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Features of modern anesthesiological measures and intensive therapy in cardiac surgery

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This article discusses the pathogenesis, risk factors, and prevention of postoperative complications such as mediastinitis, sternitis, ventilator-associated pneumonia, catheter-related bloodstream infections, sepsis, and prosthetic endocarditis occurring after open and minimally invasive cardiac surgeries. The features of intravenous (propofol, etomidate, ketamine) and inhalational (sevoflurane, isoflurane) anesthetics, opioids (fentanyl, sufentanil, remifentanil), muscle relaxants (rocuronium, cisatracurium), and vasopressors/inotropes (norepinephrine, dobutamine, vasopressin), as well as their hemodynamic implications in cardiac anesthesia, are systematized. In the perioperative period, the implementation of regional oximetry, transesophageal echocardiography, pulmonary function assessment, multimodal analgesia, and the "fast-track cardiac anesthesia" concept are evaluated as promising approaches that accelerate postoperative rehabilitation and reduce complications. Overall, a personalized, multimodal, and evidence-based anesthetic strategy is presented as one of the key components for improving the safety and clinical outcomes of cardiovascular surgery.

Keywords: *Cardiac surgery, anesthesia, infectious complications, minimally invasive cardiac procedures, opioids, hemodynamic monitoring, regional oximetry*

INTRODUCTION

Anesthesia management in cardiac surgery is complex due to the need to balance anesthesia goals with maintaining hemodynamic stability, protecting the heart, and managing organ perfusion (Raphael et al., 2019).

Anesthesia for heart surgery is a critical service, managing the patient's consciousness, pain, and vital functions (breathing, circulation) throughout the procedure and into recovery, requiring specialized cardiac anesthesiologists to handle complex physiological changes, optimize patient status, and ensure a smooth transition to post-operative care for the completion of the treatment and successful outcomes. According to global indicators, with over a million cardiac surgeries annually, anesthesiologists manage extremely complex cases, dealing with high-risk patients, advanced technologies, inflammatory responses, and heart failure, arrhythmias across the entire perioperative period, requiring constant adaptation, advanced monitoring, and skilled teamwork for better outcomes in a globally growing field facing workforce challenges. Recent advances in cardiac anesthesia focus on personalized perioperative care, using AI and big data for better risk prediction, implementing enhanced recovery pathways (ERAS) with faster extubation and less opioids, and integrating advanced monitoring like

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3D TEE and arterial waveform analysis for tailored strategies, leading to improved patient outcomes, shorter hospital stays, and reduced complications. In addition, the development of new technologies (imaging, AI) and minimally invasive methods (laparoscopy, NOTES) are drastically improving surgeries by reducing pain, hospital stays, and recovery times leading to better treatment and overall outcomes (Tnaga et al., 2025).

The last two decades saw a huge rise in minimally invasive surgery for abdominal and thoracic issues, shifting from traditional open surgery to laparoscopic and thoracoscopic techniques, leading to less pain, faster recovery, and becoming the standard of care for many conditions. literature shows surgery is a massive global undertaking, with estimates ranging from over 100 million open and endoscopic surgical procedures needs recent verification highlighting huge demand and significant disparities in access, particularly in lower-income countries. The provided statistics about 100 million surgeries, 2–3.5% complication rates, and 0.5–1.8% mortality from cardiological perioperative complications align with literature findings, though numbers vary, showing hundreds of millions of surgeries happen annually, with perioperative cardiac issues being a major concern, often causing around 1-2% overall mortality, with cardiac causes being significant. At this time, complication rates can range, with some sources citing 5% morbidity or higher for major surgeries, underscoring the importance of risk assessment. Up to 500,000 people yearly face life-threatening heart rhythm issues (ventricular tachycardia, cardiac arrest) or heart attacks around surgery, a major cause of post-operative death, often linked to underlying heart disease. Studies consistently show that age is a primary, independent risk factor for cardiovascular disease, with the incidence of ccardiac omplications like heart failure, stroke, and arrhythmias rising significantly with each decade. While risks compound with other factors, the aging process itself inherently increases heart disease vulnerability. From the WHO snippets by the second half of the 21st century, people over 65 could double their share, suggesting a significant rise of the population by the century's end, highlighting a major demographic shift with calls for better health system. Aging population means more older adults need surgery where improved tech allows complex surgery for those who need it, but better overall care reduces unnecessary procedures. Unlike in previous times, in modern times, major non-cardiac surgical interventions, especially operations on the abdominal organs, are more often performed on patients over 70–75 years of age. Older age groups, people with heart disease, those with other comorbidities, and those taking multiple drugs face significantly higher risks for serious side effects from nonsteroidal anti-inflammatory drugs, including heart attack, stroke, kidney problems, and severe gastrointestinal bleeding (Denisov et al., 2025).

