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PERIOPERATIVE CRITICAL CARE IN CARDIOTHORACIC SURGERY: A REVIEW OF RECENT ADVANCES

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Abstract
Cardiothoracic surgery is associated with significant perioperative physiological stress and a high risk of postoperative complications, including hemodynamic instability, organ dysfunction, infection, and neurological impairment. Advances in perioperative critical care have contributed substantially to improved survival and recovery, making ICU-based management an essential component of modern cardiothoracic practice. This review aims to summarize recent advances in perioperative critical care strategies for cardiothoracic surgery patients, focusing on optimized hemodynamic management, prevention of major postoperative organ dysfunction, enhanced recovery pathways, and emerging innovations shaping future practice. A narrative synthesis of contemporary literature was undertaken, emphasizing guideline updates, randomized trials, systematic reviews, and recent innovations in perioperative cardiothoracic critical care. Key domains included preoperative risk stratification, cardiopulmonary bypass management, postoperative organ protection, and supportive ICU interventions. Recent progress in perioperative care includes improved preoperative optimization through frailty assessment and anemia management, alongside innovations in cardiopulmonary bypass and goal-directed perfusion therapy. Postoperative complications such as acute kidney injury and respiratory failure remain major challenges, but biomarker-guided KDIGO bundles and protective ventilation strategies have strengthened prevention and management. Enhanced Recovery After Surgery (ERAS) protocols integrating multimodal analgesia, early mobilization, and nutritional support have demonstrated reductions in ICU stay and morbidity. Neurological complications, particularly delirium and cognitive dysfunction, highlight the importance of sedation optimization and cerebral perfusion maintenance. Emerging technologies such as point-of-care ultrasound, artificial intelligence, and digital ICU monitoring systems offer promising avenues for precision-based perioperative management. Perioperative critical care in cardiothoracic surgery is rapidly evolving, driven by multidisciplinary protocols, technological innovation, and evidence-based organ protection strategies.

Keywords: Cardiothoracic surgery; Perioperative critical care; Acute kidney injury; Enhanced recovery after surgery; Artificial intelligence

1. Introduction

One of the most complex and physiologically demanding fields of the current surgery is cardiothoracic surgery. Such surgical procedures as coronary artery bypass grafting, valve repair or replacement,

major thoracic resections, etc. are frequently associated with significant perioperative stress, systemic inflammatory response and the likelihood of multi-organ dysfunction. Perioperative period, preoperative preparation inclusive, intraoperative management and the intensive care after the surgery is therefore a decisive outcome factor. Hemodynamic instability, respiratory issues, acute kidney damage, bleeding-related issues, and neurological disorders requiring an ICU level of assistance are some of the types of surgery that can cause hemodynamic instability. Critical care care innovations have also contributed significantly to the perioperative outcomes, as they enabled the effective recognition of complications, the optimum care of the organ, and the recovery strategies of the protocol (Aneman et al., 2018). The cardiothoracic surgery patients with advanced age, frailty and comorbidity also contribute to the value of perioperative critical care, as the risk profile of this group of patients is high. The current nature of perioperative critical care is more multidisciplinary collaboration of a team of surgeons, anesthesiologists, intensivists, perfusionists, and nursing staff. This continuous process ensures continuity within the care during the operating and postoperative process. Comprehensive perioperative programs currently imply the step-by-step procedures contributing to the recovery strengthening, reduction of the effects, and patient-centered outcomes (Engelman et al., 2019). Blood loss and transfusion are still significant issues in cardiothoracic surgery. Perioperative care has come to focus on patient blood management approaches, where there is an increasing focus on the use of techniques of blood conservation that minimizes exposure to allogeneic transfusion and other associated risks. One of such methods is acute normovolemic hemodilution, and it is confirmed by evidence that it reduced the need of red blood cell transfusion in patients undergoing surgery (Barile et al., 2017). Also, pediatric and neonatal guidelines emphasize the need to apply individualized transfusion and coagulation treatment in groups at risk during surgery (Faraoni et al., 2019).

During the past ten years, the management of perioperative ICU in cardiothoracic surgery has been significantly changing with the development of new anesthetic procedures, monitoring equipment, pharmacologic treatment, and increased recovery mechanisms. Modern practice of cardiothoracic anesthesia and critical care has become identified by complex intraoperative observation, personalized hemodynamic optimization and postoperative organ support. The extensive academic literature is focusing more on a combination of perioperative anesthesia and ICU approaches as a single specialty with an aim of enhancing the outcome of surgery (Bartels & Dieleman, 2025). One of the worst causes of postoperative morbidity is still hemodynamic complications. Vasoplegic syndrome, which is a severe vasodilation and unresponsive hypotension after cardiopulmonary bypass, has become a major area of clinical interest. Recent reviews also point out the changing treatment strategies, such as the use of vasopressor regimens and adjunctive treatment to reestablish the vascular tone and organ perfusion (Busse et al., 2020). Together with hemodynamic issues, enhanced recovery after surgery (ERAS) programmes have revolutionised the management of perioperative care through the practice of early mobilisation, multimodal analgesia, and enhanced nutrition. There are some pieces of evidences that confirm the use of the ERAS principles in cardiothoracic surgery as the effective measure to minimize complications and speed up recovery (Brown et al., 2018). The data on clinical outcomes also indicate that structured enhanced recovery programs can significantly reduce the ICU and hospital length of stay and have a beneficial impact on the overall postoperative recovery patterns. The use of ERAS-related perioperative pathways is proved to be feasible and beneficial in the implementation studies performed with cardiac surgical populations (Grant et al., 2020). The neurological complications especially delirium and post operative cognitive dysfunction are also becoming known to be important determinants of long-term outcome. Delirium is particularly prevalent among the elderly patients undergoing cardiac surgery and also linked with extended ICU hospitalization, high mortality, and chronic cognitive impairment. According to meta-analytic studies, the risk factors of perioperative patients include age, comorbidity, and exposure to sedation, which is the reason why prevention methods are required (Chen et al., 2021). Also, the issue of anesthesia-related cognitive impairment still has a prominent place in the perioperative critical care literature, and the efforts to optimize the use of sedation and neuroprotective strategies continue (Belrose and Noppens, 2019).

This review aims at giving a current synthesis of the latest innovation in perioperative critical care in cardiothoracic surgery patients. The areas of interest in the review are the hemodynamic optimization, transfusion and blood conservation, improved protocols of recoveries, nervous system complication prevention, and the changing ICU treatment practices. This review will inform clinicians to adopt best practice that will enhance survival, minimize postoperative morbidity, and improve long-term recovery after cardiothoracic surgery by using current evidence and emerging innovations.

