Enhanced Recovery After Cardiac Surgery (ERACS)Integrating Cardiac Anaesthesia and Cardiac Rehabilitation

Abstract

Enhanced Recovery After Cardiac Surgery (ERACS) is a coordinated, evidence-informed perioperative framework that combines preoperative risk optimization, contemporary cardiac anaesthesia, cardiopulmonary bypass management, postoperative critical care, and longitudinal cardiac rehabilitation. Its objective is not simply earlier discharge but safer restoration of organ function, functional independence, and patient-reported recovery. This expanded narrative review examines the biological basis of surgical stress, frailty and prehabilitation, perioperative patient blood management, opioid-sparing analgesia, haemodynamic and ventilatory strategies, delirium and acute kidney injury prevention, early extubation, respiratory physiotherapy, mobilization, and outpatient rehabilitation. The 2024 ERAS Cardiac expert recommendations, 2024 AHA/AACVPR rehabilitation statement, and 2026 AHA patient blood management statement inform the updated discussion. Clinical decision algorithms emphasize haemodynamic stability, bleeding control, oxygenation, cognition, and individualized progression. Digital rehabilitation and artificial intelligence offer promising tools but require validation, governance, and equitable access. ERACS should be implemented as a measurable multidisciplinary bundle with audit of both process adherence and patient-centred outcomes.

Keywords: ERACS; cardiac anaesthesia; cardiopulmonary bypass; patient blood management; early extubation; postoperative physiotherapy; prehabilitation; cardiac rehabilitation; frailty; patient-reported outcomes.

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1. Introduction and rationale

Cardiac operations—including coronary artery bypass grafting, valve repair or replacement, selected aortic procedures, and complex combined operations—can provoke a substantial systemic inflammatory and metabolic response. Cardiopulmonary bypass, ischaemia–reperfusion, transfusion exposure, sternotomy-related pain, and prolonged inactivity can contribute to pulmonary dysfunction, arrhythmia, kidney injury, delirium, muscle weakness, and delayed recovery. A single fast-track anaesthetic technique cannot address all these pathways. ERACS instead links interventions before admission, in the operating theatre, in intensive care, on the ward, and after discharge.

Evidence supports the value of bundled care and coordinated pathways, but the effect of individual elements varies by patient group and surgical complexity. Early extubation, shorter ICU stays, and reduced opioid exposure are process or intermediate outcomes; survival, functional capacity, quality of life, readmission, and sustained participation in secondary prevention remain equally important.

2. Physiological basis of enhanced recovery

Surgical tissue injury and extracorporeal circulation activate sympathetic and hypothalamic–pituitary–adrenal pathways, complement, coagulation, leukocytes, and inflammatory cytokines. Increased catecholamines and cortisol contribute to insulin resistance and proteolysis. Ischaemia–reperfusion generates reactive oxygen species and endothelial dysfunction. Capillary leak, myocardial stunning, and altered pulmonary mechanics can impair oxygen delivery and organ function. Anaemia, hypothermia, excessive fluid administration, and prolonged deep sedation can compound these effects.

Pain-induced splinting limits tidal expansion and cough, while sedation and immobility can promote atelectasis and deconditioning. The rationale for integrated analgesia and physiotherapy is therefore mechanistic: sufficient analgesia and wakefulness permit lung expansion, airway clearance, transfers, and progressive ambulation without excessive haemodynamic demand.

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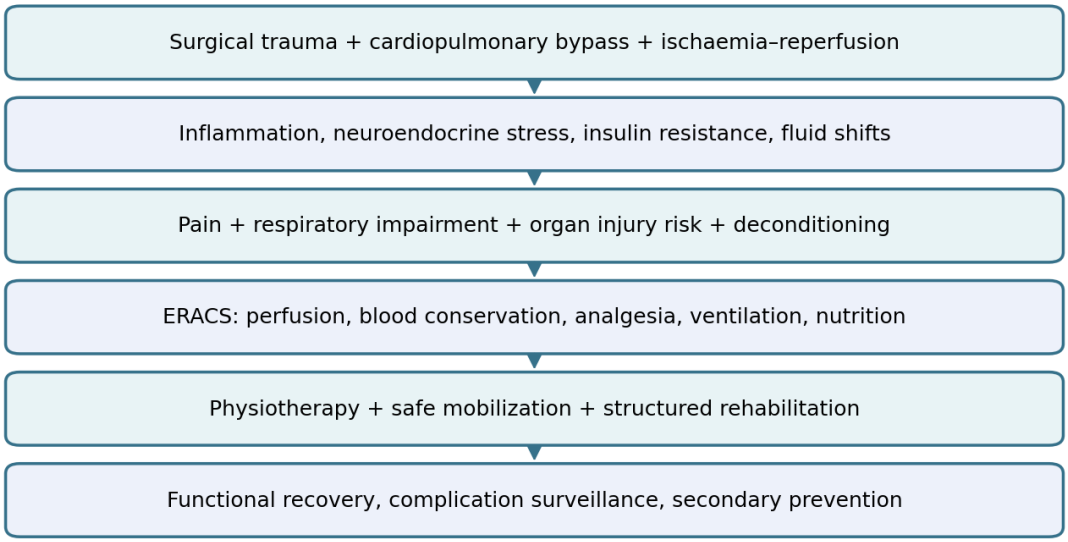


Figure 1. Original conceptual flowchart: surgical stress and ERACS countermeasures

3. Preoperative assessment and optimization

3.1 Risk assessment and shared decision-making

Assessment should integrate operative urgency, procedure complexity, ventricular function, valve pathology, coronary anatomy, pulmonary hypertension, kidney function, previous stroke, anaemia, diabetes, respiratory disease, frailty, cognition, nutritional status, and social support. Validated cardiac surgical risk tools such as EuroSCORE II or STS risk estimates can inform discussion but should not replace clinical judgement. Baseline function can be recorded using gait speed, sit-to-stand performance, or a six-minute walk test when appropriate. Identify patient goals, anticipated postoperative limitations, and barriers to outpatient rehabilitation.

3.2 Prehabilitation

For elective surgery, consider a personalized prehabilitation program combining low-to-moderate intensity aerobic activity, strength and balance work, inspiratory muscle training in selected high-risk patients, nutrition optimization, and education. Exercise prescription requires review of unstable angina, decompensated heart failure, critical symptomatic valve disease, and uncontrolled arrhythmia. Smoking and hazardous alcohol cessation ideally begins at least four weeks before elective surgery. Screen for iron deficiency and anaemia sufficiently early to investigate and treat causes. Measure HbA1c to inform diabetes-related risk and coordinate perioperative glycaemic care.

3.3 Nutrition, fasting and medicines

Screen for malnutrition and sarcopenia and correct deficiencies when feasible. Avoid unnecessarily prolonged fasting; clear-fluid timing should follow anaesthesia guidance and individual aspiration-risk assessment. Routine carbohydrate loading is not appropriate for every cardiac surgical patient, especially where gastric emptying or glycaemic control is uncertain. Anticoagulants, antiplatelet agents, beta-blockers, renin–angiotensin drugs, diabetes medicines, and SGLT2 inhibitors require procedure-specific medication plans coordinated by the surgical and anaesthesia teams.

Domain	Practical assessment	ERACS action
Frailty/function	Gait, falls, mobility, ADL limitations	Individualized prehabilitation and discharge planning
Blood management	CBC, iron indices, bleeding/antithrombotic history	Investigate anaemia; optimize iron and haemostasis

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Metabolic/nutrition	HbA1c, nutrition screen, renal function	Individualized glucose and nutrition plan
Pulmonary	Smoking, OSA, COPD, exercise tolerance	Cessation, respiratory education, CPAP plan if relevant
Psychosocial	Anxiety, cognition, transport and home support	Education, caregiver engagement, rehab referral

4. Intraoperative cardiac anaesthesia and organ protection

4.1 Individualized fast-track anaesthesia

Fast-track anaesthesia favours titratable hypnotics, short-acting opioids when needed, balanced neuromuscular blockade, avoidance of residual paralysis, temperature management, and deliberate emergence planning. A low-opioid approach is not synonymous with opioid-free anaesthesia: severe sternotomy pain still requires rescue analgesia. Selection of sedatives and adjuncts must account for conduction disease, ventricular dysfunction, vasoplegia, renal or hepatic impairment, and potential drug interactions.