INFECTION RISKS IN CARDIAC SURGERY

It should also be noted that, heart surgery carries a significant risk of surgical site infections, which are serious and can increase mortality, with reported rates varying widely in cardiac surgery clinics (0.9-20%) depending on some factors like diabetes, smoking, obesity, surgical/hospital practices, necessitating strict preventative measures (Stepin, 2022).

Infectious complications after cardiac surgery are significant, occurring in 5% to 21% of cases, raising risk of postoperative mortality, and often extending hospital stays past 14 days for affected patients, leading to common infection sites being the respiratory tract, surgical site, and catheters. Simple preventative measures and vigilant care, from preoperative screening to monitoring in the intensive care unit, can reduce these infections. In patients without severe infection, this figure is only 5.9% ($p<0.0001$). As a result, infectious complications significantly increase the overall cost of medical care. The most common infected sites are the respiratory system (45.7-57.8%), surgical site infections (27.7%), and infections associated with catheters and implanted devices (20.5-25.2%) (Cove et al., 2012).

The common infectious complications after cardiovascular surgery in the postoperative period are deep surgical site infections (sternitis, mediastinitis, wound infection), ventilator-associated pneumonia, bloodstream infections (sepsis, device-catheter-related), Urinary tract infections, and endocarditis (especially in patients

with prosthetic valves), all raising morbidity and mortality, with respiratory and surgical sites being most common, driven by diabetes, patient age and procedure-related elements (Andrioli et al., 2018, Pérez-Granda et al., 2024).

One of the more dangerous localized infectious complications after cardiac surgery is considered to be deep sternal wound infection and mediastinitis. The main risk factors for mediastinitis include: wound discharge, malodorous exudate, hyperthermia, leukocytosis, elevated CRP/procalcitonin, and in severe cases – sepsis, respiratory and hemodynamic disorders (Vos et al., 2018).

Ventilator-associated pneumonia is common in cardiac surgery patients who receive long-term intubation and mechanical ventilation. In this case, it is necessary to pay special attention to the appearance of new infiltrate shadows, fever, purulent tracheal secretion, deterioration of gas exchange, decrease in the PaO□/FiO□ ratio, and clinical and laboratory signs of infection after 48–72 hours (Kalil et al., 2016).

Bloodstream infections and sepsis can develop through central venous catheters and arterial lines. In this case, fever, chills, hemodynamic instability, and pathogens (staphylococci, enterococci, gram-negative bacilli, Candida) are detected in blood culture. Therefore, within the framework of intensive care protocols, attention should be paid to minimizing the duration of catheters, aseptic insertion techniques should be strictly followed, and the catheter should be removed quickly if in doubt (Mermel, 2009).

COMPLICATIONS IN CARDIAC SURGERY

Literature sources confirms that studying mortality and complications in cardiac surgery is of great scientific and practical importance and crucial due to high risks, especially infections, leading to longer stays, higher costs, reoperations, and increased death, with complexities arising from patient comorbidities and the need for specialized anesthesiological and resuscitation measures, making risk factor identification and management essential for better results (Mikailov, 2020).

The etiological structure of each infection is determined by its nosology. It is known that specific pathogens are characteristic for infectious foci with different localization. For example, gram-negative bacteria are most often found in pneumonia and urinary tract infections associated with artificial ventilation. However, the leading role of staphylococci is characteristic for surgical site infections, catheter-related bloodstream infections, and prosthetic endocarditis. Patients with long-term intensive care unit and intensive care unit stays have been shown to have a significantly higher incidence of infections with "problematic" staphylococci, as well as with semi-resistant strains of Acinetobacter baumannii, Pseudomonas aeruginosa, and fungi. Knowledge of these characteristics is essential for selecting adequate empirical antibiotic therapy regimens. Infections caused by microscopic fungi are a major, a serious, growing problem in hospitals, especially in intensive care units, because antibiotics kill good bacteria, allowing fungi to overgrow, and patients receiving repeated courses of antibiotics have weakened immunity, catheters, ventilators, and surgeries, leading to severe, hard-to-diagnose, life-threatening infections with high mortality (Popov, 2013).

