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Review

Postoperative Management of Coronary Artery Bypass Grafting

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Abstract

The effective postoperative management of coronary artery bypass grafting (CABG) necessitates a multifaceted and holistic approach to achieve the best possible patient outcomes. This review emphasizes the importance of consistently implementing Enhanced Recovery After Surgery (ERAS) protocols and goal-directed therapy, as well as integrating specialized care pathways to optimize patient outcomes. Key concepts and theoretical insights, including knowledge gaps, are discussed. Future research directions are explored, including the application of economic principles, such as marginal analysis, to inform cost-effective decisions, the development of comprehensive models that integrate clinical, economic, and patient-centered outcomes, and the leveraging of behavioral economics to enhance patient adherence. Systems theory and process optimization techniques are also employed to refine theoretical frameworks further, as well as patient-centered care models that emphasize individualized care plans tailored to the needs and preferences of each patient. Finally, the importance of continued research and theoretical development is underscored as the most effective approach, which will ultimately lead to improved patient outcomes and more efficient use of healthcare resources.

Keywords

coronary artery bypass grafting; enhanced recovery after surgery; goal-directed therapy; multimodal analgesia; specialized care pathways; theoretical frameworks; wearable technology

Introduction

Coronary artery bypass grafting (CABG) is a well-established surgical procedure that aims to restore blood flow to the ischemic myocardium through bypassing stenosed coronary arteries [1]. This procedure is a cornerstone in the treatment of coronary artery disease (CAD), which remains a leading cause of morbidity and mortality worldwide [2]. Despite advances in medical therapy and less invasive interventions, CABG continues to play a critical role in managing patients with severe CAD, particularly those with complex multivessel disease [3,4]. Thus, effective postoperative management is crucial for ensuring a smooth recovery and minimizing complications after CABG surgery. Safe and effective postoperative management not only enhances patient comfort but also significantly reduces the risk of adverse events and readmissions. Therefore, this review aims to analyze, clarify, and expand key concepts related to the postoperative management of CABG surgery. By synthesizing the latest research, this review aims to provide a comprehensive overview of current best practices and emerging trends in postoperative care, with a focus on improving patient outcomes and reducing complications.

Routine postoperative treatment includes wound care, medication management, dietary control, exercise rehabilitation, psychological adjustment, and regular follow-up, all of which contribute to long-term recovery and improved patient outcomes. However, this review goes beyond conventional postoperative management by emphasizing key concepts and theoretical frameworks that refine existing practices, particularly through the implementation of Enhanced Recovery After Surgery (ERAS), goal-directed therapy (GDT), and standardized care pathways (SCPs). These strategies collectively optimize postoperative recovery, enhance surgical safety and efficacy, and provide a structured, multidisciplinary approach tailored to patients undergoing CABG surgery.

The scope of this review encompasses several critical areas of postoperative management, including hemodynamic stabilization, pain management, respiratory support, antithrombotic therapy, and the prevention of complications, such as infection, bleeding, and graft failure. Additionally, the review will explore the role of ERAS protocols and the integration of cardiopulmonary rehabilitation in improving postoperative recovery [5]. Moreover, this review uniquely focuses on the role of ERAS protocols and their integration with GDT and SCPs, illustrating how these approaches enhance patient recovery and surgical outcomes in CABG. By synthesizing the latest research, this manuscript aims to provide clinicians and the wider cardiac surgical team with updated knowledge on postoperative management, guiding evidence-based clinical decision-making.

Theoretical Frameworks in Postoperative Management

The landscape of postoperative management after CABG is shaped by several theoretical frameworks designed to enhance patient outcomes and streamline care processes. This section provides an overview of the most prominent frameworks currently employed in clinical practice, including ERAS, GDT, and SCPs. Each of these frameworks incorporates evidence-based strategies to optimize various aspects of postoperative care, aiming to reduce complications and improve recovery times. In the following subsections, these frameworks are discussed in detail, highlighting their key components and underlying principles.

Enhanced Recovery After Surgery (ERAS)

ERAS is an evidence-based, multidisciplinary approach designed to enhance patient outcomes and expedite recovery after surgery [6]. ERAS protocols typically include preoperative optimization, minimizing surgical stress, and promoting early recovery [7]. Key components of ERAS include preoperative counseling, prehabilitation, optimized fluid management, early mobilization, and pain control (Table 1). These protocols prepare patients for surgery through counseling, nutritional optimization, and cessation of smoking and alcohol [7]. Additionally, techniques such as minimally invasive surgery and multimodal analgesia are employed to reduce the physiological stress response to surgery. Encouraging patients to move around soon after surgery helps prevent complications and enhance recovery, while effective pain control using multimodal analgesia reduces the need for opioids and allows for early mobilization (Table 2) [7]. Furthermore, patients are encouraged to resume oral intake as soon as possible to restore bowel function and reduce hospital stays.