2. Perioperative Optimization and Intraoperative Advances

2.1 Preoperative Risk Stratification (Frailty, Anemia, Comorbidities)

In cardiothoracic surgery, preoperative optimization is necessary since most patients come forth as feeble, anemic, diabetic, hypertensive, and with diminished physiological reserve. The preoperative recognition of individuals at risk in surgical settings enables clinicians to predict postoperative problems and provide the necessary level of care in the ICU. Risk stratification is especially relevant to forecast acute kidney injury that is still one of the most common and severe postoperative complications. All-inclusive evaluation of baseline renal functioning, hemodynamic stability, and all controllable perioperative exposures allows focused prevention procedures and enhanced postoperative recovery. Predictive frameworks focus on identifying the vulnerable patients in the early stages of care to minimize the morbidity and mortality following cardiac surgery (Hobson et al., 2017). Also, the preoperative assessment should take into account the risk of infection because postoperative bloodstream infections, particularly MRSA bacteremia, are still one of the greatest risks among critically ill surgical patients (Hassoun et al., 2017).

2.2 Cardiopulmonary Bypass (CPB) Innovations and Updated Guidelines

Cardiopulmonary bypass is still a critical component of most cardiac surgery, but it is also related to systemic inflammation, hemodilution, endothelial damage, and postoperative organ dysfunction. Recent advances in CPB management are aimed at the optimization of perfusion strategies, reduction of inflammatory stimulation, enhancement of oxygen delivery to decrease the complications in ICU. The use of bundles of preventive measures, precise flow and pressure goals, and renal protection approaches when bypassing are stressed in revised guideline-based guidelines. According to the expert beliefs, evidence-based measures are essential to mitigate the occurrence of postoperative acute kidney injury and promote organ preservation during the practice of cardiothoracic critical care (Joannidis et al., 2017). Modern perioperative paradigms are thus becoming more comprised of CPB advances and more extended approaches to recovery-oriented critical care (Gumbert et al., 2020).

2.3 Goal-Directed Therapy and Perfusion Optimization

Goal-directed therapy has taken the place of cardiothoracic surgery as a part of intraoperative and early-postoperative management. The clinicians can accurately titrate fluids, vasopressors and inotropes using advanced hemodynamic monitoring to maintain the cardiac output and provide adequate end-organ perfusion (Figure 1). This personalized therapy decreases the chance of such complications of hypoperfusion as kidney dysfunction and metabolic instability. New developments are now incorporating more and more artificial intelligence and predictive analytics in perioperative monitoring. As an illustration, AI models of lactate tracking are under consideration to assist in the early identification of postoperative degradation and real-time decision-making in the ICU (Khan et al., 2024). This form of innovation can offer a drastic shift in the method of perioperative critical care with accuracy that is planned in modern cardiothoracic surgery (Gumbert et al., 2020).

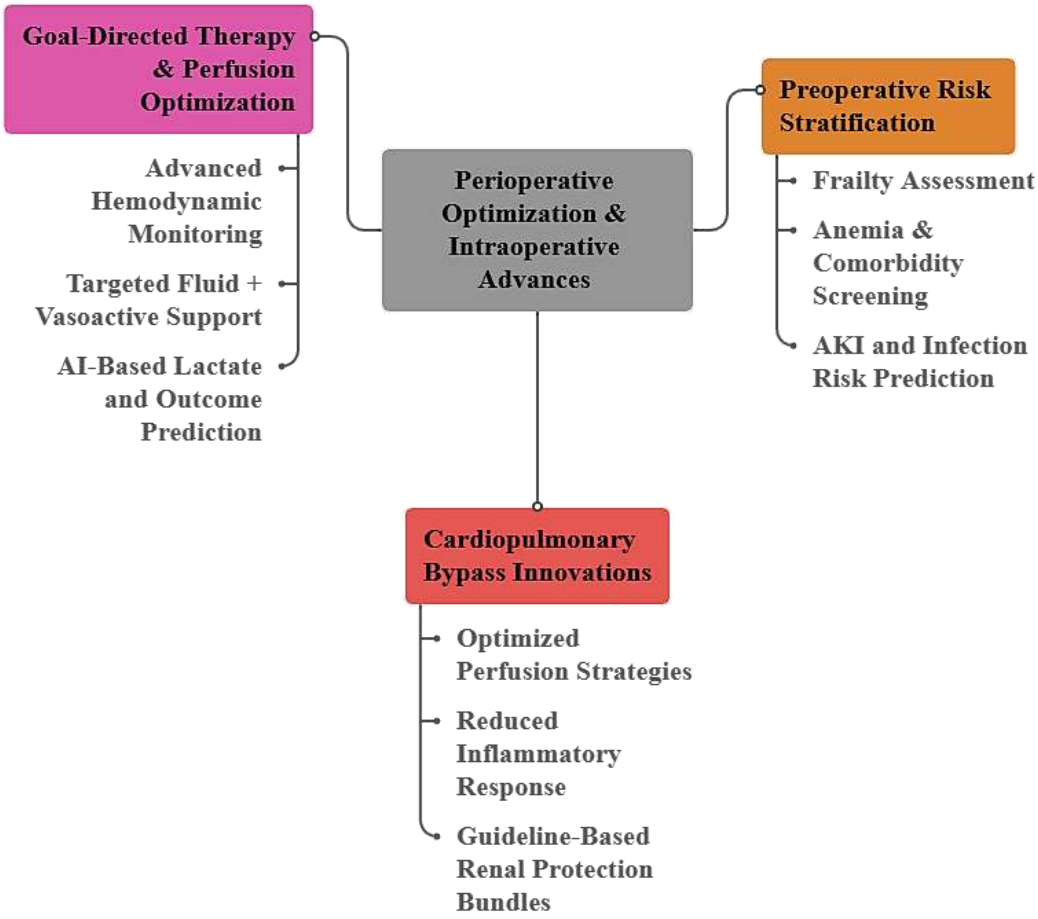

Figure 1. Perioperative Optimization and Intraoperative Advances

3. Hemodynamic and Cardiovascular Critical Care Management

Hemodynamic instability is one of the most frequent and fatal problems of perioperative cardiothoracic critical care. Patients of cardiac surgery are the most vulnerable to the alterations of preload, myocardial dysfunction, vasoplegia and systemic hypoperfusion. In order to treat it effectively, the combination of the effective fluid intake and transfusion program, high-quality monitoring, and immediate cardiovascular help is needed. The cardiothoracic critical care has become a multidisciplinary specialty that is focused on evidence-based guidelines, multi-disciplinary coordination, and precision-based hemodynamic interventions to improve the outcome of the ICU and reduce postoperative mortality (Lobdell et al., 2017).