Symptoms and signs of cardiac surgery should be identified, as well as any other problems that may be targets for additional surgery. These problems are due to the presence of numerous cardiac pathologies requiring surgical intervention and the limited ability to perform minimally invasive surgery. During echocardiographic examination, special attention should be paid to excluding the presence of poor ventricular function, aortic valve insufficiency, mitral annulus calcification, patent foramen ovale, and persistent left superior vena cava, all of which can significantly complicate minimally invasive cardiac surgery.

Assessment of the general vascular system is crucial especially if peripheral cannulation is planned for cardiopulmonary bypass because it ensures adequate blood flow, identifies risks like limb ischemia, and guides cannula size/placement, often involving Doppler ultrasound and transesophageal echocardiography to check femoral, radial vessel health and prevent complications like malperfusion or organ damage (Malik et al., 2016). In this regard, it is possible to identify the main contraindications by applying CT angiography preoperatively as standard for minimally invasive cardiac surgery. The presence

of aneurysm, significant tortuosity or atheroma, dissection, stents, grafts, or other prior surgical interventions should be carefully evaluated (White et al., 2021).

Thus, the preoperative anesthesia evaluation of a patient undergoing minimally invasive cardiac surgery includes the standard history, examination, and tests performed before any cardiac procedure. When using minimally invasive techniques, increased or special attention should be paid to certain areas. A history of previous thoracic surgery, chest wall or rib abnormalities, and certain inflammatory processes can lead to the development of adhesions and may complicate or prevent minimally invasive cardiac intervention. Severe aortic regurgitation is a contraindication to minimally invasive aortic valve implantation; Some techniques used for minimally invasive aortic valve replacement, such as rapid-deployment valve prostheses and transcatheter aortic valve replacement, can be used in cases of aortic insufficiency. When aortic regurgitation renders the antegrade pathway ineffective, effective cardioplegia is sometimes possible with minimally invasive cardiac surgery using retrograde delivery (Aston et al., 2023).

It is accurately described general anesthesia as a reversible, drug-induced state creating unconsciousness, analgesia, amnesia, lack of sensation, relaxed muscles, skeletal muscle relaxation and depression of sensory and autonomic reflexes, crucial for surgery, especially cardiac procedures, by ensuring patient stability and enabling surgical conditions. This state, induced by various medications, ensures patients don't feel pain, provides unconsciousness, muscle relaxation, and hemodynamic stability, which are essential for successful surgical treatment and making it fundamental for complex operations like heart surgery (Joshi, 2021). Innovations in anesthetic agents, monitoring techniques, and multimodal approaches to anesthesia have significantly improved perioperative care and improved patient outcomes (Zhu et al., 2024). Increased attention to a personalized approach to anesthesia, including individualized drug selection and hemodynamic monitoring, plays a key role in accelerating recovery and minimizing complications in patients undergoing complex cardiovascular surgery. Recent advances in monitoring techniques, such as the use of transesophageal echocardiography and cerebral oximetry, allow for real-time hemodynamic assessment and facilitate more effective intraoperative decision-making. The lack of advanced technologies in cardiac surgery and anesthesiology creates serious challenges such as reduced procedural accuracy, increased risk of complications, and prolonged recovery time. Surgeons face challenges in achieving optimal visualization and control during complex procedures, while anesthesiologists struggle to maintain hemodynamic stability without modern monitoring tools such as transesophageal echocardiography (Mariani et al., 2023). These limitations reduce surgical efficiency, critical decision-making, and increase stress levels. In addition, full intravenous anesthesia with propofol and opioids is increasingly preferred, especially in elderly patients, due to the lower incidence of postoperative cognitive dysfunction. These agents result in shorter ICU stays, faster overall recovery, and fewer complications. As the cardiac surgery landscape continues to evolve, a more personalized approach to anesthesia, taking into account the patient's clinical condition, the type of procedure, and available monitoring technologies, is essential to achieve optimal outcomes (Khalifa et al., 2025).