The underlying principles of ERAS involve a multidisciplinary approach, patient-centered care, and evidence-based practices. Collaboration among surgeons, anesthesiologists, nurses, and other healthcare professionals ensures comprehensive patient care, while patient education and engagement promote active participation in the recovery process [6]. ERAS protocols are based on the latest research and clinical guidelines to ensure optimal outcomes. This approach has been widely adopted in various surgical specialties, including cardiac surgery, where it has been shown to improve recovery times and reduce complications [6]. In cardiac surgery, particularly CABG, ERAS differs significantly from its applications in gastrointestinal, gynecological, and orthopedic procedures, as it must account for the unique physiological challenges posed by cardiopulmonary bypass, hemodynamic stability, and targeted pharmacotherapy. These factors necessitate a tailored approach to perioperative management, integrating specific interventions that improve cardiovascular function, promote respiratory recovery, and facilitate early mobilization. For patients undergoing CABG, discussing the ERAS plan in detail with the medical team before surgery ensures optimal postoperative recovery outcomes by aligning care strategies with individualized needs and surgical complexity. This patient-centered approach fosters active participation in recovery, reinforcing the role of ERAS in both immediate postoperative management and long-term rehabilitation.

Numerous studies have demonstrated the benefits of ERAS protocols, including reduced postoperative complications, shorter hospital stays, and improved patient satisfaction, for CABG patients [8–10]. A recently published study by Schneider *et al.* [8] reported that the ERAS program for low-risk CABG patients was associated with a significant relative risk decrease in mechanical ventilation duration (–53.1%; $p = 0.003$), length of intensive care unit (ICU) stay (–28.0%; $p = 0.015$), length of hospital stay (–10.5%; $p = 0.046$), bronchopneumonia (–51.5%; $p < 0.001$), acute respiratory distress syndrome (–50.8%; $p = 0.050$), postoperative delirium (–65.4%; $p = 0.011$), moderate-to-severe acute kidney injury (–72.0%; $p = 0.009$), 24-hour chest tube output (–26.4%; $p < 0.001$), and overall red blood cell transfusion rate (–32.4%; $p = 0.005$) compared with the control group. ERAS has also been associated with reduced length of stay (LOS) after urgent or emergency CABG without adverse effects on prolonged ventilation, reintubation, intensive care unit readmission, or 30-day outcomes [9]. ERAS implementation is also associated with reduced disparities between Caucasians and racial and ethnic minority patients for ICU readmission and postoperative LOS [10].

Goal-Directed Therapy (GDT)

GDT is a patient-centric approach that focuses on optimizing tissue perfusion by monitoring and adjusting fluid, inotrope, and vasopressor therapy based on hemodynamic parameters [11]. The primary goal of GDT is to maintain adequate blood flow and oxygen delivery to tissues, which helps in reducing postoperative complications [12]. By using advanced monitoring techniques, such as arterial waveform analysis and central venous pressure monitoring, GDT ensures that patients receive the right volume of fluids and concentration of medications to maintain optimal perfusion pressure and cardiac output [13].

A fundamental aspect of GDT is its target-driven treatment approach, where therapeutic interventions are aimed at achieving an optimized cardiac index (CI) and oxygen delivery rate. An abnormal physiological state is defined as a CI exceeding 4.5 L/min/m^2 and an oxygen delivery rate surpassing 650 mL/min/m^2. Vasoactive drugs and tailored oxygen therapy are used to correct deviations from these critical thresholds, restoring optimal perfusion and ensuring stable postoperative hemodynamics.

Table 1. Key components of Enhanced Recovery After Surgery (ERAS) protocols for coronary artery bypass grafting.

Component	Description	Benefits
Preoperative optimization	Nutritional assessment, smoking cessation, and patient education	Improves patient readiness and reduces surgical risks
Minimally invasive surgery	Off-pump CABG, minimally invasive direct coronary artery bypass grafting (MIDCAB), and robotic CABG	Reduces surgical trauma and promotes faster recovery
Intraoperative management	Goal-directed fluid therapy and anesthetic techniques to minimize stress response	Maintains hemodynamic stability and reduces complications
Postoperative pain management	Multimodal analgesia (e.g., acetaminophen, regional anesthesia)	Provides effective pain relief and reduces opioid use
Early mobilization	Encourages early ambulation and physical therapy	Prevents complications and enhances recovery
Early oral intake	Early resumption of oral intake	Restores bowel function and reduces hospital stay
Patient education	Discharge planning and education on signs of complications	Empowers patients and improves adherence to postoperative care

CABG, coronary artery bypass grafting.

Table 2. Key components of multimodal analgesia in Enhanced Recovery After Surgery (ERAS) protocols for coronary artery bypass grafting.