3.1 Fluid Balance and Transfusion Strategies

Fluid balance should be proper as hypovolemia and fluid overload can both expose a patient to postoperative complications such as pulmonary edema, overstraining of the right ventricles, and inappropriate tissue perfusion. The existing methods are aimed at restrictive and goal-oriented fluid administration in order to optimise the volume of cardiac output and reduce excessive volume dose. It should be also a balance between risks of hypoxia related with anemia and transfusion complications, which should determine the decision to carry out transfusion. The management of blood and fluids individually is one of the main points of perioperative cardiovascular optimization, which is increasingly becoming a component of the future of cardiothoracic critical care (Kopanczyk et al., 2022).

3.2 Advanced Hemodynamic Monitoring

Perioperative decision-making in cardiac surgical ICUs has been made very effective due to the development of hemodynamic monitoring. Besides the routinely used checking of the arterial and central venous pressure, clinicians are now using minimally invasive cardiac output systems, dynamic preload indices and bedside echocardiography as a way of orientating particular interventions. These technologies enable the more precise titration of fluids, vasopressors, and inotropes and reduce the possibility of a chronic shock and the damage of secondary organs. Such novelty of monitoring are linked to the present trends in the cardiovascular critical care management, in the aftermath of the complicated cardiothoracic interventions (Lomivorotov et al., 2017).

3.3 Vasoplegia and Low Cardiac Output Syndrome

Still important complications of the cardiopulmonary bypass are vasoplegic syndrome and low cardiac output syndrome. Vasoplegia is linked to widespread systemic vasodilation and refractory hypotension as compared to low cardiac output syndrome that is a complication of cardiac lack of contractility and poor systemic perfusion.. These two conditions are linked to a lengthy ICU stay, kidney failures and high rates of death in case they are not managed early. The awareness of these syndromes has led to the development of the organized hemodynamic rescue plans in the contemporary critical care pathways of the perioperative period (Landoni et al., 2017).

3.4 Inotropes, Vasopressors, and Mechanical Circulatory Support (ECMO/VAD)

Pharmacologic cardiovascular therapy is a key to treatment of postoperative shock conditions. Vasopressors and inotropes increase myocardial performance and provide vascular tone in patients with ventricular dysfunction respectively (Table 1). Mechanical circulation support devices (ECMO) and ventricular assist devices (VADs) are lifesaving support modalities when pharmacologic therapy is not possible to offer as they help sustain systemic perfusion until cardiac recovery ensues. These technologies are another significant step in the field of present-day perioperative cardiothoracic ICU (Kopanczyk et al., 2022).

Table 1. Key Components of Hemodynamic and Cardiovascular Critical Care Management

Domain	Key Focus	Clinical Importance	Reference
Fluid Balance & Transfusion	Restrictive, goal-directed fluid therapy; balanced transfusion decisions	Prevents fluid overload, optimizes oxygen delivery, reduces complications	Kopanczyk et al., 2022
Advanced Hemodynamic Monitoring	Cardiac output monitoring, dynamic preload indices, bedside echocardiography	Enables precision-guided fluid and vasoactive management	Lomivorotov et al., 2017
Vasoplegia & Low Cardiac Output Syndrome	Recognition of vasodilatory shock and myocardial dysfunction post-CPB	Major causes of ICU morbidity and mortality if untreated	Landoni et al., 2017
Inotropes, Vasopressors & Mechanical Support	Use of vasoactive drugs; ECMO/VAD for refractory shock	Provides lifesaving perfusion support in severe cardiovascular failure	Kopanczyk et al., 2022

4. Major Postoperative Organ Dysfunction

Organ dysfunction in the major part of the postoperative period is one of the most common causes of morbidity and extended ICU hospitalization following cardiothoracic surgery. Acute kidney injury (AKI) and respiratory failure are the most clinically important complications, both of which are linked to the risque of increased mortality, the expenses of healthcare and recovery delays. The modern concept of perioperative critical care is associated with the early identification of vulnerable patients, the use of biomarkers to prevent and supportive evidence-based supporting interventions. The long-

standing issues in cardiothoracic anesthesiology remain to stimulate the development of novel approaches in the postoperative organ protection practice and structure of the ICU (Pisano et al., 2023).

4.1 Acute Kidney Injury (AKI)

This complication is common and severe and occurs frequently in cardiac surgery, and it is caused by hemodynamic instability, exposure to cardiopulmonary bypass, systemic inflammation, and pre-existing comorbidities. It has also been established that preoperative anemia can be considered a crucial risk factor because lower oxygen delivery can also increase the fragility of the kidney and cause poor outcomes (Padmanabhan et al., 2019). Newer prevention techniques are now encompassing risk stratification using biomarkers and predefined KDIGO care packages. The PrevAKI randomized trial showed that AKI posing a risk to patients can be significantly prevented with the application of KDIGO-based interventions of high-risk patients (Meersch et al., 2017). In acute inspection, the patient might need postoperative renal replacement therapy due to fluid overload, electrolyte imbalance, and metabolic complications, which indicates the significance of accurate and early monitoring and timely ICU assistance.

4.2 Respiratory Failure and Pulmonary Complications

The other significant cause of postoperative morbidity after cardiothoracic surgery is respiratory dysfunction. Pneumonia, atelectasis, pneumonia, prolonged mechanical ventilation, and acute respiratory distress syndrome (ARDS) are some of the pulmonary complications. It has been indicated that intraoperative ventilation plans play a major role in determining the postoperative pulmonary outcomes, and protection ventilation plans can decrease the complications rates (Mathis et al., 2019). Fast-track recovery and early extubation are now part of the current perioperative care, which focuses on reducing ICU stay and improving functional recovery (Figure 2). Besides, keen transfusion measures should be taken, as liberal transfusion measures can contribute to pulmonary complications by the effect of volume overloading as well as inflammatory reactions. A selective trial of restrictive and liberal ways to red-cell transfusion has been employed to provide the required recommendations on how to maximize respiratory and overall outcomes of cardiac surgery patients (Mazer et al., 2017).