Traditionally, cardiac surgery which necessitates the use of high-dose opioids and general anesthesia is associated with a high degree of surgical stress due to its invasiveness, triggering significant inflammation, metabolic changes and psychological responses that challenge the body's systems and require robust patient management strategies, including education, support, and tailored nutrition (Ovechkin et al., 2019). Regional anesthesia (spinal/epidural blocks) and neuraxial blockade are considered effective for local nerve blocks and effectively reduce pain signals, lower opioid needs, and calm the body's stress response, have an anti-inflammatory effect when injected into the surgical site (inflammation, increased heart demand) by blocking nerve pathways, offering better heart stability and faster recovery (Boavista Baros Heil et al., 2020).

Some minimally invasive cardiac procedures are performed through a small thoracotomy, and many require single-lung ventilation to provide

adequate surgical access to the heart. The patient may be in the supine or semilateral position. All of these factors predispose to hypoxia, and a history of chronic respiratory disease may exacerbate the condition. Therefore, the threshold for pulmonary function testing should be low. Patients presenting for thoracic surgery may be considered at low risk for postoperative pulmonary complications if their forced expiratory volume in 1 second and transfer coefficient are greater than 40% of predicted, although patients below these values should not necessarily be excluded from surgery, as the outcome is likely to be significant (White et al., 2021). A small retrospective study of patients with chronic obstructive pulmonary disease (COPD) undergoing heart valve surgery showed that the group of patients who underwent minimally invasive techniques had better outcomes, despite the use of single-lung ventilation in this group (Santana et al., 2013).

Thus, the presence of pulmonary hypertension and right ventricular dysfunction should be assessed, as the use of single-lung ventilation can sometimes lead to complications in these patients, including further increase in pulmonary artery pressure, increased right ventricular afterload, and heart failure (Ross, Ueda, 2010). The use of transesophageal echocardiography is widely considered a prerequisite for some minimally invasive cardiac procedures, and contraindications to transesophageal echocardiography are often considered contraindications to minimal access (Aybek et al., 2005). Upper gastrointestinal pathology, such as known esophageal membranes, pouches, or varices, active peptic ulcer disease, hiatal hernia, as well as previous neck and chest surgery or radiation therapy, should be carefully evaluated and the associated risks assessed. Particular attention should also be paid to the patient's position on the operating table, as chest wall deformities, kyphoscoliosis, or other significant musculoskeletal pathology may make it difficult to achieve adequate surgical access. Orthopedic problems of the ipsilateral upper limb that impede access to the hemithorax may complicate surgical access. Certain positions may be prone to brachial plexus injury due to arm traction, so precautions should be taken to minimize this (Aston et al., 2023).

Currently, a multimodal approach is recommended for effective therapy of postoperative pain syndrome, i.e., a combination of analgesic methods aimed at different pathophysiological aspects of nociception should be used (Ovechkin et al., 2019). At this time, non-pharmacological therapy methods - subcutaneous electrical stimulation, massage and acupuncture techniques - are complementary to the concept of multimodal analgesia, but their level of evidence is low and they are not widely used in clinical practice (Chou et al., 2016).

Assessment of the effectiveness of oxygen delivery to organs and tissues remains one of the most important problems of modern cardioanesthesia. One of the indicators indicating the adequacy of oxygen transport and oxygen balance is regional oxygenation (RO), and this parameter indicates the amount of oxygen in the tissues. The use of regional oxygenation to assess homeostasis during anesthesia has a long history. As early as the 1960s, during the formation of the method of artificial blood circulation, tissue oxygenation analysis was used. The lack of widespread use of the method at that time was due to the complexity and high cost of the equipment. The problem remains relevant today, since the assessment of oxygen balance in tissues is of fundamental importance in modern anesthesiology. The emergence of the possibility of real-time monitoring of tissue oxygen status in the last decade has opened new prospects for the application of regional oximetry in the perioperative period (Akselrod, 2014).

ANESTHESIA METHODS. GENERAL ANESTHESIA WITH NARCOTIC ANALGESICS

Cardiac surgeries are complex, high-risk procedures where anesthesia is key to managing acute hemodynamic changes, protecting the heart, preventing complications like rhythm disturbances (arrhythmias) and perioperative infections, and ensuring good recovery by stabilizing blood pressure, maintaining myocardial perfusion, and using anesthetic drugs to reduce risk, safety of the operation all while tailoring postoperative rehabilitation and care to the patient's specific cardiac status (Alwardt et al., 2005).