Component	Description	Benefits
Preoperative medications	Acetaminophen, gabapentin, and pregabalin	Reduces baseline pain and minimizes opioid requirements
Regional anesthesia	Epidural anesthesia, paravertebral blocks, and PIRS plane block	Provides targeted pain relief and reduces systemic opioid use
Intraoperative medications	Ketamine, lidocaine infusion, magnesium, and dexmedetomidine	Reduces intraoperative pain and minimizes postoperative opioid use
Postoperative medications	Continuation of preoperative medications, and non-opioid analgesics	Sustains pain relief and further reduces opioid consumption

PIRS, Pectoralis-Intercostal-Rectus Sheath.

Table 3. Key studies reporting outcomes of goal-directed therapy in CABG patients.

Study	Year	Population	Intervention	GDT (n)	Control (n)	Targeted GDP parameters	Outcomes
Fellahi *et al*. [16]	2015	CABG with CPB	Early goal-directed therapy with ECOM	50	50	SVV, cardiac index	Patients in the GDT group received more often fluid loading and dobutamine. Significantly reduced time to reach extubation the GDT group. Similar length of hospital stay.
Kapoor *et al*. [17]	2016	CABG with CPB	Goal-directed therapy with FloTrac™	60	60	Cardiac index, stroke volume index, SVRI, oxygen delivery index, central venous oxygen saturation, SVV	Significantly higher average volume added and number of inotrope adjustments in the GDT group. Significantly shorter duration of ventilation, duration of inotrope usage, length of ICU stay, and length of hospital stay in GDT group. Similar mortality.
Kapoor *et al*. [18]	2017	Off-pump CABG	Goal-directed therapy with FloTrac™, PreSep™, and EV-1000®	75	88	Cardiac index, SVRI, oxygen delivery index, SVV, $ScVO_2$, global end-diastolic volume, EVLW	Significantly lower length of stay and duration of inotropes in GDT group. Similar duration of ventilated hours, mortality, and other complications.
Kapoor *et al*. [19]	2019	CABG with CPB	Goal-directed therapy with FloTrac	54	56	Mean arterial pressure, central venous pressure, urine output, oxygen saturation, hematocrit, central venous oxygen saturation, cardiac index, SVV, systemic vascular resistance index, oxygen delivery index, stroke volume index	Urinary NGAL was significantly lower immediately post-surgery (T_1), at 4 h (T_2), and at 24 h post-operatively (T_3) in GDT group. Plasma NGAL was comparable between groups at T_1 but significantly lower in the GDT group at T_2 and T_3.
Tribuddharat *et al*. [20]	2021	CABG with CPB	Early goal-directed therapy with FloTrac™/EV1000	44	42	Stroke volume variation, stroke volume index, cardiac index, systemic vascular resistance index	Significantly shorter ICU stay, ventilation time, and hospital LOS in GDT group.
Tribuddharat *et al*. [11]	2022	Off-pump CABG	Early goal-directed therapy with FloTrac™/EV1000	20	42	Stroke volume variation, stroke volume index, cardiac index, systemic vascular resistance index	Significantly shorter ICU and hospital LOS in the GDT group with comparable ventilation time.

CPB, cardiopulmonary bypass; ECOM, endotracheal cardiac output monitor; EVLW, extravascular lung water; GDT, goal-directed therapy; ICU, intensive care unit; LOS, length of stay; NGAL, neutrophil gelatinase-associated lipocalin; $ScVO_2$, continuous central venous oxygen saturation; SVRI, systemic vascular resistance index; SVV, stroke volume variation.

The key components of GDT include continuous monitoring of hemodynamic parameters, such as stroke volume variation, cardiac index, and systemic vascular resistance. These parameters provide real-time data that guide the administration of fluids, inotropes, and vasopressors to achieve target values [14]. Additionally, GDT involves the use of dynamic indices of fluid responsiveness, which help determine fluid needs for each patient more accurately than static measurements. This approach enables individualized therapy, ensuring that each patient receives the most appropriate treatment based on their specific physiological needs [15].

Several studies have demonstrated the benefits of GDT in CABG patients (Table 3) [11,16–20]. Indeed, a recently published meta-analysis of 1128 participants from seven studies reported significant differences in the duration of ICU stay (p = 0.01), with a mean difference of –0.33 (–0.59 to 0.07), and hospital LOS (p = 0.0002), with a mean difference of –0.84 (–1.29 to –0.39). There was also a notable reduction in postoperative complications ($p < 0.00001$), with an odds ratio (OR) of 0.43 (0.32–0.60). However, there was no significant decrease in the mortality rate (p = 0.54; OR, 0.77; 0.34–1.77) [21]. The GDT research involving CABG patients remains limited, and additional trials with larger participant populations and standardized protocols are required to evaluate the advantages of GDT properly.