4.2 Multimodal analgesia and regional blocks

A scheduled non-opioid foundation, often acetaminophen where suitable, can be combined with carefully selected adjuncts and rescue opioids. Ultrasound-guided parasternal intercostal plane and erector spinae plane blocks may improve chest-wall analgesia and facilitate cough and mobilization. Other blocks depend on incision location. Regional techniques require attention to systemic anticoagulation, bleeding risk, local anaesthetic systemic toxicity, block depth, and institutional expertise. Routine NSAIDs after CABG are not appropriate because of cardiovascular, renal, and bleeding concerns; adjuncts such as ketamine, dexmedetomidine, gabapentinoids, or intravenous lidocaine should not be used indiscriminately.

4.3 Perfusion, ventilation and blood conservation

Haemodynamic therapy should focus on adequate oxygen delivery and organ perfusion rather than fixed fluid volumes or a single pressure target. TEE, arterial pressure, perfusion markers, lactate trends, urine output, and cardiac output measurements may guide decisions according to risk and expertise. During cardiopulmonary bypass, avoid excessive haemodilution, severe hyperthermia during rewarming, and preventable

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oxygen-delivery deficits. Lung-protective ventilation, appropriate positive end-expiratory pressure, recruitment when tolerated, and careful postoperative respiratory assessment reduce avoidable pulmonary stress. Patient blood management combines preoperative anaemia correction, antifibrinolytics where indicated, cell salvage, point-of-care coagulation assessment, and restrictive, individualized transfusion decisions.

5. Postoperative critical care: recovery without premature escalation

5.1 Extubation readiness

Extubation within approximately six hours can be an appropriate program goal after selected elective operations, but it is not a mandate. Before extubation, confirm acceptable oxygenation and ventilation, wakefulness and airway protection, adequate analgesia, reversal of neuromuscular blockade, haemodynamic stability, controlled bleeding, normothermia, and no immediate reintervention concern. Persistent shock, severe hypoxaemia, major bleeding, significant neurologic impairment, or escalating vasoactive support should prompt delay and reassessment.

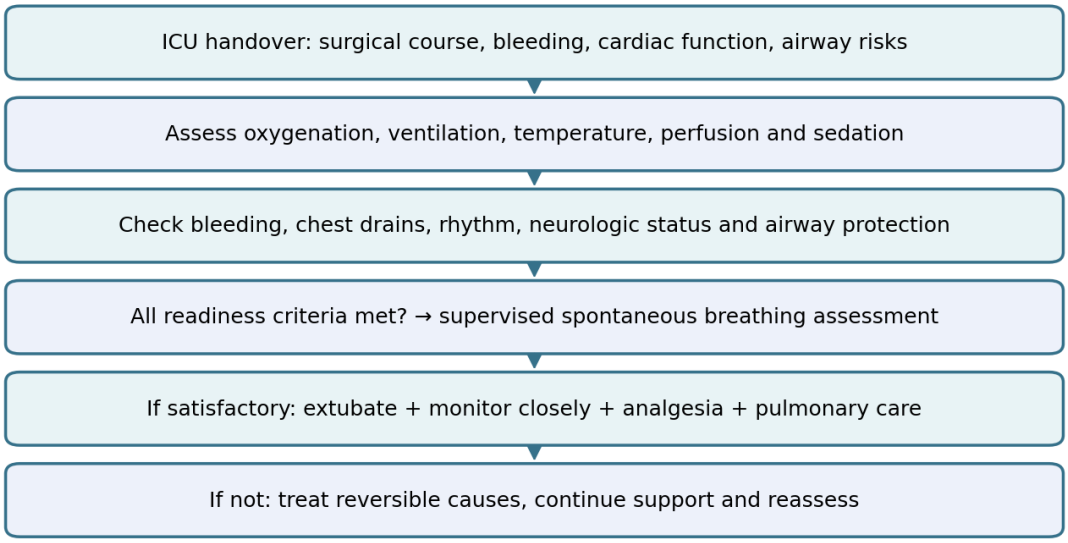


Figure 2. Original clinical decision pathway: extubation after cardiac surgery

5.2 Delirium, atrial fibrillation, kidney injury and thrombosis

Use structured delirium screening at least once per nursing shift alongside sleep promotion, orientation, sensory aids, mobilization, and minimization of unnecessary sedatives. Postoperative atrial fibrillation prevention is multifactorial and may include continuation or appropriate initiation of beta-blockade, electrolyte optimization, and management of inflammation and retained blood, guided by contraindications. Monitor

creatinine, urine output, perfusion, and nephrotoxic exposures to identify acute kidney injury early. Pharmacological venous thromboembolism prophylaxis should begin only after acceptable haemostasis, with mechanical prophylaxis and local surgical protocols considered. Maintain chest drain patency without unsafe stripping or breaking the sterile field.

5.3 Nutrition and glucose

Resume oral or enteral nutrition as soon as clinically safe, with swallowing evaluation when indicated. Avoid both persistent hyperglycaemia and hypoglycaemia; insulin protocols require regular monitoring and adaptation to nutrition and clinical status. Nutrition and adequate protein intake support wound healing and resistance to muscle catabolism, but targets should be individualized in kidney disease and critical illness.

6. Physiotherapy and cardiac rehabilitation continuum

6.1 ICU and ward rehabilitation

After haemodynamic and respiratory stabilization, rehabilitation progresses from positioning and active limb movements to sitting, standing, short assisted walking, longer corridor ambulation, and functional stair assessment. Progression is based on symptoms, rhythm, blood pressure response, oxygenation, orthostatic tolerance, pain, fatigue, drain and line security, and sternotomy integrity. Do not mobilize through new chest pain, symptomatic arrhythmia, severe hypotension, major desaturation, uncontrolled bleeding, or unstable circulatory support. Coordinate analgesia timing with therapy sessions.

Respiratory interventions include coached deep breathing, supported coughing or huffing, upright positioning, early ambulation, and targeted airway clearance when secretions are present. Incentive spirometry may be an adjunct, but should not replace mobilization and comprehensive pulmonary care. Inspiratory muscle training is most useful when tailored to a patient’s measured impairment and capacity rather than prescribed universally.

6.2 Outpatient and home-based rehabilitation

A comprehensive cardiac rehabilitation program includes baseline medical and functional assessment, individualized aerobic exercise, progressive resistance exercise when cleared, risk-factor modification, nutrition and weight management, psychosocial assessment, physical activity counselling, and program-quality monitoring. Exercise intensity should be based on symptoms, clinical risk, medications, and ideally exercise testing where available. Sternal precautions should emphasize safe, comfortable functional movement rather than unnecessarily prolonged immobility. Hybrid and home-

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based programs can improve access for appropriate patients, but must retain clinical supervision, escalation procedures, and the core components of rehabilitation.

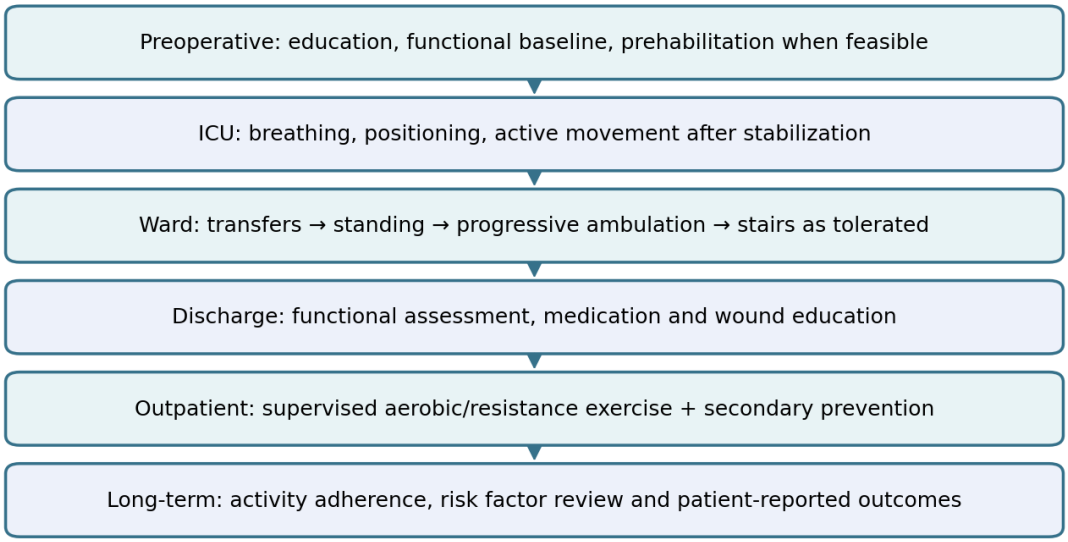


Figure 3. Original schematic: staged rehabilitation with safety gates

Phase	Main intervention	Readiness / safety check
Preoperative	Breathing education, strength, aerobic conditioning	No unstable cardiovascular contraindication
ICU	Positioning, limb activity, sitting, standing	Stable perfusion, oxygenation and bleeding
Ward	Walking progression, self-care, stairs	Rhythm, symptoms, pain, orthostasis, sternal stability
Outpatient	Aerobic/resistance training and education	Risk stratification, exercise monitoring and escalation plan
Maintenance	Home activity and secondary prevention	Adherence, symptoms and periodic reassessment

7. Integration between anaesthesia and rehabilitation teams

Daily shared goals link analgesia, sedation, ventilatory support, nutrition, line removal, mobilization, and discharge planning. For example, the anaesthesia–ICU team identifies the safest window for extubation and pain control, while physiotherapists assess respiratory and mobility readiness; nurses coordinate mobilisation and monitor adverse responses; surgeons address bleeding and sternal concerns. A structured handover should document operation type, ventricular function, haemodynamic support, rhythm, airway difficulties, analgesia and regional blocks, transfusions, drains, and activity restrictions.

