. Carbon dioxide insufflation poses additional challenges in a patient with one-lung ventilation. Insufflation pressure is generally kept below 10 mm of Hg, higher than 10 mm of Hg causes increase in intrathoracic pressure, decrease in venous return, cardiac output, and mixed venous oxygen saturation.[40] This effect is accentuated in patients with compromised ventricular function.[41] Intrapleural pressure monitoring is essential during carbon dioxide insufflation to prevent pneumothorax and capnothorax and a pressure relief system should be in place to avoid hemodynamic collapse.[42,43] Regional anesthesia in MICS is still limited to local anestheic infiltration. Thoracic epidural and paravertebral block usage are based on institutions, surgeons, and anesthesiologist's preference with the informed participation from patients. Thoracic epidural anesthesia has been associated with improved analgesia, pulmonary function, earlier extubation, and reduced arrhythmias in patients undergoing CABG.[44] Thoracic paravertebral anesthesia is comparable to thoracic epidural anesthesia in procedures involving unilateral thoracotomy incision.[45] However, the increased risk of neuraxial hematoma and possibility of neurological deficit associated with systemic heparinization during cardiac surgery has prevented their generalization despite proven benefits.

TRANSESOPHAGEAL ECHOCARDIOGRAPHY

TEE helps in confirmation of preoperative diagnosis, cannulation, cardioplegia delivery, and venting. Studies have reaffirmed its role in decision making in both open cardiac surgery and MICS and it has proven role in reducing cardiovascular complications.[46,47] The decision to proceed MICS with patient consent is based on preoperative diagnosis. In addition to the confirmation of preoperative diagnosis, it can further reveal any additional cardiac lesions which preclude from MICS. Patent foramen ovale, sinus venous atrial septal defect (ASD), and left side superior vena cava are (LSVC) sometimes remain undetected during preoperative diagnosis. Detection of ASD and LSVC rules out the possibility of MICS. Partial anomalous venous connection is present in almost 90% of patients with sinus venosus ASD and it is difficult to reroute.[48] Similarly, coronary sinus type ASD is commonly associated with LSVC. LSVC require an additional percutaneous cannulation, especially if MICS involves opening of the cardiac chambers. Inadequate venous return and ventricular distension during CPB indicate the presence of LSVC if the venous cannula is in proper position. In addition, the presence of right atrial mass or myxoma should be ruled out. The presence of patent foramen ovale in patient undergoing MIDCAB prevents us from proceeding. Surgeons generally avoid MICS if combined lesion such as the presence of ASD in addition to valvular lesion is detected. Unusually prolonged CPB and aortic cross-clamp time virtually negate the benefit of MICS. Patency and the size of SVC, inferior vena cava (IVC), and coronary sinus should be determined to facilitate the calculation and cardioplegia delivery. The aortic diameter and the patency of the aortic valve are assessed to find the way for cardioplegia delivery. Endovascular balloon occlusion is generally not advised if the ascending aortic diameter exceeds 45 mm. Aortic regurgitation is a contraindication to MICS except when aortic valve repair or replacement is required. Furthermore, ascending and descending aorta should be assessed for the presence of atheromatous plaque. Atheroma may dislodge during navigation of the guidewire and threading of arterial cannula and exposes the patient to the risk of systemic embolization. It is not advisable to do MICS in the presence of severe pulmonary hypertension as it is associated with poor prognosis.[49] Assessment of systolic and diastolic function becomes essential to predict postoperative inotrope, vasopressor, or vasodilator requirement. A single venous cannula is used to drain both SVC and IVC except in ASD. Guidewire before venous cannulation should be followed in midesophageal bicaval or modified bicaval view. Intravenous heparin in a dose of 1 mg/kg is administered before guidewire insertion. Guidewire may occasionally enter the right hepatic vein and may create difficulty in IVC cannulation. If it is seen entering the right hepatic vein, it should be redirected toward the right atrium (RA). Venous cannula should be advanced to SVC and kept 2 cm above the RA-SVC junction. An abnormally large Eustachian and the thebesian valve may block the venous cannula port and can obstruct venous drainage during CPB. The venous cannula may get obstructed by interatrium septum and might damage it. Patent foramen ovale can produce airlock in venous drainage. Preoperative computed tomography angiogram could be of help in determining the diameter of the femoral and iliac arteries. Aortic cannula should be less than the diameter of the femoral and iliac artery. Guidewire should be seen entering the ascending aorta before threading the aortic cannula. Guidewire may cause an intimal tear, aortic perforation, and aortic rupture. An excessive elevation in perfusion line pressure or detection of intimal flap could be an indicator of aortic dissection. A sudden and severe reduction in right or left radial arterial pressure indicates either intrathoracic or intraperitoneal hemorrhage or entry of guidewire in either brachiocephalic artery or left subclavian artery. There should always be a low threshold for conversion into wide incision cardiac surgery. Aortic dissection requires low blood pressure to prevent propagation and definitive correction that may include deep hypothermic circulatory arrest. In the event of aortic perforation or rupture, large volume warm crystalloid, colloid, and red blood cell infusion are required to maintain hemodynamic stability. Wide incision laparotomy is considered immediately to control the hemorrhage and aortic repair. Antegrade cardioplegia delivery with the help of a triple lumen balloon-tipped catheter is challenging and balloon requires frequent positional verification by TEE to ensure adequate cardioplegia delivery, venting, and pressure monitoring.[50] Difference in radial arterial pressure tracings suggest balloon displacement and getting an adequate TEE window for balloon reposition in an empty heart is difficult to achieve. Similar performances of endoaortic balloon occlusion and aortic transthoracic clamping in terms of feasibility and procedural efficacy have been reported.[51] Retrograde cardioplegia delivery needs the determination of the diameter and patency of the coronary sinus. Abnormally dilated coronary sinus suggests LSVC, ostial narrowing, or intracardiac shunts.[52] Live three dimensional echocardiography provides greater visibility and thus ensures precision in coronary sinus balloon placement.[53] The ratio of the diameter of coronary sinus and balloon should be kept below one to prevent its damage.[54]