Standardized Care Pathways (SCPs)

SCPs are structured, multidisciplinary plans that outline the optimal sequencing and timing of interventions by healthcare professionals for a particular diagnosis or procedure. These pathways aim to standardize care, reduce variability, and improve patient outcomes by ensuring that all patients receive evidence-based care. Key components of these pathways include preoperative optimization, intraoperative management, and postoperative care, with a focus on minimizing complications and enhancing recovery [22].

The underlying principles of standardized care pathways involve evidence-based practice, multidisciplinary collaboration, and continuous quality improvement [23]. By adhering to these principles, healthcare providers can ensure that patients receive consistent and high-quality care throughout their surgical journey. This approach also facilitates the collection and analysis of data, which can be used to identify areas for improvement and implement changes that enhance patient outcomes [24].

Meanwhile, there is evidence that following a defined pathway or protocol improves patient outcomes for patients requiring CABG. Prescriptive perioperative analgesia and extubation pathways for low-risk CABG surgical patients decrease the time to extubation and reduce ICU LOS, with mortality rates equivalent to those of usual care [25]. These postoperative protocols have even been shown to reduce costs in some circumstances, likely owing to reductions in resource utilization [26].

Analysis of Theoretical Frameworks

These frameworks standardize care processes, ensuring that all patients receive evidence-based interventions at the appropriate times, which reduces care variability and enhances overall quality of care. However, these frameworks also have limitations. The implementation of standardized care pathways requires significant coordination and collaboration among healthcare providers, which can be particularly challenging in certain settings. Additionally, adherence to these pathways can be variable, and deviations from the protocol can occur, potentially impacting patient outcomes [27]. Furthermore, while GDT has demonstrated benefits in reducing complications, this therapy requires advanced monitoring equipment and expertise, which may not be available in all healthcare facilities. Despite these limitations, the strengths of these frameworks in improving patient outcomes and reducing care variability make them valuable tools in managing CABG patients (Table 4) [28].

Key Concepts in Postoperative Management

Hemodynamic Monitoring

Hemodynamic monitoring involves the continuous assessment of cardiovascular function to ensure adequate tissue perfusion and oxygenation [29]. Therefore, detecting and managing complications such as hypotension, arrhythmias, and fluid imbalance is crucial in the postoperative period [30]. Current methods include invasive techniques, such as pulmonary artery catheterization, and non-invasive procedures such as echocardiography and pulse contour analysis. Moreover, advanced technologies, such as dynamic indices of fluid responsiveness and machine learning algorithms, are currently being integrated to enhance monitoring accuracy [30]. The theoretical basis for hemodynamic monitoring lies in the principles of cardiovascular physiology and fluid dynamics. GDT, which tailors interventions based on individual patient hemodynamic parameters, has been shown to improve outcomes by reducing perioperative complications and hospital LOS [30].

Pain Management

Effective pain management is essential for enhancing patient comfort, facilitating early mobilization, and reducing the risk of complications, including deep vein thrombosis and pulmonary embolism. Indeed, effective pain management involves the use of multimodal analgesia to achieve optimal pain control with minimal side effects. Current pain management protocols include the use

Table 4. Strengths and limitations of theoretical frameworks.

Framework	Strengths	Limitations
ERAS	- Reduces hospital stay and complications - Optimizes preoperative preparation and postoperative recovery - Minimizes surgical stress	- Requires strict adherence to protocols - Potential resistance from healthcare providers accustomed to traditional practices - Needs multidisciplinary collaboration
GDT	- Optimizes oxygen delivery and tissue perfusion - Reduces complications associated with hemodynamic instability - Provides individualized patient care	- Risk of fluid overload and arrhythmias - Potential for myocardial necrosis due to aggressive fluid/inotrope administration - Lack of consensus on optimal parameters and endpoints
SCP	- Standardizes care processes - Improves communication among healthcare providers - Enhances patient safety - Optimizes resource utilization	- Challenges in implementation across different healthcare settings - Requires continuous review and updates - May be difficult to adapt to specific patient needs - Possible resistance to change from staff

ERAS, Enhanced Recovery After Surgery; SCP, standardized care pathways.

of opioids, non-opioid analgesics, regional anesthesia techniques, and adjuvant medications. The 2024 guidelines by the British Pain Society emphasize a patient-centered approach, incorporating individualized pain management plans and the involvement of dedicated pain teams [31]. Theories related to pain perception and management in postoperative care focus on the gate control theory of pain and the biopsychosocial model. These theories guide the development of pain management strategies that address both the physiological and psychological aspects of pain.