8. Implementation, measurement and equity

Institutions should establish an ERACS steering group, define inclusion and exception criteria, pilot a standardized pathway, educate staff, and audit adherence with case-mix adjustment. Suggested process metrics include preoperative anaemia screening, documented shared decision-making, multimodal analgesia use, extubation timing in eligible patients, delirium assessment completion, first mobilization time, and referral to cardiac rehabilitation. Outcome measures should include clinically important bleeding, AKI, postoperative atrial fibrillation, pneumonia, delirium, ICU and hospital length of stay, readmission, functional capacity, patient-reported recovery, and mortality. Track disparities in rehabilitation access related to cost, geography, language, disability, and digital literacy.

Process measures	Clinical outcomes	Patient-centred outcomes
Anaemia screening, prehabilitation offered	Bleeding/transfusion, AKI, atrial fibrillation	Pain interference, satisfaction
Extubation eligibility and time	Ventilation duration, pneumonia, delirium	Mobility and functional independence
Early mobilization and rehab referral	ICU/hospital stay, readmission, mortality	Quality of life and rehab participation

9. Emerging approaches and research gaps

Remote monitoring, wearable sensors, virtual cardiac rehabilitation, automated risk prediction, and AI-assisted decision support may help personalize recovery and detect deterioration. However, algorithmic performance can drift across institutions; external

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validation, clinician oversight, privacy safeguards, and transparent escalation pathways are essential. Priority research questions include which ERACS components drive patient-important benefit, optimal prehabilitation for frail adults, comparative effectiveness of chest-wall blocks, rehabilitation after complex aortic surgery, and the cost-effectiveness of hybrid programs in low-resource settings.

10. Practical multidisciplinary ERACS checklist

Time point	Minimum team discussion
Before surgery	Risk/frailty, anaemia, nutrition, medicines, expectations, rehabilitation access
Operating theatre	Perfusion, temperature, blood conservation, ventilation, analgesia, handover
ICU admission	Bleeding, haemodynamics, sedation, extubation plan, delirium/AKI surveillance
Daily ward review	Pain, sleep, breathing, mobility, nutrition, rhythm, lines and drains
Discharge	Functional status, medication education, warning signs, rehab appointment, follow-up

11. Limitations of the evidence

The ERACS literature includes consensus recommendations, observational implementation studies, and trials with variable protocols and populations. Bundled interventions make attribution to any single element difficult, and improvements in length of stay may reflect institutional workflow as well as clinical recovery. Some rehabilitation evidence derives from broader coronary disease and heart failure populations and should not be assumed to apply equally to all postoperative cardiac surgical patients. Accordingly, the present review distinguishes established

recommendations from plausible but still emerging technologies and avoids universal targets for high-risk patients.

12. Conclusion

ERACS is best understood as a continuum of perioperative organ protection and functional restoration. Contemporary cardiac anaesthesia facilitates physiotherapy through haemodynamic stability, adequate pain control, timely awakening, and safe liberation from ventilation; rehabilitation, in turn, translates physiological recovery into independence and durable cardiovascular health. The strongest programs combine individualized decisions, evidence-based bundles, coordinated team communication, and ongoing audit. Safety, equity, and meaningful patient outcomes must remain central as digital technologies and precision approaches develop.

13. Detailed preoperative assessment and preparation

13.1 Structured risk stratification

The multidisciplinary assessment begins by distinguishing elective, urgent, and emergency procedures. Document coronary anatomy, ventricular function, significant valvular lesions, pulmonary vascular disease, conduction disorders, prior sternotomy, aortic disease, implanted devices, and the anticipated cardiopulmonary bypass strategy. Surgical risk calculators such as EuroSCORE II or STS models can supplement, but not replace, individualized judgement. Frailty, cognitive impairment, activities of daily living, nutritional status, functional capacity, and patient priorities are important because conventional mortality scores incompletely reflect the burden of postoperative disability.

13.2 Anaemia and patient blood management

Preoperative haemoglobin and iron indices should be reviewed sufficiently early to permit investigation and treatment where feasible. Anaemia may reflect iron deficiency, renal disease, inflammation, bleeding, or mixed causes. Management requires identifying the cause rather than giving empiric therapy to every patient. Review antiplatelet and anticoagulant treatment against procedure-specific thrombotic and bleeding risks; interruption, bridging, and resumption should follow specialist protocols. Document patient preferences concerning blood products and any constraints relevant to perfusion or postoperative care.

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13.3 Respiratory and functional prehabilitation

Patients with poor functional reserve may benefit from supervised aerobic conditioning, lower-limb strengthening, balance training, inspiratory muscle training, smoking cessation, and breathing education. Exercise prescriptions must account for unstable angina, severe symptomatic aortic stenosis, decompensated heart failure, uncontrolled arrhythmia, and other contraindications. Prehabilitation duration is constrained by urgency: it should not delay clinically necessary surgery. Teach supported coughing, safe transfers, the anticipated ICU environment, and realistic milestones before admission.

13.4 Patient communication and discharge planning

Explain the expected trajectory from anaesthetic emergence to assisted sitting, walking, oral intake, and discharge. Provide written information about pain, drains, oxygen therapy, delirium prevention, and participation in rehabilitation. Involve family or caregivers in education where appropriate. Assess access to transport, home support, and outpatient rehabilitation before the operation so discharge planning does not begin only when the patient is medically ready.

14. Detailed intraoperative anaesthetic and perfusion strategies

14.1 Monitoring and echocardiography

Standard monitoring includes ECG, invasive arterial pressure, oxygen saturation, capnography, temperature, urine output when appropriate, and laboratory or point-of-care tests guided by complexity. Central venous access, pulmonary artery catheterization, cerebral oximetry, and transoesophageal echocardiography should be selected by clinical indication rather than used reflexively. Echocardiography can help characterize preload responsiveness, ventricular performance, valve function, tamponade physiology, and causes of separation-from-bypass instability.

14.2 Myocardial and end-organ protection

Before cardiopulmonary bypass, coordinate the plan for anticoagulation, cannulation, myocardial protection, and anticipated transfusion. During bypass, perfusion management integrates flow, oxygen delivery, haematocrit, temperature, acid–base balance, and cerebral or renal risk. Avoid reducing management to one universal mean arterial pressure or haemoglobin threshold. Following bypass, reassess ventricular function, regional wall motion, residual lesions, bleeding, and rhythm. Prompt identification of low cardiac output or right ventricular dysfunction is essential before attempting rapid recovery milestones.

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14.3 Lung protection and ventilatory transition

Ventilator settings should account for predicted body weight, compliance, gas exchange, and the effects of sternotomy, bypass, and pulmonary oedema. Use individualized tidal volumes, appropriate positive end-expiratory pressure, recruitment when indicated, and avoidance of excessive airway pressure. Following surgery, ventilator liberation requires a coordinated approach to sedation, analgesia, temperature, haemodynamics, and respiratory mechanics. A fast-track approach is not equivalent to universal immediate extubation.

14.4 Opioid-sparing multimodal analgesia

Multimodal analgesia combines interventions acting at different pain pathways to permit comfortable ventilation, cough, and movement. Paracetamol is commonly a foundation when suitable; other drugs are selected according to renal function, bleeding risk, haemodynamic effects, delirium risk, and local practice. Nonsteroidal anti-inflammatory drugs require particular caution after coronary bypass and in renal dysfunction. Fascial plane blocks such as parasternal or erector spinae techniques may be useful, but clinicians must consider anticoagulation, local anaesthetic systemic toxicity, block failure, and institutional expertise. Opioid-free anaesthesia should not be assumed superior to careful opioid-sparing practice.

