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REVIEW ARTICLE

Anesthesia Management in Minimally Invasive Cardiac Surgery: A Comprehensive Protocol

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ABSTRACT

Minimally invasive cardiac surgery (MICS) has emerged as an alternative to conventional median sternotomy, offering benefits such as reduced trauma, faster recovery, and decreased postoperative complications. However, MICS presents unique challenges for anesthetic management, including airway control, one-lung ventilation (OLV), hemodynamic stability, pain management, and postoperative recovery. This article provides a structured anesthesia protocol for MICS, focusing on preoperative assessment, perioperative management, and postoperative care.

Keywords: Anesthesia protocol, cardiac anesthesia, cardiopulmonary bypass, harlequin syndrome, minimally invasive cardiac surgery, one lung ventilation, pain management, perioperative management

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Introduction

Minimally invasive cardiac surgery (MICS) is increasingly performed due to its advantages over traditional open-heart surgery. While reducing surgical trauma, it also demands a tailored anesthetic approach to address specific challenges, including limited surgical access, the need for lung isolation, and modified cardiopulmonary bypass (CPB) strategies. This article outlines a comprehensive anesthesia protocol for MICS, aiming to optimize patient outcomes.

Incision Types

Proper patient selection is crucial to ensure the safety of MICS. Suitable candidates should have adequate cardiopulmonary function and no absolute contraindications such as severe aortic calcification or severe generalised peripheral arterial disease.[1,2]

The upper hemi-sternotomy, often referred to as J-sternotomy, is frequently utilized for procedures involving the aortic valve, aortic root, and/or ascending aortic pathologies. The lower hemi-sternotomy, also known as inferior partial sternotomy, is rare and primarily used for mitral and tricuspid valve surgeries, atrial septal defect (ASD) and patent foramen ovale (PFO) repairs, as well as cardiac tumor excisions.[1,3] Right anterior mini-thoracotomy (RAT) is performed through the 2–3rd intercostal space and is primarily used for aortic valve and aortic root procedures.[1] Right anterolateral mini-thoracotomy, an approach made via the 4–5th intercostal space, is predominantly chosen for mitral and tricuspid valve surgeries. These procedures can be carried out using direct vision, endoscopic (port-access), or robotic techniques. Direct vision techniques typically involve the use of an invasive rib retractor, which can lead to postoperative discomfort. In contrast, port-access and robotic approaches avoid the need for rib spreading, thereby minimizing trauma.[2,3]

For coronary bypass grafting, a left anterolateral mini-thoracotomy is commonly performed. In minimally invasive direct coronary artery bypass (MIDCAB), the internal mammary artery graft can be harvested through direct vision, endoscopic techniques, or robotic assistance. Additionally, total endoscopic coronary artery bypass (TECAB), total endoscopic right anterior thoracotomy (TERAT) for valve and ASD procedures are becoming popular.[4,5]

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All types of MICS incisions are shown in Figure 1. Incision size has a significant impact on postoperative pain, beyond the anatomical and procedural differences outlined in Table 1. MICS can be classified into four levels of invasiveness.[5]

Preoperative Assessment and Preparation

Preoperative optimization of comorbidities in MICS is crucial for ensuring the best possible outcomes. This process involves thoroughly assessing, managing, and optimising any existing health conditions, such as diabetes, hypertension, renal-hepatic, or respiratory issues, before the surgery. By stabilizing these conditions, the risk of complications during and after the procedure is significantly reduced.

A thorough patient history is essential as it provides a comprehensive overview of the patient's past illnesses, surgeries, allergies, and family health history. This information helps in identifying potential risk factors and tailoring the surgical approach to the patient's unique needs. Patients undergoing cardiac surgery are often elderly and may already be taking multiple medications with anticholinergic effects. Additionally, perioperative drugs used for anesthesia, sedation, and postoperative pain management can contribute to anticholinergic burden, increasing the risk of complications.[6]

Anticholinergic burden refers to the cumulative effect of medications with anticholinergic properties, which can lead to cognitive impairment, delirium, cardiovascular complications, and other adverse effects, especially in older patients or those with comorbidities. Reviewing the patient's current medications is vital to avoid dangerous interactions and ensure that all medications are used correctly.