Respiratory Support

Respiratory support in the postoperative period is vital for patients at risk of respiratory complications. This support includes measures to ensure adequate oxygenation and ventilation, prevent atelectasis, and manage acute respiratory failure [32]. Current methods of respiratory support include mechanical ventilation, non-invasive ventilation, and high-flow nasal cannula oxygen therapy. Meanwhile, protocols for weaning from mechanical ventilation and the use of non-invasive support to prevent reintubation are widely implemented [33]. Theoretical frameworks guiding respiratory management emphasize the importance of lung-protective ventilation strategies (Table 5) and early mobilization. Research has shown that non-invasive respiratory support can reduce the incidence of reintubation, nosocomial pneumonia, and ICU LOS [33].

Personalized Medicine in Postoperative Care

Personalized medicine, often referred to as precision medicine, is a transformative approach to healthcare that tailors medical treatment to the individual characteristics of each patient [34]. This approach considers genetic, environmental, and lifestyle factors to guide decisions in the prevention, diagnosis, and treatment of diseases. In the context of postoperative management for CABG, personalized medicine aims to optimize recovery by addressing the unique needs and responses of each patient. By considering the specific genetic makeup of each patient, customized medicine can lead to more accurate predictions of drug efficacy and adverse reactions, thereby enhancing overall patient care [34].

The application of personalized medicine in postoperative care is becoming increasingly prevalent. A notable example is pharmacogenetics, which involves tailoring medication to the genetic profile of a patient. This approach has shown promising results in improving the efficacy of pain management and reducing the adverse effects of medications. For instance, genotype-guided therapy has been effective in lowering opioid consumption and enhancing pain control post-surgery [34,35]. Another example of this approach is seen with antiplatelet medicines, such as clopidogrel, which is a prodrug that requires activation by the liver enzyme CYP2C19. Hence, genetic variations in the *CYP2C19* gene can significantly impact the ability of a patient to metabolize clopidogrel. For instance, individuals with certain genetic variants may be classified as "poor metabolizers", meaning these individuals cannot effectively convert clopidogrel into its active form, leading to reduced platelet inhibition and an increased risk of adverse cardiovascular events. In such cases, alternative antiplatelet agents, such as prasugrel or ticagrelor, which are not affected by CYP2C19 genetic variants, may be prescribed to ensure better therapeutic outcomes [36,37]. This personalized approach enables the optimization of treatment plans based on individual genetic profiles, thereby enhancing patient safety and treatment efficacy. Moreover, individualized rehabilitation programs are designed based on patient-specific factors, such as physical capacity and comorbid conditions, to improve recovery outcomes [38]. Risk stratification, which uses genetic and clinical data to identify patients at higher risk of postoperative complications, enables targeted interventions and proactive management strategies.

Table 5. Lung protection ventilation strategies.

Strategy	Description	Pros	Cons
Low tidal volume (4–8 mL/kg PBW)	Uses lower tidal volumes to minimize lung injury.	Reduces ventilator-associated lung injury, volutrauma, and barotrauma.	May lead to hypercapnia, requiring permissive hypercapnia.
Permissive hypercapnia	Allows higher levels of carbon dioxide to reduce lung injury.	Reduces lung injury and inflammation.	Can cause respiratory acidosis, requiring careful monitoring.
Positive end-expiratory pressure (PEEP)	Maintains positive pressure in the lungs at the end of expiration.	Prevents alveolar collapse and improves oxygenation.	Can cause barotrauma and requires careful titration.
Lung recruitment maneuvers	Uses transient increases in airway pressure to open collapsed alveoli.	Improves oxygenation and recruits collapsed lung units.	Can cause hemodynamic instability and requires careful monitoring.
Prone positioning	Places the patient in a prone position to improve ventilation-perfusion matching.	Enhances oxygenation and reduces ventilator-induced lung injury.	Requires additional staff and can be uncomfortable for patients.
Optimal PEEP setting	Adjusts PEEP to achieve optimal oxygenation without causing lung injury.	Improves oxygenation and reduces lung injury.	Requires careful titration and can cause hemodynamic instability.

PBW, predicted body weight.

Table 6. Current wearable technology for health monitoring.

Technology	Pros	Cons
Smartwatches	Continuous heart rate monitoring, sleep tracking, activity tracking, and notifications	Battery life limitations, potential accuracy issues, and data privacy concerns
Continuous glucose monitors	Real-time blood glucose monitoring, alerts for high/low levels and reduces the need for finger-prick tests	Cost, potential skin irritation, and requires calibration
Wearable ECG monitors	Real-time heart rhythm monitoring, early detection of arrhythmias, and integration with health apps	Limited to cardiac monitoring, and potential for false positives/negatives
Fitness trackers	Activity tracking, step counting, sleep monitoring, and goal setting	Accuracy issues, limited health metrics compared to medical-grade devices
Microfluidic patches	Real-time analysis of bodily biomarkers, non-invasive, enhances diagnostic accuracy	Limited availability, potential skin irritation, and data interpretation challenges
Smart clothing	Continuous monitoring of vital signs, integration with health apps, and comfort	Higher cost, potential for data inaccuracies, and maintenance requirements

ECG, electrocardiogram.