15. Postoperative complications: prevention and response

15.1 Postoperative atrial fibrillation

Postoperative atrial fibrillation is common after cardiac operations and may worsen haemodynamics or delay discharge. Prevention includes correction of electrolyte abnormalities, avoidance of unnecessary catecholamine exposure, appropriate beta-blocker continuation or reintroduction when safe, and institution-specific prophylaxis. New arrhythmia warrants evaluation for pain, hypoxia, infection, volume disturbance, ischaemia, and pericardial complications. Decisions regarding rhythm versus rate control and anticoagulation depend on instability, bleeding risk, duration, and surgical context.

15.2 Acute kidney injury

Cardiac surgery–associated acute kidney injury is multifactorial: reduced renal perfusion, inflammation, haemolysis, venous congestion, nephrotoxins, and pre-existing chronic kidney disease may contribute. Monitor creatinine trends and urine output, interpret them in the context of fluid balance, and investigate reversible causes. Avoid routine fluid boluses in a patient who is already congested. Escalate promptly for persistent oliguria,

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worsening acidosis, hyperkalaemia, or fluid overload. Early rehabilitation must be adapted to haemodynamic and renal stability.

15.3 Delirium and neurocognitive recovery

Screen for delirium using a validated ICU instrument and assess pain, sleep, sensory impairment, hypoxaemia, medication exposure, and metabolic abnormalities. Encourage reorientation, daylight exposure, sleep protection, use of hearing aids or glasses, family engagement, and mobilization. Sedative choice and depth should be individualized. A patient who is awake but delirious may not be safe to ambulate without close supervision; the rehabilitation plan should reflect cognitive as well as cardiovascular readiness.

15.4 Pulmonary complications and infection

Atelectasis, pleural effusions, pulmonary oedema, pneumonia, and respiratory muscle weakness have overlapping clinical manifestations but different treatments. Use examination, ultrasound, radiography, and blood gases as clinically indicated. Supported coughing, breathing exercises, pain control, upright positioning, and mobilization are complementary measures; incentive spirometry alone should not substitute for comprehensive respiratory care. Fever or worsening oxygenation warrants investigation rather than automatic attribution to post-bypass inflammation.

16. Rehabilitation prescription and safety criteria

16.1 ICU phase: first mobilization

Begin with an interdisciplinary safety huddle assessing consciousness, pain, vasoactive support, rhythm, oxygenation, bleeding, drains, lines, and surgical restrictions. When stable, progress from positioning and active limb movement to edge-of-bed sitting, standing, transfer to chair, and short supervised walking. Record symptoms and physiologic responses before, during, and after activity. Stop or defer activity for new chest pain, severe breathlessness, syncope, dangerous arrhythmia, escalating vasoactive requirement, active bleeding, or clinically important oxygen desaturation.

16.2 Ward phase: progressive independence

Set daily mobility goals individualized to the operation and baseline functional status. Progress corridor walking frequency and duration, stair assessment when needed, transfer practice, breathing exercises, and self-care tasks. After sternotomy, emphasize comfortable functional movement and locally approved sternal precautions rather than blanket long-term immobilization. Pain, fatigue, dizziness, anaemia, orthostasis, and

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sleep disruption can limit progress; document and address the limiting factor instead of merely marking a missed session.

16.3 Outpatient rehabilitation

Refer eligible patients to comprehensive cardiac rehabilitation with exercise training, medication review, cardiovascular risk reduction, nutritional counselling, psychological support, and education. Initial intensity should be based on symptoms, surgical recovery, exercise testing where available, ventricular function, and arrhythmia or ischaemia risk. Aerobic exercise can be complemented by progressive resistance training when wounds and clinical status permit. Monitor perceived exertion and symptoms; heart rate alone may be misleading with beta-blockade or pacing.

16.4 Home-based and hybrid programmes

Home-based or hybrid rehabilitation can improve access when programmes include appropriate initial assessment, clear exercise instructions, symptom escalation plans, and follow-up. Wearables may support adherence but do not establish medical safety by themselves. Consider digital literacy, language, device cost, network access, and the need for caregiver support. Document functional outcomes and adverse events, and arrange a route back to face-to-face review when symptoms change.

17. Evidence interpretation and quality improvement

17.1 What can reasonably be attributed to ERACS?

Enhanced recovery is a multicomponent intervention. Shorter ventilation or length of stay may reflect patient selection, minimally invasive surgery, institutional staffing, discharge practices, and the entire care bundle. Observational comparisons are vulnerable to secular trends and confounding. Report whether an outcome is directly demonstrated in cardiac-surgery cohorts or extrapolated from other perioperative settings. Avoid claiming that any single analgesic block or mobilization intervention independently reduces mortality unless supported by appropriately designed studies.

17.2 Suggested programme indicators

Collect process measures such as preoperative anaemia screening, prehabilitation referral, documented analgesia plan, time to first mobilization, and rehabilitation referral. Balance these against safety measures: reintubation, unplanned ICU readmission, major bleeding, stroke, acute kidney injury, delirium, falls, and thirty-day readmission. Patient-centred outcomes include pain on movement, sleep, functional independence, health-related

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quality of life, and return to usual activities. Stratify results by operation type, frailty, and baseline risk.

17.3 Research priorities

Priorities include pragmatic trials comparing clearly defined ERACS bundles, patient-level assessment of prehabilitation dose, comparative effectiveness of regional analgesic techniques, long-term functional outcomes, and equitable delivery of home-based rehabilitation. Digital decision-support systems require external validation, transparent calibration, bias evaluation, clinician oversight, and data governance. Future manuscripts should distinguish guideline recommendations, consensus opinions, pilot feasibility findings, and high-certainty randomized evidence.

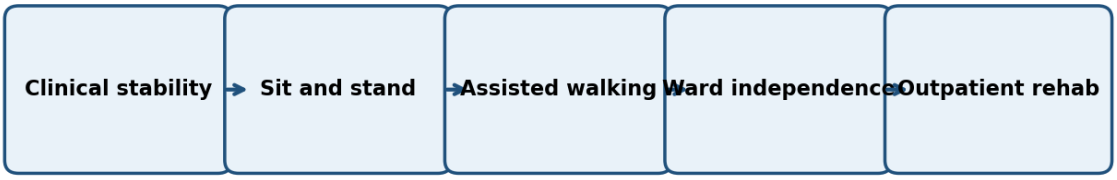


Figure 4. Original illustration: staged cardiac rehabilitation with clinical safety reassessment at every transition.



Figure 5. Original illustration: continuous ERACS quality-improvement cycle.

18. Practical safety and monitoring matrix

Clinical domain	Assess before progression	Reason to defer or escalate
Cardiovascular	Rhythm, perfusion, symptoms, vasoactive trends	New instability, ischaemic symptoms, uncontrolled arrhythmia
Respiratory	Work of breathing, oxygen requirement, gas exchange	Escalating oxygen need or respiratory distress
Neurological	Alertness, commands, delirium, balance	Inability to participate safely, new focal deficit
Surgical	Drain output, wound, sternum, bleeding	Active bleeding, suspected mechanical complication
Functional	Pain with movement, fatigue, transfers	Severe uncontrolled pain, near-syncope, fall risk

This matrix is an original educational synthesis, not a validated numerical decision rule. Local postoperative cardiac surgery protocols and clinician judgement take precedence.

19. Integrated clinical example

Preoperative day

An older adult scheduled for elective CABG undergoes assessment of ventricular function, diabetes, anaemia, nutrition, cognition, and walking capacity. The team explains anticipated postoperative pain control and mobility goals; any exercise programme is adjusted to coronary symptoms and operative urgency.

Operating theatre

The team uses individualized haemodynamic monitoring, appropriate anticoagulation for bypass, lung-protective ventilation, temperature management, blood conservation, and a multimodal analgesic strategy. The plan for postoperative ventilation is agreed before transfer.

ICU recovery

Once haemodynamics, bleeding, ventilation, temperature, and consciousness are satisfactory, a spontaneous breathing trial and extubation assessment are performed. Pain

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treatment and delirium prevention support safe bedside sitting and subsequent mobilization.

Ward and discharge

Walking and self-care goals advance according to symptoms, haemoglobin, rhythm, oxygenation, and wound status. The discharge plan includes medication reconciliation, wound instructions, red-flag symptoms, rehabilitation referral, and a defined follow-up appointment.

The case is hypothetical and illustrates coordinated decision-making; it is not evidence of efficacy in an individual patient.