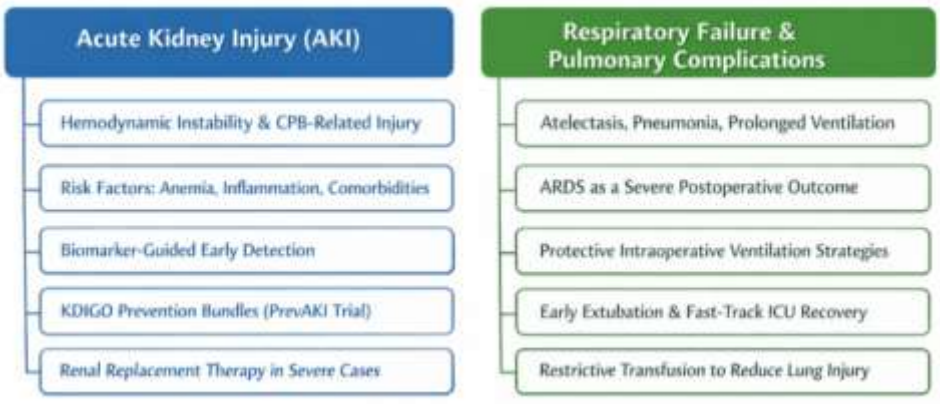

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Figure 2. Major Postoperative Organ Dysfunction

5. Enhanced Recovery and Supportive ICU Care

ERAS programs have become the center of attention of the pursuit of enhancing cardiothoracic surgery perioperative outcomes using the evidence-based, multidisciplinary care pathways. These recommendations revolve around reducing stress during surgery, early rehabilitation and reduction of complications in the ICU. The contemporary frameworks of perioperative care encompass optimization strategies during the surgical course, through which the intraoperative care would be transferred to the ICU setting postoperative recovery more efficiently (Pokhrel et al., 2021).

5.1 ERAS Principles in Cardiothoracic Surgery

The ERAS principles of cardiothoracic and thoracic surgery target structured perioperative pathways that include preoperative counseling, reduction of fasting, intentional fluid management and early debridement of ventilator tubes. These procedures are expected to decrease the days of stay in the hospital and decrease the postoperative morbidity. The programs of thoracic ERAS demonstrate that the regular recovery protocols improve the functional results and decrease the incidence of complications, which underlines the additional introduction of the protocols into the cardiothoracic surgery practice (Semenkovich et al., 2018).

5.2 Multimodal Analgesia and Opioid-Sparing Strategies

A major supportive element of ERAS is pain management because poor analgesia slows down mobilization and respiratory complications. Recent guidelines focus on multimodal analgesia, the use of non-opioid agents, regional methods and close sedation guidelines with reduced exposure to

Component	Key Elements	Clinical Benefit	Reference
ERAS Framework	Multidisciplinary perioperative recovery pathways	Reduces surgical stress and ICU-related complications	Pokhrel et al., 2021
Core ERAS Principles	Counseling, reduced fasting, early extubation, goal-directed therapy	Shortens hospital stay and lowers morbidity	Semenkovich et al., 2018
Multimodal Analgesia	Opioid-sparing regimens, regional techniques, optimized hemostasis	Improves pain control and supports early mobilization	Raphael et al., 2019
Mobilization & Nutrition Support	Early ambulation, immune-supportive nutrition, adjunct statin therapy	Enhances rehabilitation and decreases complications	Putzu et al., 2018
Outcomes & Barriers	Reduced ICU stay; challenges include resources and protocol variability	Highlights need for standardized implementation	Prowle et al., 2021

Table 2. Enhanced Recovery and Supportive ICU Care in Cardiothoracic Surgery

opioids. Moreover, perioperative bleeding and hemostasis management has a direct effect on analgesic planning and postoperative recovery, and clinical advisories have identified best practices of the balance between coagulation control and postoperative comfort (Raphael et al., 2019).

5.3 Early Mobilization and Nutrition Support

The basic tenets of increased recovery pathways are early mobilization and nutritional optimization. Mobilization helps to decrease the risk of thromboembolism, delirium, and pulmonary complications and early nutrition helps to support immune activity and wound healing. Perioperative statin therapy in the form of adjunctive pharmacologic modalities is another previously investigated approach that has the potential to benefit cardiac and non-cardiac surgery patients with their anti-inflammatory and protective effects (Putzu et al., 2018).

5.4 Impact on Outcomes and Implementation Barriers

The methods of improved recovery have been linked to shortened ICU stay, decreased complications, and better patient outcomes. Nevertheless, it is still difficult to implement it because of institutional inconsistency, resource shortages, and patient risk differences (Table 2). The significance of standardized protocols and multidisciplinary involvement to overcome the barriers and improve the postoperative recovery pathways are highlighted in consensus initiatives within the community of perioperative and critical care (Prowle et al., 2021).

6. Neurological and Cognitive Complications

Neurological and cognitive complications are also becoming well-known as the key predictors of postoperative recovery and long-term outcomes of cardiothoracic surgery. Delirium, cognitive dysfunction, and neuropsychiatric disturbances are among the significant contributors of the extended ICU stay, a higher mortality rate, and poorer quality of life. Perioperative critical care today focuses on the identification of vulnerable patients in early stages, prevention of vulnerable patients, and optimization of sedation practices to reduce the neurological morbidity. Delirium in the postoperative period has remained one of the most common complications, especially in elderly and high-risk groups of surgical patients, and thus the necessity to develop systematic neuroprotective ICU pathways (Smilowitz et al., 2017).

6.1 Postoperative Delirium Epidemiology and Prevention

Delirium in the postoperative period is typical and occurs after cardiac surgery, which is occasioned by systemic inflammation, metabolic turmoil, and hemodynamic variability in the postoperative period. Prevention measures are aimed at the prevention of the modifiable risk factors like sleep disturbance, immobility, and sedative exposure inappropriately. It is also necessary to maintain the stability of intraoperative blood pressure since hypotension and poor cerebral perfusion have been associated with negative neurological outcomes. Recommendations on consensuses are based on the significance of blood pressure optimization as a part of perioperative strategies to help minimize postoperative complications, such as the risk of delirium (Sessler et al., 2019).

6.2 Sedation Strategies and Dexmedetomidine Trials

Sedation administration is highly involved in the prevention of delirium and cognitive protection. Alpha-2 agonist Dexmedetomidine has received interest in its possible role in the treatment of delirium and atrial fibrillation subsequent to cardiac surgical procedures. In the DECADE randomized placebo-controlled trial, it was proved that the use of dexmedetomidine-based strategy of sedation can also help in achieving better postoperative neurocognitive outcomes, which justifies its inclusion in the current perioperative ICU protocols (Turan et al., 2020).