A thorough preoperative airway examination is critical for identifying potential difficulties during intubation and ventilation.[7] Proper airway assessment helps in planning the anesthesia strategy and ensuring that the necessary equipment is available to manage any challenges that may arise. Pulmonary function tests are necessary to assess any decreased pulmonary capacity, as these may affect one-lung ventilation tolerance.[8] Studies have shown that the risk of postoperative pulmonary complications increases significantly when the forced expiratory volume in one second is less than 40% of the predicted value.[9,10]

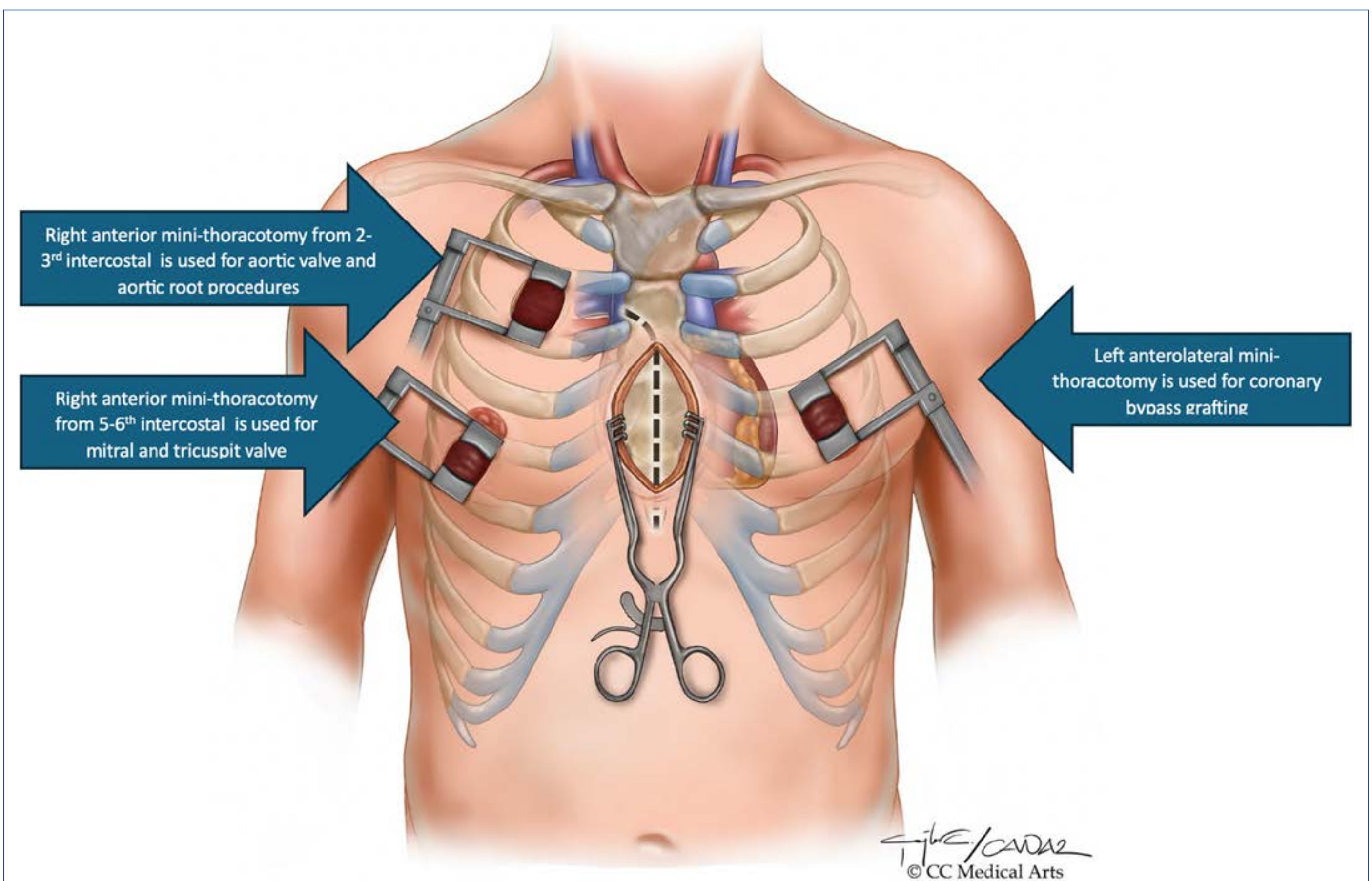

Figure 1. Most incision types used in minimally invasive cardiac surgery (MICS) are presented.

Table 1. MICS can be classified into four levels of surgical invasiveness

MICS level	Incision size	Surgical approach
Level 1	10–15 cm	Direct visualization
Level 2	4–6 cm	Direct visualization with video assistance
Level 3	1.5–4 cm	Video-assisted and robotic procedures
Level 4	< 1.5 cm	Robotic telemanipulation and totally endoscopic port-access surgeries

MICS: Minimally invasive cardiac surgery.

Additionally, a partial pressure of oxygen below 60 mmHg or a partial pressure of carbon dioxide above 50 mmHg contraindicates the use of one-lung ventilation (OLV). Furthermore, diffusing capacity of the lung for carbon monoxide values below 40% are associated with a higher incidence of postoperative pulmonary complications.[9–11]

Intraoperative Anesthetic Management

Monitoring and Hemodynamic Management

Besides routine cardiac anesthesia monitoring such as ECG, pulse oximetry, capnography, invasive arterial blood pressure, central venous pressure, and temperature monitoring, advanced monitoring techniques are required in MICS. Transesophageal echocardiography (TEE) allows the evaluation of existing cardiac pathologies and surgical success in the pre- and post-procedure period. During