20. Editorial and reference integrity note

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2026 Evidence Update: Integrated Anaesthesia–Physiotherapy Practice

1. Evidence hierarchy and implementation context

The 2024 joint ERAS Cardiac Society, ERAS International Society and Society of Thoracic Surgeons consensus is a foundation for adult cardiac surgical enhanced recovery. It describes a bundle rather than a single intervention; individual components vary in strength of evidence. Its recommendations must be reconciled with operative complexity, ventricular function, frailty, bleeding, respiratory failure and institutional resources. Local implementation should document both adherence and patient-centered outcomes.

The distinction between early recovery and accelerated discharge is essential. Early extubation and ambulation are goals only after clinical readiness is established; an arbitrary clock target must not override safe ventilation, perfusion or haemostasis. Anaesthesia and physiotherapy teams should conduct shared daily rounds, agree on mobilization restrictions and document the reason when an element is deferred.

2. Preoperative assessment, risk and prehabilitation

Preoperative review should encompass planned procedure, coronary and valvular disease, pulmonary hypertension, ventricular and right-heart function, rhythm and implanted devices, airway and aspiration risk, renal function, diabetes, nutritional status, anaemia, cognitive vulnerability and patient goals. Validated cardiac surgical risk tools may complement—not replace—clinical judgment. Frailty and baseline mobility should be documented because postoperative recovery depends on reserve as well as operative risk.

Prehabilitation may include supervised walking or cycle exercise, lower-limb strengthening, breathing education and inspiratory muscle training for selected high-risk patients. Exercise prescription should be individualized according to symptoms, resting haemodynamics and cardiology clearance. Evidence is heterogeneous; it is not justified to claim every prehabilitation modality reduces mortality. Education should include postoperative pain expectations, splinted cough, incentive devices where indicated, early mobility and discharge rehabilitation.

Preoperative anaemia should be screened early enough to investigate iron deficiency and other causes. The 2024 European blood-management guideline and 2026 AHA scientific statement emphasize patient-centered blood conservation. Treatment choice depends on diagnosis, time to surgery and comorbidity. Antiplatelet and anticoagulant plans require procedure-specific agreement between cardiac surgery, anaesthesia and cardiology teams.

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3. Anaesthesia, ventilation and perfusion

Cardiac anaesthesia should maintain adequate myocardial oxygen supply–demand balance, cerebral and renal perfusion, temperature and haemostasis. Transoesophageal echocardiography is particularly useful in moderate- and high-risk patients when available and indicated. Fluid therapy should be guided by integrated clinical assessment rather than isolated pressure values; fluid responsiveness, ventricular performance, vasoplegia and bleeding must be distinguished before treatment.

Lung-protective ventilation is a high-evidence component of the 2024 consensus. During and after cardiopulmonary bypass, ventilator settings must be tailored to mechanics, oxygenation and haemodynamics. Avoid injurious tidal volumes and unnecessary hyperoxia, while balancing PEEP against right-ventricular function and venous return. Protective ventilation during CPB and goal-directed perfusion are discussed in the consensus, but specific parameters should follow local perfusion and anaesthesia protocols.

Use a balanced, short-acting anaesthetic plan with multimodal analgesia and antiemetic prophylaxis appropriate to individual risk. Opioid-sparing does not necessarily mean opioid-free. Acetaminophen and carefully selected adjuncts can reduce opioid burden; NSAIDs, systemic lidocaine, ketamine, alpha-2 agonists and gabapentinoids each have important cardiac-specific cautions. Avoid routine use of any agent without evaluating renal function, conduction, hypotension, sedation and bleeding risk.

4. Regional analgesia and respiratory rehabilitation

Ultrasound-guided parasternal intercostal plane and erector spinae plane blocks are promising components of multimodal sternotomy analgesia, but studies vary in technique and outcome definitions. Selection must account for anticoagulation, coagulopathy, local anaesthetic systemic toxicity, anatomical risks and expertise. A fascial-plane block is not a substitute for haemodynamic stability or comprehensive postoperative assessment.

Effective analgesia enables deep inspiration, supported cough, upright positioning and mobility. Respiratory physiotherapy should start when the patient is awake and clinically suitable; it may include coached deep breathing, thoracic expansion, positioning, supported cough and targeted airway clearance. Incentive spirometry is an adjunct, not a universal replacement for active breathing and mobilization. Inspiratory muscle training may be considered in selected patients; report training intensity, duration and adherence if evaluating outcomes.

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Physiotherapists should assess pain at rest and with movement, respiratory rate, oxygen requirement, secretion retention, chest radiograph when clinically relevant, cough effectiveness and functional mobility. Treatment must be individualized after sternotomy, minimally invasive thoracotomy or complex aortic procedures; wound stability and surgeon-specific restrictions supersede generic exercise advice.

5. Extubation readiness and postoperative ICU bundle

The 2024 consensus supports facilitating extubation within six hours in suitable patients, while selected low-risk patients may be candidates for even earlier liberation. This is not a universal mandate. Readiness includes adequate consciousness and airway protection, acceptable oxygenation and ventilation, controlled bleeding, stable rhythm and circulation, adequate temperature, neuromuscular recovery and a feasible reintubation plan.

Postoperative care should incorporate regular delirium screening, sedation minimization when safe, sleep preservation, analgesia, glucose management, nausea prevention, nutrition and acute kidney injury surveillance. Screen for new neurological deficits and low-output states before advancing activity. Physiotherapy progression is inappropriate during uncontrolled arrhythmia, escalating vasoactive support, active bleeding, severe hypoxaemia or other acute instability.

6. Physiotherapy and exercise prescription by recovery phase

Phase 0 (preoperative): document functional baseline, gait aid, exercise tolerance, respiratory limitations, falls risk and home support. Provide breathing and mobility education, and a tailored exercise or inspiratory-muscle program when clinically appropriate.

Phase I (ICU and ward): after a structured safety screen, progress from in-bed active movement and bed-edge sitting to chair transfer, standing, short assisted walking and longer corridor ambulation. Monitor symptoms, blood pressure, heart rate/rhythm, SpO_2, perceived exertion, lines and drains. Progression is based on response rather than fixed postoperative day. Reassess after each session; stop for new chest pain, syncope, marked dyspnoea, symptomatic hypotension, unstable arrhythmia or device compromise.

Phase II (supervised outpatient or hybrid rehabilitation): conduct a comprehensive intake, stratify risk and prescribe aerobic training with warm-up and cool-down, progressing duration before intensity. Add appropriate resistance, balance and flexibility work after surgical clearance and wound assessment. Use symptom-limited testing or CPET when

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available; when unavailable, combine perceived exertion, symptoms, haemodynamics and functional testing. Avoid one-size-fits-all heart-rate targets in patients taking beta blockers or with chronotropic limitations.

Phase III (long-term prevention): support habitual physical activity, medication adherence, smoking cessation, blood pressure/lipid/diabetes management, nutrition, psychosocial care and ongoing exercise. The 2024 AHA/AACVPR update identifies program quality as a core component and recognizes supervised, home-based and hybrid models provided essential clinical components are preserved.

7. Special populations and precautions

Frailty and sarcopenia: prioritize functional goals, nutritional evaluation, low-load progressive activity and fall prevention. High-risk older adults may require more sessions at lower intensity and additional discharge support.

Heart failure, pulmonary hypertension and right-ventricular dysfunction: mobilization and ventilatory strategies must be synchronized with fluid and vasoactive management; abrupt preload changes or excessive intrathoracic pressure may worsen circulation.

Chronic lung disease, obesity and sleep-disordered breathing: assess oxygenation, secretion clearance and possible non-invasive respiratory support; use symptom-guided activity and monitor for respiratory fatigue.

Sternotomy and anticoagulation: encourage functional upper-limb use within patient-specific wound and surgeon guidance, avoiding unsupported rigid restrictions. Evaluate chest tube, temporary pacing wires, vascular access and bleeding risk before transfer or gait training.

8. Outcomes, audit and research gaps

An integrated ERACS dashboard should include pathway eligibility, anaemia screening and treatment, ventilator duration, reintubation, opioid exposure, pain on movement, delirium, acute kidney injury, atrial fibrillation, transfusion, ICU/hospital length of stay, mobility milestones, referral and enrollment in cardiac rehabilitation, readmission, and patient-reported recovery. Record balancing measures such as falls, exercise-related adverse events and unplanned ICU return.

Future studies should compare standardized anaesthesia–physiotherapy bundles against usual care using transparent eligibility and adverse-event reporting. Priorities include long-term function, quality of life, frailty-responsive rehabilitation, cost-effectiveness and

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access to hybrid programs. AI-supported prediction and wearable monitoring remain promising but require external validation, privacy safeguards and clinical oversight before routine autonomous use.