Table 7. Key components of the theory of organizational culture.

Component	Description
Definition	Organizational culture refers to the shared values, beliefs, and behaviors that shape how employees interact and work within an organization.
Levels of culture	There are three levels: artifacts (visible elements), espoused values (stated norms and values), and basic underlying assumptions (deeply embedded beliefs).
Types of culture	Common types include clan culture (collaborative), adhocracy culture (innovative), market culture (competitive), and hierarchy culture (structured).
Impact on performance	A strong, positive culture can improve employee satisfaction, productivity, and overall organizational performance. A negative culture can lead to low morale, high turnover, and reduced efficiency.
Change management	Changing an organizational culture involves altering underlying assumptions and values, which requires leadership commitment, effective communication, and employee involvement.
Measurement tools	Tools, such as surveys, interviews, and observational studies, can be used to assess organizational culture. Common frameworks include the Competing Values Framework and the Organizational Culture Assessment Instrument.
Theoretical models	Schein's Model of Organizational Culture, Hofstede's Cultural Dimensions Theory, and the Denison Organizational Culture Model are prominent theories used to understand and analyze organizational culture.

The future of personalized medicine in postoperative care holds immense potential. One promising area is the integration of omics data, including genomics, proteomics, and metabolomics, to provide a comprehensive understanding of the responses of patients to treatment [39]. Additionally, the development of advanced predictive models using machine learning algorithms can enhance the accuracy of predicting patient outcomes and tailoring interventions accordingly [40,41]. The implementation of personalized monitoring devices, such as wearable technology (Table 6), can facilitate continuous health monitoring and real-time adjustments to treatment plans, leading to improved patient care and outcomes [42,43]. Future research should focus on validating these approaches and exploring their broader applications in various surgical contexts, including CABG.

Challenges and Barriers in Conceptualizing Postoperative Management

Despite the proven benefits of ERAS, the adoption of this protocol in CABG surgery faces notable barriers, including institutional hesitancy, limited training among healthcare providers, and resource constraints in lower-income settings. Addressing these challenges requires policy interventions, structured training programs, and enhanced interdisciplinary coordination. This section provides a detailed discussion of some key challenges.

Hospital Culture and Interdisciplinary Collaboration

Hospital culture and interdisciplinary collaboration play a vital role in the postoperative management of CABG. Hospital culture encompasses the collective values, beliefs, and practices within a healthcare setting that influence the working environment [44]. A positive hospital culture fosters effective teamwork, communication, and a patient-centered approach to care, which are essential for successful postoperative outcomes following CABG. Interdisciplinary collaboration involves the coordinated efforts of a diverse team of healthcare professionals, including cardiothoracic surgeons, anesthesiologists, nurses, cardiologists, physiotherapists, and pharmacists. Effective collaboration ensures that all aspects of postoperative care, from pain management and wound care to rehabilitation and patient education, are comprehensively addressed [45].

Despite the benefits of interdisciplinary collaboration, several challenges and barriers hinder its effective implementation in the context of CABG. One major challenge is the hierarchical structure within hospitals, which can limit open communication and collaboration among different healthcare professionals [46]. Variations in knowledge, expertise, and experience levels can lead to conflicts and misunderstandings within the team. Time constraints and heavy workloads often limit opportunities for team meetings and discussions, further complicating collaborative efforts [47]. Additionally, differences in professional cultures and practices can create silos, where healthcare providers work in isolation rather than as a cohesive unit [48]. These challenges can result in fragmented care, miscommunication, and suboptimal patient outcomes for CABG patients.

Theories related to organizational behavior and team dynamics offer valuable insights into overcoming challenges in interdisciplinary collaboration for CABG management. The theory of organizational culture highlights the importance of fostering a positive and inclusive culture to enhance teamwork and effective communication (Table 7) [49]. The TeamSTEPPS (Team Strategies and Tools to Enhance Performance and Patient Safety) framework emphasizes leadership, mutual support, and situation monitoring to improve team performance [50]. The Interprofessional Collaboration Framework underscores the significance of role clarification, shared goals, and mutual respect in facilitating effective collaboration [51]. Thus, by

Table 8. Gaps in postoperative management of coronary artery bypass grafting.