TEE, several mandatory points must be addressed. Firstly, it is essential to rule out significant aortic valve regurgitation. The size and morphology of the aortic root and ascending aorta should be carefully assessed. Any atheromatous disease in the aorta should be identified and reported. The presence of an ASD or PFO must be noted. It helps in the navigation of the guide wire and correct placement of the cannulae (Fig. 2). The positioning of the endoballoon occluder—if used—must be guided. Additionally, the placement of other lines, such as pulmonary artery vents or coronary sinus catheters, should be directed if used. The presence of thrombus, intracardiac air, and myocardial function should also be evaluated.[12]

Processed EEG monitoring assists in maintaining adequate depth of anesthesia and avoiding awareness; in this way, hemodynamic fluctuation is prevented. Hemodynamic targets are to ensure adequate tissue oxygenation by maintaining optimal pressure, stroke volume, and blood flow performance during surgery. For this purpose, hemodynamic monitors such as pulse contour analysis devices and TEE can be used both before and after CPB.[13]

Near-infrared spectroscopy (NIRS) is used to monitor cerebral and tissue oxygenation. It can provide early detection of cannula malpositions, pump flow problems, hemodilution, and ischemic events. Cerebral rSO_2 values below 45 or a decrease of more than 20% from the initial value indicate hypoperfusion.[14] In such cases, technical factors like NIRS sensor placement, head position, and cannula positioning are first assessed. Oxygen delivery is optimized by correcting hypotension, increasing FiO_2, addressing ventilation issues, and ensuring adequate blood flow and pressure. If hemoglobin levels drop below 7.5–8.5 g/dL, erythrocyte replacement is performed. Elevated venous pressure, which may impair cerebral oxygenation, can be managed with low-dose nitroglycerin or increased CO_2 partial pressure.