Original Clinical Algorithm: Coordinated Recovery Decisions

- PREOPERATIVE → risk, frailty, anaemia and functional assessment
- ANAESTHESIA PLAN → haemodynamic and ventilatory strategy + multimodal analgesia
- ICU SAFETY CHECK → bleeding, perfusion, rhythm, consciousness, oxygenation
- IF STABLE → extubation assessment → respiratory therapy → assisted mobilization
- IF UNSTABLE → investigate and treat → repeat readiness assessment
- WARD → progressive walking + education + rehabilitation referral
- DISCHARGE → individualized outpatient / home-based / hybrid cardiac rehabilitation

Evidence-to-Practice Summary

Element	Guideline basis	Practical interpretation
Multidisciplinary pathway	2024 ERAS Cardiac/STS	Assign a coordinator and audit adherence
Protective ventilation	2024 ERAS Cardiac/STS	Tailor to lung mechanics and haemodynamics
Blood conservation	2024 EACTS/EACTAIC; 2026 AHA	Screen anaemia; manage bleeding and transfusion risk
Early extubation	2024 ERAS Cardiac/STS	Target selected stable patients; never force a clock target
Early ambulation	2024 ERAS Cardiac/STS	Use a structured physiotherapy safety screen
Comprehensive cardiac rehabilitation	2024 AHA/AACVPR	Assess, prescribe exercise and address secondary

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1. Scope, population, and conceptual framework

Enhanced recovery after cardiac surgery (ERACS) is not synonymous with accelerated discharge. It is a coordinated system that reduces avoidable physiological stress while protecting organ perfusion and functional reserve. Relevant procedures include coronary artery bypass grafting, isolated or combined valve operations and selected aortic procedures. Evidence from elective, lower-risk populations must not be generalized uncritically to emergency surgery, cardiogenic shock, complex aortic repair or patients requiring mechanical circulatory support.

The central mechanistic link is bidirectional: cardiac anaesthesia preserves oxygen delivery and enables analgesia, awakening and ventilator liberation; rehabilitation restores ventilation, mobility, muscle performance and self-efficacy. Rehabilitation readiness therefore depends on haemodynamic and respiratory physiology, not simply postoperative time. The anaesthesiologist and physiotherapist should agree on patient-specific thresholds, mobility goals, escalation triggers and documentation.

2. Preoperative cardiac anaesthesia assessment and optimization

Risk evaluation should combine procedure-specific operative risk, left and right ventricular function, valvular lesions, pulmonary hypertension, renal function, cerebrovascular history, pulmonary disease, glycaemic status, anaemia, nutritional status, frailty and baseline exercise capacity. STS risk models or EuroSCORE II can inform discussion, but neither replaces multidisciplinary clinical judgment. Identify patients with high-risk airway features, obstructive sleep apnoea, prior sternotomy, anticoagulant exposure, implanted cardiac devices and difficult vascular access.

Investigations are individualized: complete blood count, renal function and electrolytes, ECG and echocardiography are often central; additional pulmonary assessment, iron studies, natriuretic peptides or functional testing should be ordered when likely to change care. Correct reversible anaemia and iron deficiency where feasible; document antiplatelet and anticoagulant decisions jointly with the surgical team. Medication decisions must follow the indication, urgency and current institutional protocol rather than blanket discontinuation.

Preoperative education should explain pain expectations, supported coughing, breathing exercises, early sitting and walking, sleep and delirium prevention, nutrition, discharge goals and outpatient cardiac rehabilitation. Smoking cessation, alcohol risk assessment, glycaemic optimization and nutrition support are important. Clear-fluid fasting policies

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should be adapted to aspiration risk; cardiac surgery patients with gastroparesis, severe reflux, urgent procedures or other contraindications may require different plans.

3. Prehabilitation and inspiratory muscle training

Prehabilitation is a multimodal strategy combining supervised or prescribed activity, respiratory training, nutrition and psychological preparation. Assess frailty, falls risk, functional independence, walking tolerance and respiratory limitations. For elective patients with sufficient lead time, low-to-moderate intensity aerobic walking or cycling and progressive strengthening may be introduced under appropriate clinical supervision; the exercise prescription should be tailored to symptoms and cardiac stability.

Inspiratory muscle training may benefit selected high-risk patients with low inspiratory muscle strength or elevated pulmonary complication risk. Protocols vary in load, frequency and duration, and a single universally accepted cardiac-surgical dose cannot be claimed. Baseline maximal inspiratory pressure, technique quality and adherence should be documented when feasible. Avoid strenuous unsupervised exercise in unstable angina, decompensated heart failure, severe symptomatic valve disease or uncontrolled arrhythmia.

Prehabilitation outcomes should include completion and adherence, baseline and presurgical function, respiratory muscle performance where available, postoperative pulmonary complications and time to independent ambulation. Evidence is promising but heterogeneous across populations and interventions; the 2024 ERAS consensus grades multicomponent prehabilitation evidence as low.

4. Intraoperative anaesthetic strategy and myocardial protection

Fast-track anaesthesia aims for predictable emergence without sacrificing haemodynamic stability, amnesia, analgesia or organ protection. Anaesthetic drug selection should reflect ventricular function, procedure duration, cardiopulmonary bypass exposure and expected postoperative ventilation. Short-acting hypnotics and titrated opioids may facilitate early awakening; excessively deep anaesthesia and residual neuromuscular blockade should be avoided. Neuromuscular monitoring and adequate reversal are particularly important before extubation.

Transoesophageal echocardiography is useful in moderate- or high-risk patients to assess ventricular function, volume status, valvular repair, new regional wall-motion abnormalities and other reversible causes of instability. Advanced monitoring should be selected by clinical need rather than applied indiscriminately. Tissue perfusion depends

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on cardiac output, haemoglobin, oxygen saturation and microcirculation; fluid boluses should be guided by fluid responsiveness and signs of congestion, not blood pressure alone.

Lung-protective ventilation should minimize excessive tidal volumes and driving pressures while maintaining adequate gas exchange; individualized PEEP and recruitment strategies should account for haemodynamics. During cardiopulmonary bypass, perfusion and oxygen-delivery targets, temperature management, anticoagulation, acid–base management and glucose control are coordinated with the perfusion team. Avoiding severe hyperthermia and prolonged postoperative hypothermia supports organ protection.

5. Patient blood management and haemostasis

Patient blood management begins before surgery with detection and treatment of anaemia and iron deficiency, assessment of bleeding risk and rational antithrombotic management. Intraoperative measures may include antifibrinolytic therapy when indicated, meticulous surgical haemostasis, cell salvage and point-of-care coagulation testing. The 2024 EACTS/EACTAIC guidelines emphasize comprehensive, phase-specific blood conservation rather than an isolated transfusion threshold.

Transfusion decisions should integrate haemoglobin concentration with ongoing bleeding, oxygen delivery, haemodynamic instability, ischaemia and patient comorbidities. Viscoelastic tests may help direct targeted component therapy in bleeding patients where available. Postoperative monitoring includes chest drain output, temperature, coagulation status and signs of tamponade or retained blood. Early physiotherapy must be deferred during uncontrolled haemorrhage or haemodynamic deterioration.

6. Multimodal analgesia and regional anaesthesia

Effective analgesia should permit deep inspiration, supported cough, turning and mobilization without undue sedation. A multimodal regimen may include scheduled paracetamol, carefully titrated opioids for breakthrough pain and selected adjuncts according to renal function, bleeding risk, cardiovascular stability and local policy. Nonsteroidal anti-inflammatory drugs require particular caution after CABG and in patients at risk of kidney injury, bleeding or cardiovascular events; they should not be presented as routine for all cardiac surgical patients.

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Ultrasound-guided fascial plane techniques such as parasternal intercostal plane and erector spinae plane blocks can reduce pain and opioid use in selected patients. The anatomical target and surgical incision should guide block selection. Evidence varies by block, local anaesthetic regimen and outcome; effects on major morbidity and length of stay remain less certain than short-term analgesic benefits. Systemic anticoagulation and timing of heparinization require careful assessment of bleeding and block-related risk.

Use validated pain scales at rest and with cough or movement. Reassess sedation, respiratory rate, nausea, pruritus and delirium, and coordinate analgesic timing with respiratory physiotherapy sessions. Pain that abruptly worsens or is accompanied by instability should prompt evaluation for surgical complications rather than automatic opioid escalation.