6.3 Long-Term Cognitive Dysfunction and Rehabilitation

In addition to acute delirium, persistent cognitive impairment which amounts to memory, executive, and long-term independence is observed in most cardiothoracic surgery patients. Early screening of cognition, multidisciplined follow-up, and specific recovery plans are becoming used more in rehabilitation strategies (Figure 3). Optimal nutrition has also become an aspect of supportive care, and there is now consensus among the experts that sufficient perioperative nutrition can positively influence the recovery processes in patients of a cardiac surgery and decrease the number of complications in the ICU (Stoppe et al., 2017). Risk stratification can also be improved with emerging technologies, such as machine learning models trained on postoperative organ dysfunction prediction, which can also be used to implement specific neuroprotective interventions (Tseng et al., 2020).

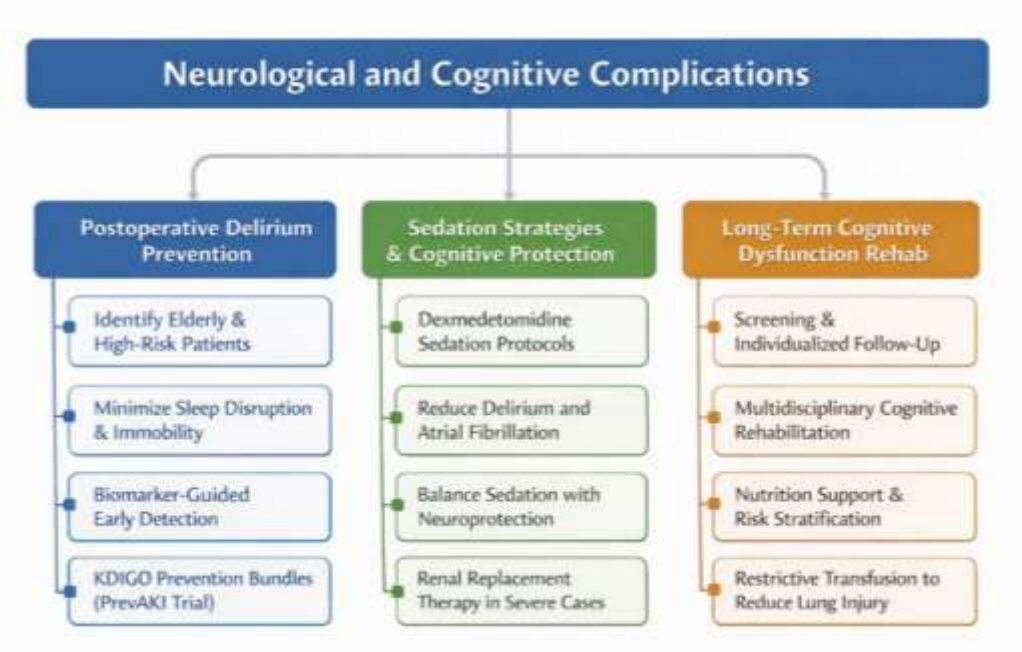

Figure 3. Neurological and Cognitive Complications

7. Inflammation, Infection, and Immune Challenges

The central characteristics of cardiothoracic surgery perioperative critical illness include inflammation and immune dysregulation. The cardiopulmonary bypass (CPB) prompts the development of systemic inflammatory response due to the interaction of blood and surface, cytokine release, complement, and endothelial dysfunction. This inflammatory cascade adds to postoperative organ damage, vasoplegia as well as long ICU recovery. The latest global standards focus on optimizing CPB methods and perfusion strategies to reduce the burden of inflammation and enhance the postoperative outcomes of patients undergoing adult cardiac surgery (Wahba et al., 2020).

7.1 CPB-Associated Systemic Inflammation

The syndrome of systemic inflammatory response that follows cardiac surgery is closely associated with the postoperative conditions like acute kidney injury, myocardial dysfunction and respiratory failure. Microvascular damage and oxidative stress caused by inflammation are involved in the etiology of cardiac surgery AKI. In-depth reviews point to the fact that a combination of CPB-induced inflammation, hemodynamic instability, and ischemia-reperfusion injury is a frequent cause of renal dysfunction (Wang and Bellomo, 2017). Early identification and organ-protective approaches to ICU are therefore needed by the management to restrain inflammatory-mediated injury (Vives et al., 2019).

7.2 Sepsis Prevention and ICU Infection Control

The issue of postoperative infection has been a significant problem in the cardiothoracic intensive care because of invasive monitoring, long ventilatory support, and postoperative immune suppression. ICU-based infection control measures aim at early antimicrobial stewardship, high-level aseptic measures, and prevention bundles in an attempt to lower bloodstream and surgical site infections. More complex methods of diagnostics, such as critical care echocardiography, may also assist in the early detection of septic cardiac dysfunction and decision making in hemodynamics of the complex ICU patients (Vieillard-Baron et al., 2019).

7.3 MRSA and Multidrug-Resistant Organism Concerns

The problem of multidrug-resistant organism, especially MRSA, still remains a significant threat in postoperative cardiothoracic ICU. MRSA bacteremia is linked to a high mortality rate, a long period of stay in the hospital, and a low number of treatment options (Table 3). The prevention of microbes involves stringent screening and isolation measures and antimicrobial specific protocols that are

effective in high-risk surgical groups. These difficulties are even increased in low- and middle-income countries, as the lack of resources hinders the access to high-level infection control facilities and critical care capacity (Vervoort et al., 2021).

Table 3. Key Immune and Infectious Challenges in Cardiothoracic ICU Care

Challenge	Underlying Mechanism	Critical Care Focus
CPB-Associated Systemic Inflammation	Blood–surface interaction activates cytokines, complement, and endothelial injury	Optimize bypass techniques and reduce inflammatory burden (Wahba et al., 2020)
Inflammation-Mediated Organ Injury (AKI)	Oxidative stress and ischemia–reperfusion damage impair renal microcirculation	Early recognition and renal-protective ICU strategies (Wang & Bellomo, 2017)
Postoperative Sepsis Risk	Immune suppression + invasive devices increase susceptibility to infection	Strict ICU prevention bundles and antimicrobial stewardship (Vieillard-Baron et al., 2019)
Multidrug-Resistant Pathogens (MRSA)	Limited therapeutic options and higher mortality in critically ill patients	Screening, isolation, and targeted antimicrobial protocols (Vervoort et al., 2021)
Global Resource Constraints	Reduced access to infection-control infrastructure in LMIC settings	Capacity-building and scalable critical care protocols (Vives et al., 2019)

8. Emerging Technologies and Future Innovations

New technologies are quickly changing the perioperative critical care in cardiothoracic surgery that allows to diagnose complications in a timely manner, conduct operations with greater accuracy, and monitor patients in the postoperative period. New technologies like point-of-care ultrasound, predictive analytics through artificial intelligence, and digital ICUs are becoming part of the current cardiothoracic practice. Such innovations help in a shift of personalized and information-based critical care models that encourages decision making, organ dysfunction, and recovery courses in high-risk preoperative patients. One of the major directions in the development of perioperative ICU care is the research of biomarkers (Wu et al., 2019).