Completeness of the surgical procedure, de-airing, and assessment of cardiac function should be ensured before coming off from CPB. Ensuring the adequacy of surgical procedure is mandatory for uneventful recovery and long-term prognosis. Residual defects in septal defect closure, grading of prosthesis-patient mismatch in mitral and aortic valve replacement, and paravalvular leak should be ruled out before termination of CPB. A difference between calculated and predicted effective valve orifice area indexed to body surface area coupled with high mean and peak pressure gradient across the prosthetic valve suggest prosthesis-patient mismatch.[55] The severity of aortic or mitral paravalvular regurgitation is defined by accepted aortic or mitral regurgitation criteria such as jet width, jet density, regurgitant volume, aortic diastolic flow reversal in aortic regurgitation, and pulmonary vein flow reversal in mitral regurgitation.[56] The reasonable quantification of paravalvular leak is a challenge, especially if it is multiple. The assessment of severity is hampered by jet eccentricity and Coanda effect. However, the guideline suggests a paravalvular leak as mild if the proportion of regurgitant areas to the circumference of prosthesis is <10% and severe if it is >20%.[57] Three dimensional TEE is better suited for the evaluation of paravalvular leak as it helps in determination of size, shape, location, and planimetry of valve area.[58,59] In addition, urine should be checked for hemolysis. Similarly, adequacy of mitral valve repair is ensured. The postrepair valvular stenosis and regurgitation should be assessed. The peak and mean mitral valvular pressure gradient should be below 17 and 7 mm of Hg, respectively.[59] Residual mitral regurgitation is evaluated for its significance based on flow convergence, vena contracta, and regurgitant volume ideally at a systolic pressure of 140 mm of Hg. Hemodynamic instability in the post-CPB period may suggest systolic anterior motion, especially in mitral valve repair and aortic valve replacement. Infusion of volume, vasopressor, and reduction in cardiac contractility may stabilize hemodynamic parameter if it is due to systolic anterior motion.[60] Systolic anterior motion associated with moderate to severe mitral regurgitation needs definitive correction. In addition, sustained hemodynamic instability during post-CPB period could be due to inadvertent air entry into coronary circulation. Right ventricular dysfunction and inferior electrocardiographic ST change point toward air emboli in right coronary circulation. Vasopressor with a coronary dilator may mitigate this transient reduction in the ventricular function. A thorough search should be made to find the reasons, if there is continued difficulty in separation from CPB. There should always be a low threshold for sternotomy to correct the reversible and residual cardiac lesions if it is not possible with MICS as patient’s life is paramount.