7. Extubation readiness and postoperative critical care

Early extubation within approximately six hours is a reasonable pathway goal for appropriately selected elective patients, not a mandatory performance target. Assess consciousness, airway protection, haemodynamic stability, bleeding, temperature, acid–base balance, oxygenation, ventilation and residual neuromuscular blockade. Persistent high vasoactive requirements, significant bleeding, hypoxaemia, uncontrolled arrhythmia, severe metabolic derangement or neurologic concerns warrant continued support and investigation.

After extubation, prioritize pulmonary hygiene, oxygen titration, pain control and surveillance for atelectasis, respiratory failure and delirium. Noninvasive respiratory support may be appropriate for selected patients under unit protocols. A structured ICU bundle includes systematic delirium screening, sleep promotion, early nutrition when safe, glucose management, appropriate thromboprophylaxis, early removal of unnecessary lines and prompt mobilization after safety screening.

The decision to mobilize should be made at bedside with current haemodynamic trends and line security in view. Mechanical circulatory support, temporary pacing, chest drains and vasoactive infusions are not automatic absolute contraindications, but they require specialist supervision and explicit local criteria.

8. Respiratory physiotherapy: assessment and interventions

Post-sternotomy respiratory dysfunction arises from pain, reduced functional residual capacity, diaphragmatic impairment, secretion retention and cardiopulmonary bypass-related inflammation. Physiotherapists should evaluate respiratory rate, work of

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breathing, oxygen requirement, breath sounds, cough effectiveness, secretion burden, pain on inspiration and relevant imaging. Treatment is individualized: upright positioning, thoracic expansion exercises, coached deep breathing, supported huffing or coughing, assisted airway clearance and graded activity.

Incentive spirometry may serve as a visual feedback tool but should not be described as independently superior to coached breathing or mobilization in all patients. Inspiratory muscle training can be considered for selected patients, with load titration according to measured capacity and symptoms. Patients with excessive fatigue, respiratory distress, unstable haemodynamics or acute neurologic change need reassessment rather than automatic progression.

For sternotomy patients, teach functional movement strategies that distribute load and avoid excessive unilateral strain. Modern individualized sternal precautions emphasize symptom-guided, symmetrical movement and wound stability rather than prolonged blanket prohibition of all upper-limb activity. Specific restrictions remain necessary with sternal instability, complex reconstruction or surgeon-directed precautions.

9. Progressive mobility and exercise prescription

Phase I begins in the ICU or ward after a structured safety screen. Progression may include active ankle and limb movement, supported sitting, transfer to chair, standing, short assisted walking and repeated corridor ambulation. Dose should be determined by physiological response, not fixed postoperative day. Track exertion, symptoms, heart rate and rhythm, blood pressure, oxygen saturation, orthostatic tolerance and line safety.

Exercise must stop and prompt reassessment for new chest pain, syncope, marked dizziness, clinically significant arrhythmia, rapidly worsening dyspnoea, symptomatic hypotension, new neurological signs, active bleeding or major oxygen desaturation. Numeric stop thresholds are institution- and patient-specific; a generic universal heart-rate or blood-pressure cutoff would be unsafe for this heterogeneous population.

Before discharge, document transfer independence, walking ability, stair safety when relevant, exercise self-monitoring, medication and wound education, and referral to structured Phase II rehabilitation. In outpatient rehabilitation, aerobic exercise and resistance training should be individualized using functional testing, risk stratification and symptom response. The 2024 AHA/AACVPR core components also include nutrition, weight and body composition, psychosocial health, cardiovascular risk management, physical activity counselling and program quality.

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10. High-risk subgroups and clinical adaptations

Older adults and patients with frailty need tailored exercise intensity, falls prevention, delirium screening and nutritional support. Patients with reduced ejection fraction, right ventricular dysfunction or pulmonary hypertension may have limited haemodynamic reserve and require closer supervision during posture change and walking. Chronic kidney disease increases the importance of fluid balance, drug selection and postoperative kidney injury surveillance.

For patients with COPD, obesity or obstructive sleep apnoea, integrate airway planning, ventilatory support, secretion management and individualized respiratory exercises. Patients after complex aortic surgery, reoperation or mechanical circulatory support require procedure-specific restrictions. A single ERACS pathway can provide common goals while allowing high-risk exception pathways and explicit documentation of why milestones are delayed.

11. Discharge transition, Phase II rehabilitation and digital models

Discharge readiness should include stable clinical status, an agreed medication plan, appropriate wound and sternal education, a clear emergency contact pathway and a documented referral to cardiac rehabilitation. Rehabilitation access is not simply a discharge leaflet: confirm program availability, patient preferences, transport, affordability, home support and follow-up arrangements.

Center-based, home-based and hybrid rehabilitation models can improve access. Remote delivery is best supported in appropriately risk-stratified, generally low-to-moderate risk patients and must preserve medical oversight, individualized exercise planning, risk-factor modification and outcome measurement. Wearable step counts, heart rate and patient-reported symptoms may support adherence, but device data are imperfect and cannot replace assessment of new clinical symptoms.

Psychosocial support is integral. Screen for anxiety, depressive symptoms, fear of movement and low self-efficacy, and provide culturally appropriate education and support. Long-term outcomes include sustained activity, return to work and participation, cardiovascular risk control, health-related quality of life and readmission.

12. Outcomes, implementation science and research agenda

A mature ERACS program measures process fidelity and outcomes simultaneously. Suggested process indicators are documented preoperative risk assessment, anaemia screening, analgesic pathway use, time to first safe mobilization, rehabilitation referral

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and completion, delirium screening and patient education. Outcome indicators include postoperative pulmonary complications, acute kidney injury, atrial fibrillation, opioid exposure, ventilation duration, ICU and hospital length of stay, falls, readmission, functional capacity and patient-reported recovery.

Interpret observed improvements cautiously: early extubation and short stays are susceptible to selection bias, while bundled pathways make it difficult to isolate the benefit of individual interventions. Prospective registries and multicentre pragmatic trials should examine frail and high-risk patients, standardize rehabilitation dose reporting and assess functional outcomes at 30 and 90 days or later.

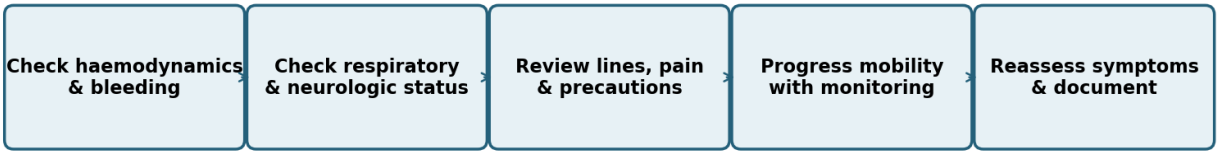
Future work should test whether structured anaesthesia–physiotherapy handovers improve adherence, compare regional analgesic strategies using patient-centered outcomes, and assess equity and cost-effectiveness of hybrid rehabilitation. Artificial intelligence and wearable monitoring remain promising adjuncts; external validation, clinician oversight, privacy protection and evaluation for algorithmic bias are prerequisites to routine use.

Figure A. Integrated perioperative ERACS pathway



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Figure B. Physiotherapy readiness and escalation sequence



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Evidence source	Relevant recommendation	Clinical integration
2024 ERAS Cardiac expert consensus	Risk screening, multidisciplinary coordination, protective ventilation, early extubation and ambulation	Link readiness criteria to anaesthesia–physiotherapy handover
2024 EACTS/EACTAIC blood management	Patient blood management across pre-, intra- and postoperative phases	Assess anaemia, bleeding, anticoagulation and perfusion before mobilization
2024 AHA/AACVPR cardiac rehabilitation statement	Comprehensive assessment, aerobic/strength exercise, risk-factor and psychosocial care, quality improvement	Continue recovery beyond discharge with individualized Phase II rehabilitation
2019 ERAS Society cardiac surgery recommendations	Multimodal analgesia, delirium screening, glycaemic management, chest drain patency	Use multidisciplinary recovery bundle and audit adherence

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Current evidence-informed updates: anaesthesia and physiotherapy (2024–2026)

This section integrates guideline publications and consensus statements available through November 2026. Publication year is distinguished from the date of clinical adoption. The recommendations below require individualization to operative complexity, physiological reserve, bleeding risk, institutional resources and multidisciplinary clinical judgement.

A. Updated ERAS Cardiac consensus and operational priorities

The 2024 ERAS Cardiac Society, ERAS International Society and Society of Thoracic Surgeons consensus emphasizes coordinated, protocolized perioperative care rather than a single fast-track intervention. Core elements include shared decision-making, multidisciplinary teams, prospective auditing, comprehensive risk assessment, prehabilitation, lung-protective ventilation, early extubation when appropriate and early postoperative ambulation and upper-extremity exercise.