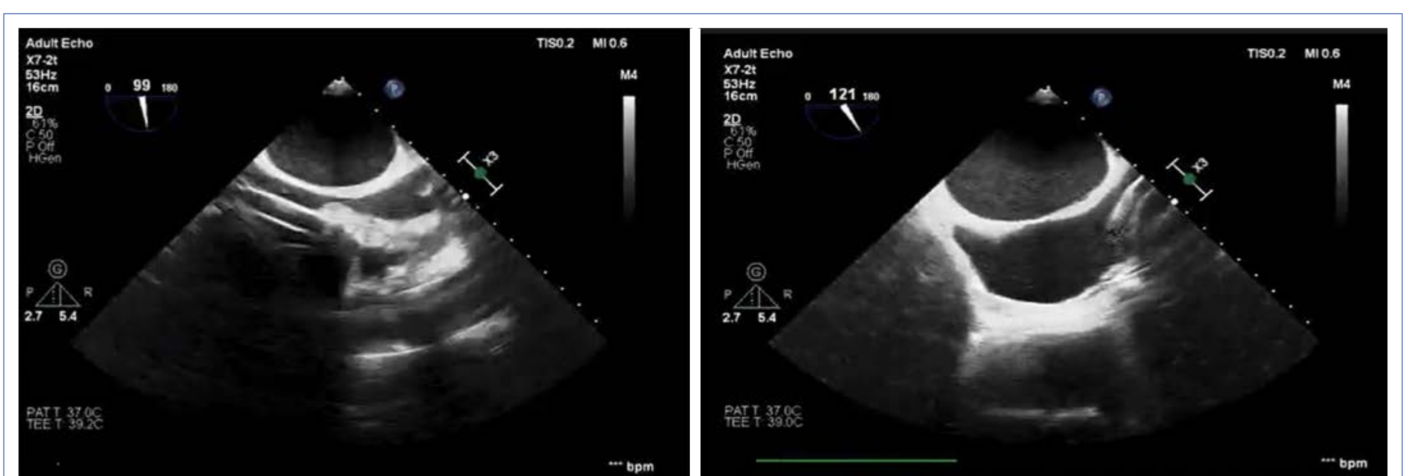

Figure 2. Visualization of guidewire and cannula in the right atrium using transesophageal echocardiography.

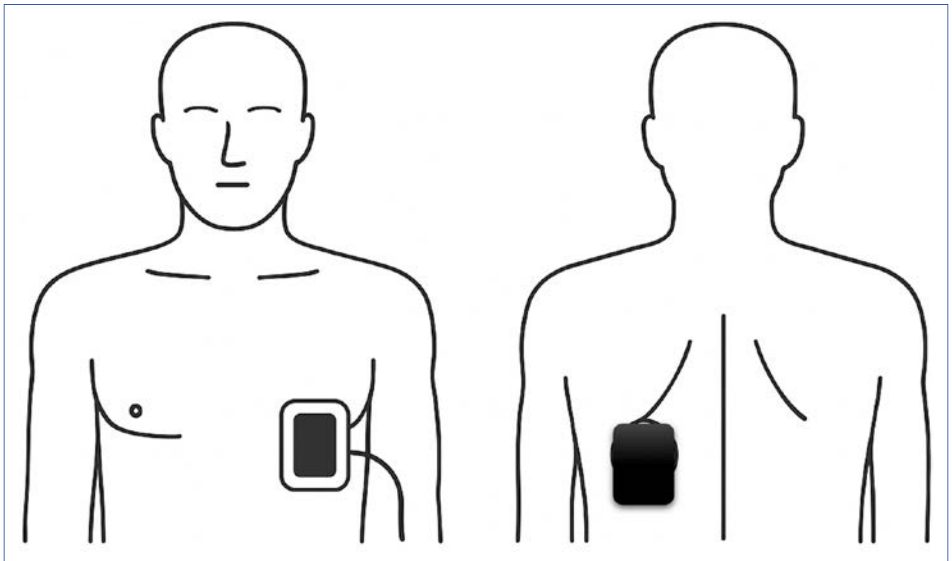

Figure 3. Illustrates an example of an effective defibrillator pad placement for RAT.
RAT: Right anterior mini-thoracotomy.