8.1 Point-of-Care Ultrasound and Critical Care Echocardiography

POCUS and bedside echocardiography have now become a constituent of cardiothoracic critical care. Such modalities allow the rapid identification of the ventricular performance, the condition of the volume and the after operation complications. Having been applied in the ICU, Echocardiography-guided assessment assists in diagnosing shock conditions and pulmonary dysfunctions in advance, thus, supporting a decision made based on the accuracy.

8.2 Artificial Intelligence and Predictive Analytics

Two ways of applying artificial intelligence to perioperative critical care are predictive models and clinical decision-support systems. Physiologic trends can be predicted with machine learning and used to intervene earlier with the help of complications, which enhances personalized postoperative management pathways that can be applied to cardiothoracic surgery.

8.3 Digital ICU Monitoring Systems

The digital ICU technologies which are a combination of continuous monitoring platforms and automated alerts are shaping the future of cardiothoracic critical care. The systems enhance affirmative intervention and an improved recovery evaluation. At the same time, the favorable changes in the field of pain management are also required, and the effect of postoperative pain on mobility, respiratory performance, and postcardiac surgery rehabilitation is significant (Zubrzycki et al., 2018).

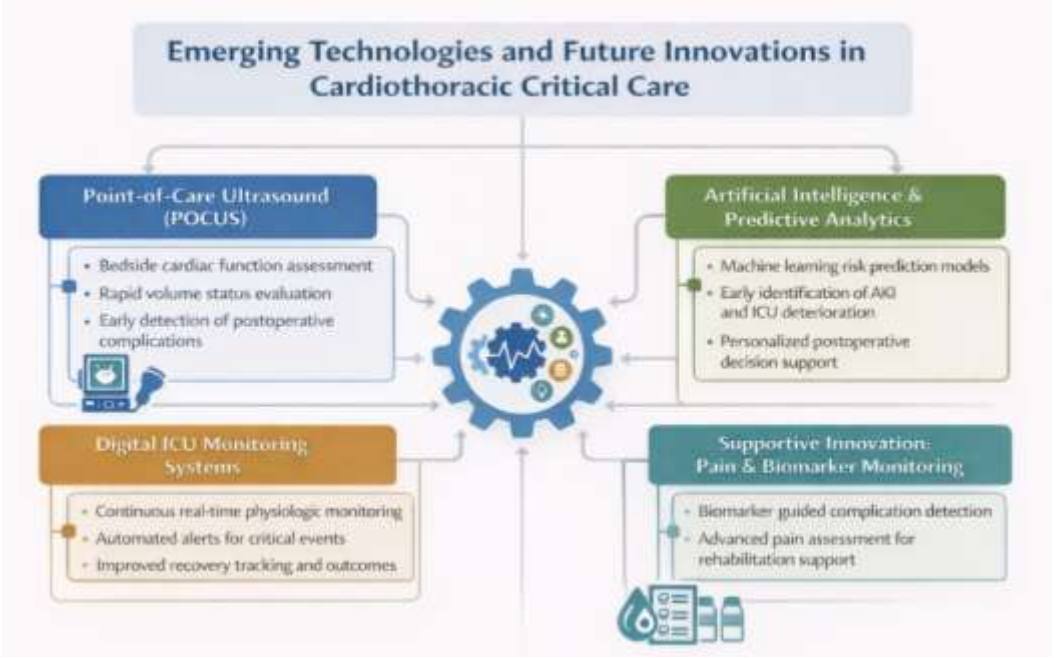

Figure 4. Emerging Technologies and Future Innovations

9. Global Challenges and Future Research Priorities

One of the most crucial questions of the improvement of the perioperative outcomes is the disparities of access to cardiothoracic surgical critical care in the global scenario. Though the high-income countries have enjoyed the advantage of advanced monitoring tools, specialized ICUs, and protocol-like recovery pathways, many low- and middle-income countries (LMICs) have insurmountable difficulties in delivering an extensive perioperative critical care system. Some of the causes of late interventions and higher postoperative morbidity and mortality include poor infrastructure, shortage of trained personnel and unavailability of required technologies. There is thus an urgent need to increase the cardiothoracic critical care capacity in resource-constrained environments in an attempt to achieve balanced global surgical processes. The distribution of resources and equal access is a pressing problem of the modern perioperative medicine. The advanced supportive measures such as the extracorporeal life support, renal replacement therapy and continuous observation of blood pressure and heart rate are not accessible in most regions due to the cost and logistical reasons. The unequal patient outcomes may be caused by the inequalities in the conditions of the ICU staffing, the institutional policies, and the postoperative rehabilitation services in the most resource-stabilized medical systems. To close these gaps, the policy-makers must collaborate with each other, and international collaborations are required to introduce the scaled perioperative care models, which can be modified to the specifics of the various healthcare environments. There is an opportunity of having viable alternatives based on the attainment of better results in situations with limited resources using universalized recovery protocols and reduced evidence-based packages. The primary spheres of the future research priorities in the cardiothoracic perioperative critical care are precision medicine and modern technologies implementation. The sphere of postoperative care can be altered as individualized risk forecasting models, biomarker-directed therapy, and AI-based surveillance may ensure the possibility to diagnose the complications sooner and adjust the treatment plan. However, these innovations must be demonstrated through large multicentered trials and global research networks to ensure that they are applicable to various groups of patients and health settings. Creation of standardized guidelines, mutual registries construction and propagation of equitable access to emerging technology will be significant in enhancing the field.