Implementation should identify a designated coordinator and standardize the handover from operating theatre to ICU, ward and rehabilitation services. A pathway should specify readiness criteria, escalation triggers, documented exceptions and outcome measures. Targets must not override clinical safety in haemodynamically unstable patients.

The ERAS Cardiac Society 2026 website provides implementation summaries of the 2024 expert recommendations; it is not a separate newly issued 2026 clinical guideline. Evidence strength varies across pathway elements, with particularly strong support for lung-protective ventilation and more limited certainty for some prehabilitation components.

B. Updated cardiac anaesthesia: risk, medication and perfusion

Preoperative evaluation should integrate procedure-specific risk (including STS or EuroSCORE II where applicable), frailty, functional status, ventricular and valvular function, pulmonary hypertension, chronic kidney disease, diabetes, obstructive sleep apnoea, nutritional status and anticipated transfusion risk. In selected patients, cardiopulmonary exercise testing and echocardiography refine functional and haemodynamic assessment.

The 2024 EACTS perioperative medication guideline supports procedure- and patient-specific decisions about antiplatelets, anticoagulants and cardiovascular therapies. Avoid universal medication-withholding schedules: timing must account for drug type, renal

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function, thrombotic risk, bleeding risk and urgency. Explicitly document decisions and restart plans.

Intraoperative care combines individualized anaesthetic depth, adequate analgesia, echocardiographic assessment when indicated, normothermia, goal-directed perfusion during cardiopulmonary bypass, avoidance of severe haemodilution and organ-protective ventilation. Use dynamic and echocardiographic information together rather than treating any single pressure or cardiac-output number as an absolute treatment trigger.

For lung protection, select tidal volume relative to predicted body weight, apply appropriate PEEP and recruitment as tolerated, and consider right-ventricular function and haemodynamic effects. During cardiopulmonary bypass, pulmonary management should follow a local protocol because the optimal ventilation approach remains debated.

C. Patient blood management and haemostatic safety

The 2024 EACTS/EACTAIC/EBCP guideline expands preoperative anaemia investigation, individualized anticoagulant management, point-of-care haemostasis, transfusion strategy and postoperative bleeding management. Assess haemoglobin and iron status early enough for treatment when possible; correct reversible causes rather than relying on perioperative transfusion alone.

Use an integrated blood-conservation plan covering surgical haemostasis, appropriate antifibrinolytic use, cell salvage where available, perfusion circuit management and viscoelastic testing where indicated. Tranexamic acid can reduce bleeding but dose-related seizures and renal function require attention. Transfusion decisions must consider bleeding, oxygen delivery, perfusion and clinical context rather than a fixed haemoglobin number in isolation.

Postoperative surveillance includes chest drainage, haemodynamics, serial haemoglobin, coagulation parameters, temperature and signs of tamponade. Urgent surgical review takes precedence over rehabilitation in suspected active bleeding, tamponade or major instability.

D. Analgesia, extubation and delirium prevention

An opioid-sparing multimodal plan may combine scheduled acetaminophen, titrated opioids for breakthrough pain, selected adjuncts and ultrasound-guided fascial-plane techniques. Parasternal intercostal plane, erector spinae plane and other blocks should be selected according to incision, anticoagulation, local anaesthetic systemic toxicity risk

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and available expertise. Avoid assuming that any block has conclusively reduced mortality or long-term complications.

Extubation within approximately six hours is an ERAS target for appropriate elective cases, not a mandatory deadline. Readiness requires adequate consciousness and airway protection, acceptable oxygenation and ventilation, manageable secretions, satisfactory temperature, stable haemodynamics, controlled bleeding and an agreed reintubation plan. Complex surgery, right-ventricular failure, ongoing shock or major bleeding justify delay.

Use validated pain and delirium tools, prioritize sleep and reorientation, minimize unnecessary sedatives and assess sedation depth. Delirium screening should be systematic, and clinicians should consider pain, hypoxaemia, infection, metabolic disturbance and drug effects when acute confusion develops.

E. Physiotherapy assessment and prehabilitation

Prehabilitation is individualized to baseline fitness, frailty, symptoms and waiting time before surgery. Assessment may include six-minute walk distance, sit-to-stand performance, inspiratory muscle strength where available, balance, exercise tolerance, dyspnoea, activities of daily living and social support. Document baseline measures for meaningful follow-up.

Preoperative inspiratory muscle training may benefit selected higher-risk patients, particularly those with reduced respiratory reserve; the certainty of benefit and optimal dose vary by population. Exercise should be supervised or appropriately prescribed, symptom-limited and stopped for chest pain, presyncope, unstable arrhythmia or concerning breathlessness. Education should cover supported coughing, breathing exercises, movement after sternotomy and expected recovery milestones.

Postoperative respiratory therapy should be driven by assessment: supported cough, upright positioning, breathing exercises, early activity and targeted airway-clearance techniques when secretion retention is present. Incentive spirometry alone should not be presented as a substitute for comprehensive respiratory care or as universally proven to prevent complications.

F. ICU-to-ward progressive mobilization: practical clinical safeguards

Before first mobilization, physiotherapists and bedside clinicians review consciousness, haemodynamic trend, vasoactive support, oxygenation, rhythm, active bleeding, drains,

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lines, sternum stability and neurological status. Clinical stability is a trajectory rather than a single numeric cut-off. Mechanical circulatory support and temporary pacing require specialized team protocols.

Progression can include active limb movement and bed mobility, sitting at the edge of the bed, transfer to a chair, standing, short corridor walking and increased walking duration. Dose is guided by symptoms, perceived exertion, oxygen requirement and recovery after each session. Monitoring commonly includes heart rate, rhythm, blood pressure, SpO2, dyspnoea and fatigue.

Stop and reassess for new chest pain, syncope, sustained clinically important arrhythmia, symptomatic hypotension, worsening hypoxaemia, acute neurological change, unexpected drain output or major respiratory distress. Escalate promptly to the medical team; do not continue activity merely to meet a postoperative-day milestone.

Upper-extremity movement should be progressive and functional while respecting wound integrity and individual sternal stability. Blanket prolonged restriction of all arm movement may worsen function; conversely, painful heavy loading or unstable sternal symptoms requires modification and review.

G. Outpatient cardiac rehabilitation and long-term secondary prevention

The 2024 AHA/AACVPR update defines comprehensive cardiac rehabilitation through patient assessment, nutritional counselling, body composition and weight management, cardiovascular risk management, psychosocial care, aerobic exercise, strength training, physical-activity counselling and program quality. Cardiac rehabilitation should not be reduced to walking alone.

After discharge, prescribe aerobic training using baseline capacity, symptoms, exercise test findings when available, heart-rate response and perceived exertion; add gradual resistance exercise after surgical clearance and individualized wound/sternal assessment. Patients with heart failure, complex valve procedures, arrhythmias or major postoperative complications may need closer supervision.

Home-based or hybrid rehabilitation can extend access when suitable monitoring, patient education, escalation pathways and clinical oversight exist. Wearables and tele-rehabilitation are delivery tools, not replacements for risk assessment or supervised care in unstable patients. Track adherence, functional capacity, patient-reported outcomes and readmissions.

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H. Coordinated pathway and research priorities

Integrating anaesthesia and physiotherapy requires shared daily goals: analgesia adequate for deep breathing, planned extubation assessment, delirium prevention, respiratory therapy, nutrition, safe mobilization and discharge preparation. Daily team huddles should document why an intervention was deferred and when reassessment will occur.

Future research should distinguish individual interventions from whole-pathway effects; prioritize pragmatic multicentre trials, implementation fidelity, postoperative pulmonary complications, persistent pain, functional recovery, quality of life, equity of access and longer-term cardiovascular outcomes. Evidence for AI-guided rehabilitation and automated haemodynamic management remains emerging and should not be described as established standard care.

Updated guideline-to-practice matrix

Source	Clinical application	Important qualification
ERAS Cardiac/STS 2024	Integrated pathway, early ambulation, selected early extubation	Consensus elements have differing evidence certainty
EACTS/EACTAIC/EBCP 2024	Anaemia, bleeding risk, PBM and haemostasis	Individualize to procedure, anticoagulation and renal function
EACTS 2024 medication	Perioperative cardiovascular/antithrombotic therapy	No universal drug-hold interval
AHA/AACVPR 2024	Comprehensive exercise and secondary-prevention rehabilitation	Clinical oversight essential in remote delivery
RCoA cardiac services 2025	Physiotherapy availability and defined pain protocols	Service standards complement clinical recommendations

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