Additionally, factors that raise oxygen consumption, such as shivering and pain, are controlled.[14,15] It allows the diagnosis of Harlequin syndrome, which will be discussed later.

External defibrillator pads should be placed properly prior to draping to allow for rapid intervention in case of arrhythmias or fibrillation. Figure 3 illustrates an example of an effective defibrillator pad placement for right anterior thoracotomy, positioned at a safe distance from the surgical field.

Airway and Ventilation Strategies

MICS necessitates a limited surgical field and OLV to improve visualization and access to the heart and great vessels. The implementation of OLV presents unique physiological challenges, necessitating careful anesthetic and ventilatory management. Several methods are employed to achieve OLV in MICS. The double-lumen endotracheal tube (DLT) is the most commonly used device, allowing selective lung ventilation and bronchoscopic confirmation. Bronchial blocker (BB) devices provide lung isolation in patients where DLT placement is difficult or according to the anesthesiologist's preference. Selective endobronchial intubation is a simpler technique but with less precise lung isolation.

Although placed under bronchoscopy, DLT and BB displacement and related malfunctions may occur due to various factors. Patient movement during surgery, such as repositioning or changes in body posture, can lead to dislodgement. Additionally, anatomical variations in the patient's airway can complicate the initial placement and stability of these devices. The use of high airway pressures during ventilation can also contribute to displacement, as the increased pressure may push the device out of its intended position. Furthermore, surgical manipulation in the thoracic cavity can inadvertently cause the BB and DLT to shift. Inadequate securing of the device at the time of insertion can result in gradual movement over the course of the procedure. Lastly, the presence of secretions or blood in the airway can obstruct the lumen of the device, rendering it non-functional.

In certain cases, the lower dependent lung needs to be inflated during CPB to enhance surgical visibility. To achieve this, the nondependent lung is deflated while the dependent lung is manually inflated. A clamp is then placed on the endotracheal tube to maintain lung inflation. These factors highlight the importance of careful placement, continuous monitoring, and prompt adjustment of BB and DLT to ensure effective lung isolation throughout procedures.[16]

To optimize oxygenation and minimize lung injury during OLV, several strategies are employed. Low tidal volume (4–6 mL/kg) reduces volutrauma and barotrauma. Positive end-expiratory pressure is applied to the ventilated lung to prevent atelectasis and optimize gas exchange. In intermittent re-inflation, the collapsed lung may be periodically reinflated to improve post-OLV recovery. Following OLV, the collapsed lung should be reinflated cautiously using recruitment maneuvers with a sustained positive pressure (e.g., 20–30 cmH_2O) to prevent atelectasis and ensure optimal postoperative lung function.

CPB Considerations

Anticoagulation is ensured by the standard heparinization protocol with activated clotting time (ACT)>400 seconds before CPB initiation. Arterial cannulation can be performed using various approaches, including central aortic cannulation, femoral artery cannulation (either percutaneous or direct), brachial artery cannulation, and axillary artery cannulation (direct or indirect). The choice of arterial access depends on patient-specific factors such as aortic pathology, peripheral vascular disease, and the need for antegrade cerebral perfusion in complex procedures. According to a study, peripheral arterial cannulation may carry an increased risk of retrograde aortic dissection, limb ischemia, differential perfusion, or embolic stroke, necessitating careful patient selection and intraoperative monitoring.[17]

Venous cannulation strategies include central venous cannulation and femoral vein cannulation (either percutaneous or direct), with vacuum-assisted venous drainage (VAVD) playing a crucial role in optimizing venous return. Effective VAVD is essential for maintaining adequate drainage pressures between 30 and 70 mmHg to prevent excessive negative pressure, which could lead to endothelial damage or air entrainment. Transesophageal echocardiography is widely utilized to confirm optimal positioning of the venous cannula, ensuring unobstructed blood return and preventing complications such as venous airlock or inadequate drainage. In cases requiring superior vena cava (SVC) drainage (>2 body surface area or >80 kg, right atrial procedures, etc.), right internal jugular vein cannulation is often performed, with VAVD.[12,18]