Tear and transaction of the femoral and iliac artery may happen during arterial cannula removal, especially if the diameter of arterial cannula approximates the diameter of the femoral and iliac artery. The increased risk of vascular complications and stroke has been consistently observed in percutaneous cannulation as compared to the central cannulation.[61,62] Similarly, venous tear and transaction may happen during venous cannula removal. We should always ready to mitigate this catastrophe.

POSTOPERATIVE MANAGEMENT

Patients with MICS generally have lesser pain, shorter duration of ICU stay if surgery is uneventful. However, the complications associated with peripheral cannulation always linger. Arterial repair following decannulation may compromise the arterial flow to extremities, upper or lower, according to arteries (femoral or axillary) chosen for cannulation. The repair site becomes very prone to arterial thrombosis. Similarly, repair of femoral vein following decannulation becomes a potential source of venous thrombosis and pulmonary thromboembolism. Arterial catheter navigation can dislodge atheromatous debris or thrombi and can produce neurological, liver, and kidney dysfunction. Postoperative monitoring with the help of manual peripheral arterial palpation, Doppler, and duplex ultrasound is required to assess arterial insufficiency and venous thrombosis. Adequate pain control with multimodal analgesia and early mobilization further helps in speeding the recovery.

CONVENTIONAL VERSUS MINIMALLY INVASIVE CARDIAC SURGERY

Both techniques may cause transient neuropathy, permanent neurological deficit, pain, perioperative myocardial infarction, renal events, low cardiac output syndrome, pericardial tamponade, cardiac rupture, postcardiotomy syndrome, need for inotropes, need for an IABP, infective endocarditis, pulmonary events, and gastrointestinal events did not differ across studies in patients undergoing mitral valve surgery.[63-71] However, a society of thoracic surgeon database revealed a higher incidence of stroke (odds ratio-2) in MICS group compared to classical sternotomy with central cannulation.[61] In an another meta-analysis, the incidence of stroke was found to be similar.[63] Learning curve associated with MICS is largely responsible for variance in complications reported across the institutions. The incidence of phrenic nerve palsy and groin hematoma and infection were found to be higher in the minimally invasive group.[66,67] Nevertheless, the incidence of society of thoracic surgeons (STS) defined overall complication rate was similar between the MICS and conventional sternotomy approach for mitral valve surgery.[72]

FUTURE DIRECTION

The main concern during MICS is patient safety, which arises due to reduced surgical exposure. Inadequate surgical repair and associated complications are getting increasingly diagnosed by three-dimensional and four-dimensional TEE. Matrix array probe and echocardiographic software are continuously getting upgraded. It would allow the anesthesiologist to detect all possible complications and residual cardiac defects postoperatively. Anesthesiologist's approaches to MICS will change with innovations in anesthesia drug delivery, monitoring devices, and increasing use of newer and short-acting anesthetic and analgesic drugs. Technological innovations in thermal imaging, Doppler technology, and contrast echocardiography have helped us in ascertaining the graft patency after coronary revascularization. Anesthesiologist role will continue to grow with the increasing use of percutaneous technology and hybrid operating rooms. Furthermore, additional cardiac lesions would also continue to come under the ambit of MICS with the evolving expertise of surgeons. Surgical approaches and treatment modalities would further change with innovations in endoscopic robotic-assisted MICS with computer elimination of tremor and motion scaling.

CONCLUSION

MICS encompasses wide ranges of cardiac lesions managed with a variety of surgical approaches and techniques. Reduced cardiac exposure, percutaneous cannulation, and confirming the adequacy of surgical procedures have led to increasing reliance on TEE. Re-establishing the diagnosis to assess the eligibility for MICS, provision of optimal surgical field, and an application of appropriate monitoring modalities consistent with cardiac lesions, approaches, cannulation, and cardioplegia delivery are indeed challenging. Minimal invasiveness requires maximum awareness and vigilance from the surgeon and the anesthesiologist equally. Continuous coordination and communication among all stakeholders (surgeon, anesthesiologist, and perfusionist) is essential at each step of MICS to deal with perfusion associated emergencies.

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Conflicts of interest
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