Gap	Description
Postoperative medicines	Gaps include inconsistent use of antiplatelet therapy [63], suboptimal management of anticoagulants, and inadequate lipid-lowering therapy. Addressing these gaps can improve graft patency and overall patient outcomes.
Non-pharmacological interventions	Effective non-pharmacological interventions include preoperative patient education, mind-body modalities (e.g., relaxation techniques, mindfulness), physical therapies (e.g., exercise programs, physical rehabilitation), and psychological support (e.g., counseling and support groups) [64]. These interventions can help reduce readmissions and improve patient outcomes.
Readmission rates	Approximately 9.5% of CABG patients are readmitted urgently within 30 days of surgery [64]. Identifying and addressing gaps in postoperative care can help reduce these readmissions.
ERAS implementation	Despite proven benefits, ERAS protocols are inconsistently used in practice, and barriers to implementation need to be addressed.
GDT consensus	There is no general consensus on the use of GDT, and future trials are needed to evaluate patient-centered outcomes.
Specialized care pathways	Integrating specialized services within care pathways is essential for improving outcomes; however, gaps in coordination and integration remain.
Patient education	Educating patients about postoperative care, including lifestyle changes and medication adherence, is crucial for improving long-term outcomes.
Interdisciplinary coordination	Enhancing communication and coordination among care teams can lead to more efficient and effective patient care.

applying these theories, healthcare organizations can develop strategies to overcome barriers and enhance interdisciplinary collaboration in the postoperative management of CABG.

Cost and Resource Allocation

The significance of cost and resource allocation in postoperative care for CABG is paramount. Efficient allocation ensures that patients receive the necessary care without unnecessary expenditure, which is crucial in a healthcare system with finite resources. Proper resource management can lead to better patient outcomes, reduced hospital stays, and overall cost savings [52]. A recently published study by Chen *et al*. [24] highlights the importance of cost-effective care in CABG, emphasizing the need for efficient resource utilization to sustain high-quality services.

Financial and resource-related challenges in postoperative care for CABG are multifaceted. Limited funding, high costs of medical supplies, and staffing shortages are significant barriers [53,54]. Additionally, the need for specialized equipment and technology can strain budgets, especially in resource-limited settings. These barriers can lead to disparities in care quality and access, affecting patient outcomes [24]. A recently published study outlines the financial challenges faced by healthcare systems, including the need for improvements in efficiency and productivity [55].

Economic theories and models provide valuable insights into healthcare resource management. The principles of scarcity, supply, and demand, as well as opportunity cost, are particularly relevant [56]. For instance, the theory of supply and demand helps in understanding how resources should be allocated to meet patient needs efficiently. Additionally, concepts, such as marginal analysis, can aid in making cost-effective decisions in postoperative care [57]. Turner *et al*. [58] discuss the application of economic principles to healthcare, emphasizing the need for efficient resource allocation to achieve improved health outcomes.

Efficient cost and resource allocation in postoperative care following CABG is critical for optimizing patient outcomes while maintaining financial sustainability. Marginal analysis plays a key role in evaluating the incremental benefits and costs of different interventions, helping healthcare providers to determine whether additional treatments, such as extended antiplatelet therapy, enhanced monitoring with wearable technology, or early mobilization programs, offer sufficient benefits to justify their expenses. For instance, while extending dual antiplatelet therapy (DAPT) may reduce cardiovascular complications, marginal analysis helps weigh its financial feasibility against its effectiveness. Similarly, wearable devices for real-time hemodynamic tracking may improve recovery; however, these devices require substantial investment, making marginal analysis essential in assessing cost-effectiveness compared to traditional follow-up methods. Economic modeling further supports resource allocation by predicting cost-efficiency across various postoperative strategies. Predictive models estimate long-term healthcare costs associated with differing levels of postoperative care, ensuring financial planning aligns with sustainable treatment options. This includes evaluating hospital readmission rates to guide preventive measures, quantifying cost reductions linked to ERAS implementation, and leveraging health informatics to optimize hospital resource distribution based on patient demand patterns. By integrating these economic principles, healthcare providers can prioritize interventions that yield the highest impact on patient recovery while ensuring cost-effective decision-making in postoperative CABG management.

Implications for Practice and Future Research

Best Practices and Recommendations

Integrating the concepts discussed into practical recommendations for postoperative care of CABG patients is crucial. For instance, efficient resource allocation and cost-effective care can significantly improve patient outcomes. Implementing standardized protocols for postoperative care, such as the use of DAPT, can reduce the risk of major adverse cardiovascular events [59]. Additionally, ensuring proper follow-up care and monitoring for complications can facilitate early detection and management of issues, leading to better long-term outcomes [60].

Proposing strategies for implementing best practices in clinical settings involves several key steps. First, healthcare institutions should adopt evidence-based guidelines and protocols for postoperative care [61]. Training and education programs for healthcare professionals can also ensure that the institutions are well-versed in the latest practices and technologies. Furthermore, leveraging health information technology, such as electronic health records and telemedicine, can enhance communication and coordination among care teams, leading to more efficient and effective patient care [62].