Carbon dioxide (CO_2) insufflation is widely utilized in MICS to reduce the risk of air embolism by displacing ambient air from the surgical field. Due to its high solubility and rapid absorption into the bloodstream, CO_2 effectively minimizes intracardiac and vascular air entrapment, thereby decreasing the incidence of air embolism-related neurological complications.[19] Despite its advantages, excessive insufflation pressures may lead to hemodynamic instability by increasing intrathoracic pressure, potentially resulting in decreased venous return, reduced cardiac output, and transient hypotension. Improper CO_2 delivery techniques, particularly in patients with compromised pulmonary function, can contribute to hypercapnia and respiratory acidosis, necessitating close intraoperative monitoring of arterial blood gases.[20] Another concern is the potential for subcutaneous emphysema, particularly if CO_2 inadvertently tracks along tissue planes due to prolonged or excessive insufflation pressures. To mitigate these risks, controlled CO_2 flow rates (typically 2–5 L/min) and careful monitoring using TEE are recommended to ensure safe and effective application.[21]

For myocardial protection, different cardioplegia methods may be used based on surgical preference.

Harlequin syndrome (differential perfusion) awareness is another crucial issue. During CPB, differential perfusion and oxygenation issues, particularly in cases with femoral arterial cannulation, should be closely monitored. When CPB is initiated, the blood returning from the femoral artery cannula converges with the blood being pumped by the beating heart, complicating the maintenance of optimal circulation. If the lungs are deflated before the application of the aortic cross-clamp, deoxygenated blood may circulate in the upper half of the body. In such scenarios, NIRS becomes crucial.[22,23]

Postoperative Management

Effective postoperative management is crucial for optimizing recovery and minimizing complications following MICS. Early extubation, ideally within 4–6 hours in hemodynamically stable patients, is a key component, reducing the risk of pulmonary complications. Some studies have demonstrated that on-table extubation can be applicable in certain cases, which is linked to a lower risk of postoperative pneumonia and a reduced need for vasopressors.[12,24]

A multimodal analgesia approach is recommended to ensure adequate pain relief while minimizing opioid-related side effects. Regional analgesic techniques, such as paravertebral blocks, erector spinae plane block, serratus anterior plane block, incision catheterization, or epidural analgesia, have been shown to provide superior pain control compared to systemic analgesia alone. These techniques reduce the reliance on opioids, thereby lowering the incidence of opioid-induced respiratory depression, nausea, and constipation. Systemic analgesics, including acetaminophen and, in selective cases, nonsteroidal anti-inflammatory drugs, should be incorporated into the pain management regimen to enhance analgesic efficacy.

Opioid-sparing strategies, such as dexmedetomidine or ketamine infusions, may further reduce opioid consumption while providing effective pain control and sedation. Gabapentinoids and lidocaine infusions may be considered in selected patients to attenuate neuropathic pain and improve overall comfort. However, the current evidence supporting their efficacy and safety remains limited, and further research is ongoing. For instance, a meta-analysis on the perioperative use of gabapentinoids reported that these agents did not provide clinically significant analgesic benefits and were associated with an increased risk of adverse events.[25] Similarly, a study investigating the effects of intravenous lidocaine on postoperative pain and recovery emphasized the need for cautious use, as inappropriate administration could lead to severe complications.[26]

Regular pain assessment using standardized scoring systems is essential to tailor analgesic regimens to individual patient needs, ensuring optimal recovery and early mobilization.

Complications and Catastrophic Events in MICS

MICS has revolutionized cardiac care by offering treatment options for both adult and congenital heart diseases while minimizing surgical trauma. These procedures reduce postoperative pain, shorten recovery times, and improve cosmetic outcomes. However, despite these advantages, MICS presents several limitations and challenges that must be considered.[27]

Airway complications: Airway-related issues remain a significant concern in MICS, particularly OLV. Difficult intubation and airway edema can complicate perioperative management, while malposition of the devices may lead to inadequate lung collapse, impairing surgical exposure. During OLV, ventilated lung pneumothorax can lead to severe hypoxemia. In right infra-axillary thoracotomy, a bronchial plug may induce complete left lung collapse. Hypoxemia and hypercapnia can occur during OLV, necessitating vigilant monitoring and timely interventions to optimize ventilation and gas exchange.