Using rapid-acting inhalational anesthetics, like propofol, remifentanil, modern volatile agents and opioid-sparing multimodal analgesia (Sridharan, Ueda, 2019), regional blocks enable quicker awakening, faster recovery of consciousness and reflexes, reduced postoperative nausea/vomiting, and early patient activation, aligning perfectly with Enhanced Recovery After Surgery principles for better outcomes.

However, in recent years, the negative effects of opioids during heart surgery have been increasingly emphasized. According to S.de Hooged and co-authors, the use of remifentanil reduces the quality of postoperative analgesia in cardiac surgery and prolongs the duration of medical rehabilitation. In addition, there is information that excessive use of opioids causes immunosuppression, which can negatively affect the outcome of the operation. Therefore, additional methods of analgesia in cardiac surgery patients remain relevant (Paromov, 2021). The drugs used in anesthesia are distinguished by their hemodynamic effects, myocardial oxygen balance, peripheral vascular resistance, as well as their effects on the respiratory system. The anesthesia strategy in modern cardiovascular surgery is based on a multimodal approach and requires an optimal combination of intravenous, inhaled, opioid analgesics, muscle relaxants, and hemodynamic support drugs (Pisano, 2021).

Propofol is one of the most commonly used intravenous anesthetics. Its rapid onset of action and short half-life make it ideal for induction and Total Intravenous Anesthesia (TIVA). However, propofol can cause peripheral vasodilation, lowering blood pressure, and should be used with caution in left ventricular dysfunction. Etomidate, which has minimal hemodynamic effects, is considered safer for induction in patients with cardiogenic shock and severe heart failure, but its side effects, such as adrenal suppression and myoclonic effects, should be considered. Ketamine has a sympathomimetic effect, increases blood pressure and heart rate, and is therefore suitable for patients in hypovolemic and shock states (Marik, 2004).

Sevoflurane and isoflurane are widely used inhalation anesthetics in cardiac surgery. These drugs improve coronary blood flow and have a protective effect against surgical stress by activating the myocardial "preconditioning" mechanism. The rapid administration of sevoflurane is preferred in cardiac surgery, while isoflurane is preferred for its coronary vasodilation properties (Morel et al., 2011).

Fentanyl, sufentanil, and especially the short-acting remifentanil are the most widely used opioids in the analgesic component. These drugs reduce the surgical stress response, maintain hemodynamic stability, and prevent myocardial overload during cardiopulmonary bypass (CPB). However, high-dose opioid anesthesia can cause respiratory depression and bradycardia, requiring careful titration (Greco, Landoni, 2016).

Among the muscle relaxants, rocuronium and cisatracurium are considered more suitable for cardiac surgery. The rapid onset of action and hemodynamic stability of rocuronium make it suitable for intubation. Cisatracurium, on the other hand, is safer in patients with liver and kidney failure because it is metabolized via the Hofmann cleavage.

Maintaining hemodynamic stability (blood pressure, cardiac output) is crucial in cardiac surgery, and drugs like norepinephrine, epinephrine, an inotrope, and vasopressin are key to regulate arterial pressure and managing hypotension, increasing cardiac function, and correct vasoplegia syndrom. These inotropes and vasopressors work by constricting blood vessels or improving heart contractility to restore adequate blood flow and perfusion, especially after complex procedures. Noradrenaline is the drug of choice for hypotension in the setting of vasodilation, while dobutamine is more appropriate for increasing cardiac output in left ventricular systolic dysfunction. Vasopressin has been shown to be superior in cases of resistant vasoplegia after surgery in patients receiving angiotensin receptor blockers (Overgaard, Mehta, 2005).

The optimal combination of all these drugs and a modern approach using specific short-acting drugs and protocols (low-dose opioids, early extubation within hours, pain control, ambulation) summarizes the core principles and goals of Fast-Track Cardiac Anesthesia (FTCA) aims to minimize anesthesia's impact, reduce the level of stress hormones, achieve early awakening, extubation and reduce complications like arrhythmias, low perfusion in the postoperative

period and cut costs after heart surgery.

The main goals of modern anesthesia are reducing myocardial oxygen demand, maintaining perfusion pressure, preventing rhythm disturbances and getting patients stablethrough precise drug choices and integrated post-op care, aligning with ERAS (Enhanced Recovery After Surgery).

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CONFLICT OF INTEREST

The authors declare no conflict of interest related to this study.

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