Research Directions

Gaps in Literature

Identifying gaps in existing research is essential for advancing the field of postoperative management of CABG (Table 8) [63,64]. One area that requires further investigation is the long-term impact of different antiplatelet therapy strategies on patient outcomes. While DAPT with aspirin and a P2Y12 inhibitor is a widely adopted strategy in CABG postoperative management, questions remain regarding optimal duration, patient selection, and balancing thrombotic protection with bleeding risk. Emerging evidence suggests that individualized antiplatelet regimens, guided by platelet function testing and patient-specific risk factors, may offer improved outcomes [65]. Additionally, optimizing adjunctive pharmacotherapy, including beta-blockers, statins, and anticoagulants, plays a crucial role in enhancing vascular protection and minimizing complications. Further studies are needed to evaluate the efficacy and safety of these pharmacological strategies in different patient populations to refine postoperative management protocols. Additionally, research on the cost-effectiveness of various postoperative care interventions can provide valuable insights into resource allocation and financial management in healthcare systems.

Theoretical Development

Expanding and refining theoretical frameworks in the postoperative management of CABG can significantly enhance patient outcomes and optimize resource utilization. One promising research direction involves applying economic principles to postoperative care, such as marginal analysis. Thus, by analyzing the marginal benefits and costs of different interventions, healthcare providers can make cost-effective decisions that maximize patient outcomes while minimizing unnecessary expenditure. This approach ensures efficient allocation of healthcare resources and may lead to reduced costs and improved care quality.

Developing and testing new theoretical models that integrate clinical, economic, and patient-centered outcomes is another crucial area of focus. Future research can create comprehensive models that consider clinical metrics, such as complication and readmission rates, alongside economic factors, including the cost of care and resource utilization. Patient-centered outcomes, including satisfaction and quality of life, should also be integrated into these models. By providing a holistic understanding of postoperative care, these models can guide healthcare providers in making balanced decisions that optimize all aspects of patient care.

Leveraging principles from behavioral economics can also help improve postoperative management. Meanwhile, research can explore strategies, such as nudges, incentives, and decision aids, to enhance medication adherence, follow-up attendance, and lifestyle modifications [66]. Aligning patient behavior with best practices can lead to improved postoperative outcomes and a reduction in complications. Additionally, utilizing health informatics, such as electronic health records (EHRs) and telemedicine, can enhance communication and coordination among care teams. Research in this area can focus on developing advanced EHR systems that support real-time data sharing and decision-making, as well as telemedicine platforms that facilitate remote monitoring and follow-up [67].

Finally, applying systems theory and process optimization techniques to postoperative management can further refine theoretical frameworks [68]. Systems theory can help understand the complex interactions between different components of postoperative care, while process optimization techniques can streamline care pathways by identifying and addressing bottlenecks in care delivery. Developing patient-centered care models that emphasize individualized care plans based on patient needs and preferences can also enhance postoperative management. By pursuing these research directions and refining theoretical frameworks, the field of postoperative management of CABG can continue to evolve, ultimately leading to improved patient outcomes and more efficient use of healthcare resources.

Conclusion

The postoperative management of CABG is a complex and multifaceted process requiring a structured and evidence-based approach to optimize patient outcomes. This review highlights several key concepts and theoretical frameworks, including the implementation of ERAS, GDT, and SCPs as critical strategies for improving recovery, reducing complications, and enhancing surgical safety and efficacy. These approaches provide a structured framework for postoperative care, ensuring personalized management tailored to individual patient needs.

To achieve optimal postoperative outcomes, clinicians should prioritize early mobilization, comprehensive pain management, individualized hemodynamic stabilization, and evidence-driven pharmacotherapy. The integration of health information technology, such as advanced electronic health records and telemedicine platforms, further enhances communication and coordination among care teams, streamlining postoperative recovery and improving continuity of care.

While continued research and theoretical development remain essential for advancing CABG postoperative management, these methods should complement, rather than overshadow, the implementation of existing best practices. Future investigations should focus on refining treatment protocols, assessing the long-term impact of antiplatelet therapy strategies, improving resource allocation models, and optimizing ERAS and GDT frameworks for diverse patient populations.

In conclusion, the effective implementation of evidence-based strategies in CABG postoperative management can lead to improved patient outcomes, reduced hospital readmissions, and more efficient use of healthcare resources. By continuously refining best practices and integrating emerging research, clinicians and healthcare providers can enhance recovery trajectories and ensure the highest standard of postoperative care. The collaborative efforts of researchers, clinicians, and multidisciplinary teams will be instrumental in driving continued advancements in the field.

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The single author was responsible for the conception of ideas presented, writing, and the entire preparation of this manuscript.

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Conflict of Interest

The author declares no conflict of interest. Shahzad Gull Raja is serving as one of the Editorial Board members of this journal. We declare that Shahzad Gull Raja had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to Yunpeng Zhu.

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