Hemodynamic complications: Hemodynamic instability is a major concern, with hypotension and low cardiac output syndrome observed particularly in patients with pre-existing cardiac dysfunction. The sudden onset of arrhythmias, including atrial fibrillation and ventricular tachycardia, can further compromise circulatory stability. Harlequin syndrome is a rare but serious complication.

CPB complications: Peripheral cannulation increases the risk of limb ischemia and requires meticulous perfusion monitoring. Air embolism, particularly after femoral artery cannulation, poses a significant risk of systemic embolization, including cerebral infarction. Furthermore, myocardial ischemia due to inadequate cardioplegia can result in persistent low cardiac output syndrome, requiring aggressive postoperative hemodynamic management.

Surgical catastrophes: Intraoperative disasters such as iatrogenic cardiac perforation, aortic dissection, or major vascular injury can lead to life-threatening hemorrhage. Uncontrollable bleeding despite meticulous hemostatic measures may necessitate emergent intervention. Cardiac tamponade, resulting from pericardial bleeding, can rapidly progress to hemodynamic collapse if not promptly recognized and treated.

One of the primary concerns associated with MICS is the extended operative duration. According to a meta-analysis, MICS is associated with significantly longer cross-clamp time, CPB time, and total operation time. It may result in low cardiac output syndrome and acute kidney injury.[28,29] Acute kidney injury can also develop due to perioperative hypoperfusion and hemolysis, requiring close renal function monitoring and appropriate supportive therapy. Careful perioperative management, including fluid optimization and hemodynamic stabilization, is essential to mitigate these risks and improve postoperative outcomes. Additionally, complications related to peripheral cannulation, such as increased stroke risk, groin seromas, infections, and, in rare cases, arterial trauma or retrograde aortic dissection, add to the risks of MICS.[30]

Furthermore, unilateral pulmonary edema, an underreported but critical complication, may contribute to increased mortality rates. Stroke remains one of the most devastating complications, occurring either due to embolic events or global hypoperfusion. Postoperative cognitive dysfunction and delirium are also prevalent, particularly in elderly patients, and can significantly prolong recovery. While concerns exist regarding stroke and vascular complications, studies indicate that the risks may not be significantly higher than those in conventional surgery. In an analysis of 2400 MICS patients with femoral cannulation, a 1.17% rate of cerebrovascular events was reported postoperatively, with no cases of aortic dissection, a 0.8% compartment syndrome, a 0.7% femoral arterial pseudoaneurysms, and a 6.65% incidence of groin wound seromas.[31]

Another critical challenge of MICS is the steep learning curve required for surgeons to achieve proficiency. It is emphasized that extensive training is necessary to optimize patient outcomes, particularly in the early adoption phase.[32] The successful application of MICS demands meticulous preoperative planning, mastery of specialized instruments, and advanced surgical expertise. Despite these efforts, conversion to conventional median sternotomy remains a possibility in some cases. It is reported that conversion occurs in approximately 2–3% of cases due to factors such as lung adhesions, cannulation difficulties, hemorrhage, or atrioventricular rupture.[33] This transition is not merely a procedural shift; it is associated with significant perioperative complications and a markedly elevated 30-day mortality rate, exceeding 23% in cases of minimally invasive mitral valve surgery.[34]

Conclusion

Anesthesia for MICS requires a highly specialized approach tailored to the unique challenges of these procedures. Comprehensive preoperative evaluation, meticulous intraoperative management, and structured postoperative care are essential to ensuring optimal outcomes. The integration of advanced monitoring, lung-protective strategies, and multimodal pain control techniques enhances patient recovery and overall surgical success.

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