10. Conclusion

The history of perioperative critical care in cardiothoracic surgery has undergone massive transformation during the past 10 years and has been a highly specialized and multidisciplinary

discipline, which is the fundamental theme of improving the outcome of surgery. The theme that this review places is that contemporary perioperative care is no longer confined in the near future to intraoperative successes but rather, it is a broader ICU-focused method of preventing and treating life-threatening complications. The other important modifications include an improved preoperative risk stratification in terms of which the frailty, anemia, comorbidity, and susceptibility to infections have been taken into consideration to provide the possibility to identify the vulnerable patients at a more advanced phase. Intraoperative new technologies have been developed, in particular, the optimization of cardiopulmonary bypass and goal-directed perfusion therapy have brought about better hemodynamic stability and reduced organ damage. One of the major problems is still the dysfunction of the organ functioning following the operation, acute kidney damage, and respiratory complications are the most common factors leading to morbidity. Evidence-based KDIGO bundles, biomarker-based preventive strategies and protective ventilation have been added as possible critical care strategies to these complications. Multimodal analgesia, opioid-sparing, early mobilization, and nutritional support have also transformed the perioperative care with ERAS enhanced pathways resulting in a shorter ICU stay and improved recovery. Neurological issues like delirium and cognitive impairment in the long run are also emerging very visible as determinants of importance to quality of life and thus very critical optimised methods of sedation and cerebral perfusion strategies are of the utmost concern. Emerging technologies, such as point-of-care ultrasound, artificial intelligence, and digital ICU monitoring systems, influence the future of cardiothoracic critical care, allowing making interventions more accurate and risk prediction more precise. Finally, disparities in the availability of current perioperative critical care policies on an international level accentuate the necessity of scaling policies, international collaboration, and multicenter research. More innovation, standardization and equality in implementation of cardiothoracic surgical outcomes in the world will still need further development.

Reference

1. Aneman, A., Brechot, N., Brodie, D., Colreavy, F., Fraser, J., Gomersall, C., ... & Vallely, M. (2018). Advances in critical care management of patients undergoing cardiac surgery. *Intensive Care Medicine*, *44*(6), 799-810.
2. Barile, L., Fominskiy, E., Di Tomasso, N., Castro, L. E. A., Landoni, G., De Luca, M., ... & Monaco, F. (2017). Acute normovolemic hemodilution reduces allogeneic red blood cell transfusion in cardiac surgery: a systematic review and meta-analysis of randomized trials. *Anesthesia & Analgesia*, *124*(3), 743-752.
3. Bartels, K., & Dieleman, S. (Eds.). (2025). *Cardiothoracic Anesthesia and Critical Care, An issue of Anethesiology Clinics: Cardiothoracic Anesthesia and Critical Care, An issue of Anethesiology Clinics, E-Book* (Vol. 43, No. 2). Elsevier Health Sciences.
4. Belrose, J. C., & Noppens, R. R. (2019). Anesthesiology and cognitive impairment: a narrative review of current clinical literature. *BMC anesthesiology*, *19*(1), 241.
5. Brown, J. K., Singh, K., Dumitru, R., Chan, E., & Kim, M. P. (2018). The benefits of enhanced recovery after surgery programs and their application in cardiothoracic surgery. *Methodist DeBakey cardiovascular journal*, *14*(2), 77.
6. Busse, L. W., Barker, N., & Petersen, C. (2020). Vasoplegic syndrome following cardiothoracic surgery—review of pathophysiology and update of treatment options. *Critical Care*, *24*(1), 36.
7. Chen, H., Mo, L., Hu, H., Ou, Y., & Luo, J. (2021). Risk factors of postoperative delirium after cardiac surgery: a meta-analysis. *Journal of Cardiothoracic Surgery*, *16*(1), 113.
8. Engelman, D. T., Ali, W. B., Williams, J. B., Perrault, L. P., Reddy, V. S., Arora, R. C., ... & Boyle, E. M. (2019). Guidelines for perioperative care in cardiac surgery: enhanced recovery after surgery society recommendations. *JAMA surgery*, *154*(8), 755-766.
9. Faraoni, D., Meier, J., New, H. V., Van der Linden, P. J., & Hunt, B. J. (2019). Patient blood management for neonates and children undergoing cardiac surgery: 2019 NATA guidelines. *Journal of cardiothoracic and vascular anesthesia*, *33*(12), 3249-3263.

10. Grant, M. C., Isada, T., Ruzankin, P., Whitman, G., Lawton, J. S., Dodd-o, J., ... & Mandal, K. (2020). Results from an enhanced recovery program for cardiac surgery. *The Journal of thoracic and cardiovascular surgery*, *159*(4), 1393-1402.
11. Gumbert, S. D., Kork, F., Jackson, M. L., Vanga, N., Ghebremichael, S. J., Wang, C. Y., & Eltzschig, H. K. (2020). Perioperative acute kidney injury. *Anesthesiology*, *132*(1), 180.
12. Hassoun, A., Linden, P. K., & Friedman, B. (2017). Incidence, prevalence, and management of MRSA bacteremia across patient populations—a review of recent developments in MRSA management and treatment. *Critical care*, *21*(1), 211.
13. Hobson, C., Ruchi, R., & Bihorac, A. (2017). Perioperative acute kidney injury: risk factors and predictive strategies. *Critical care clinics*, *33*(2), 379-396.
14. Joannidis, M., Druml, W., Forni, L. 3., Groeneveld, A. B. J., Honore, P. 4., Hoste, E., ... & Schetz, M. (2017). Prevention of acute kidney injury and protection of renal function in the intensive care unit: update 2017: Expert opinion of the Working Group on Prevention, AKI section, European Society of Intensive Care Medicine. *Intensive care medicine*, *43*(6), 730-749.
15. Khan, R., Zainab, H., Khan, A. H., & Hussain, H. K. (2024). Advances in predictive modeling: The role of artificial intelligence in monitoring blood lactate levels post-cardiac surgery. *International Journal of Multidisciplinary Sciences and Arts*, *3*(4), 140-151.
16. Kopanczyk, R., Lester, J., Long, M. T., Kossbiel, B. J., Hess, A. S., Rozycki, A., ... & Bhatt, A. M. (2022). The Future of Cardiothoracic Surgical Critical Care Medicine as a Medical Science: A Call to Action. *Medicina*, *59*(1), 47.
17. Landoni, G., Lomivorotov, V. V., Alvaro, G., Lobreglio, R., Pisano, A., Guarracino, F., ... & Zangrillo, A. (2017). Levosimendan for hemodynamic support after cardiac surgery. *New England Journal of Medicine*, *376*(21), 2021-2031.
18. Lobdell, K. W., Haden, D. W., & Mistry, K. P. (2017). Cardiothoracic critical care. *Surgical Clinics*, *97*(4), 811-834.
19. Lomivorotov, V. V., Efremov, S. M., Kirov, M. Y., Fominskiy, E. V., & Karaskov, A. M. (2017). Low-cardiac-output syndrome after cardiac surgery. *Journal of cardiothoracic and vascular anesthesia*, *31*(1), 291-308.
20. Mathis, M. R., Duggal, N. M., Likosky, D. S., Haft, J. W., Douville, N. J., Vaughn, M. T., ... & Engoren, M. C. (2019). Intraoperative mechanical ventilation and postoperative pulmonary complications following cardiac surgery. *Anesthesiology*, *131*(5), 1046.
21. Mazer, C. D., Whitlock, R. P., Fergusson, D. A., Hall, J., Belley-Cote, E., Connolly, K., ... & Shehata, N. (2017). Restrictive or liberal red-cell transfusion for cardiac surgery. *New England Journal of Medicine*, *377*(22), 2133-2144.
22. Meersch, M., Schmidt, C., Hoffmeier, A., Van Aken, H., Wempe, C., Gerss, J., & Zarbock, A. (2017). Prevention of cardiac surgery-associated AKI by implementing the KDIGO guidelines in high risk patients identified by biomarkers: the PrevAKI randomized controlled trial. *Intensive care medicine*, *43*(11), 1551-1561.
23. Padmanabhan, H., Siau, K., Curtis, J., Ng, A., Menon, S., Luckraz, H., & Brookes, M. J. (2019). Preoperative anemia and outcomes in cardiovascular surgery: systematic review and meta-analysis. *The Annals of thoracic surgery*, *108*(6), 1840-1848.
24. Pisano, A., Angelini, M., Vlasakov, I., & Landoni, G. (2023). Old issues and new challenges in cardiothoracic anesthesiology: work in progress…. *Frontiers in Anesthesiology*, *1*, 1115750.
25. Pokhrel, S., Gregory, A., & Mellor, A. (2021). Perioperative care in cardiac surgery. *BJA education*, *21*(10), 396-402.
26. Prowle, J. R., Forni, L. G., Bell, M., Chew, M. S., Edwards, M., Grams, M. E., ... & Kellum, J. A. (2021). Postoperative acute kidney injury in adult non-cardiac surgery: joint consensus report of the Acute Disease Quality Initiative and PeriOperative Quality Initiative. *Nature Reviews Nephrology*, *17*(9), 605-618.
27. Putzu, A., de Carvalho, C. M. P. D., de Almeida, J. P., Belletti, A., Cassina, T., Landoni, G., & Hajjar, L. A. (2018). Perioperative statin therapy in cardiac and non-cardiac surgery: a systematic review and meta-analysis of randomized controlled trials. *Annals of intensive care*, *8*(1), 95.

28. Raphael, J., Mazer, C. D., Subramani, S., Schroeder, A., Abdalla, M., Ferreira, R., ... & Lau, W. T. (2019). Society of Cardiovascular Anesthesiologists clinical practice improvement advisory for management of perioperative bleeding and hemostasis in cardiac surgery patients. *Anesthesia & Analgesia*, *129*(5), 1209-1221.
29. Semenkovich, T. R., Hudson, J. L., Subramanian, M., & Kozower, B. D. (2018, September). Enhanced recovery after surgery (ERAS) in thoracic surgery. In *Seminars in thoracic and cardiovascular surgery* (Vol. 30, No. 3, pp. 342-349). WB Saunders.
30. Sessler, D. I., Bloomstone, J. A., Aronson, S., Berry, C., Gan, T. J., Kellum, J. A., ... & Hamilton, M. (2019). Perioperative quality initiative consensus statement on intraoperative blood pressure, risk and outcomes for elective surgery. *British journal of anaesthesia*, *122*(5), 563-574.
31. Smilowitz, N. R., Gupta, N., Guo, Y., Berger, J. S., & Bangalore, S. (2017). Perioperative acute myocardial infarction associated with non-cardiac surgery. *European heart journal*, *38*(31), 2409-2417.
32. Stoppe, C., Goetzenich, A., Whitman, G., Ohkuma, R., Brown, T., Hatzakorzian, R., ... & Heyland, D. K. (2017). Role of nutrition support in adult cardiac surgery: a consensus statement from an International Multidisciplinary Expert Group on Nutrition in Cardiac Surgery. *Critical Care*, *21*(1), 131.
33. Tseng, P. Y., Chen, Y. T., Wang, C. H., Chiu, K. M., Peng, Y. S., Hsu, S. P., ... & Lee, O. K. S. (2020). Prediction of the development of acute kidney injury following cardiac surgery by machine learning. *Critical care*, *24*(1), 478.
34. Turan, A., Duncan, A., Leung, S., Karimi, N., Fang, J., Mao, G., ... & Raza, S. (2020). Dexmedetomidine for reduction of atrial fibrillation and delirium after cardiac surgery (DECADE): a randomised placebo-controlled trial. *The Lancet*, *396*(10245), 177-185.
35. Vervoort, D., Swain, J. D., Pezzella, A. T., & Kpodonu, J. (2021). Cardiac surgery in low-and middle-income countries: a state-of-the-art review. *The Annals of Thoracic Surgery*, *111*(4), 1394-1400.
36. Vieillard-Baron, A., Millington, S. J., Sanfilippo, F., Chew, M., Diaz-Gomez, J., McLean, A., ... & Fletcher, N. (2019). A decade of progress in critical care echocardiography: a narrative review. *Intensive care medicine*, *45*(6), 770-788.
37. Vives, M., Hernandez, A., Parramon, F., Estanyol, N., Pardina, B., Muñoz, A., ... & Hernandez, C. (2019). Acute kidney injury after cardiac surgery: prevalence, impact and management challenges. *International journal of nephrology and renovascular disease*, 153-166.
38. Wahba, A., Milojevic, M., Boer, C., De Somer, F. M., Gudbjartsson, T., Van Den Goor, J., ... & Puis, L. (2020). 2019 EACTS/EACTA/EBCP guidelines on cardiopulmonary bypass in adult cardiac surgery. *European Journal of Cardio-Thoracic Surgery*, *57*(2), 210-251.
39. Wang, Y., & Bellomo, R. (2017). Cardiac surgery-associated acute kidney injury: risk factors, pathophysiology and treatment. *Nature Reviews Nephrology*, *13*(11), 697-711.
40. Wu, B., Chen, J., & Yang, Y. (2019). Biomarkers of acute kidney injury after cardiac surgery: a narrative review. *BioMed research international*, *2019*(1), 7298635.
41. Zubrzycki, M., Liebold, A., Skrabal, C., Reinelt, H., Ziegler, M., Perdas, E., & Zubrzycka, M. (2018). Assessment and pathophysiology of pain in cardiac surgery. *Journal of pain research*, 1599-1611.