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Current insights on temporary mechanical circulatory support in adults with post-cardiotomy cardiogenic shock

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Post-cardiotomy cardiogenic shock (PCCS) is a critical condition characterized by persistent low cardiac output syndrome (LCOS) that manifests either as an inability to wean from cardiopulmonary bypass (CPB) or as severe cardiac dysfunction in the immediate post-operative period despite optimal medical therapy. With an incidence of 2–20%, PCCS is associated with high morbidity, mortality, and healthcare resource utilization. This review explores the pathophysiology of PCCS while emphasizing mechanisms such as direct myocardial damage, ischaemia-reperfusion injury, and systemic effects of extracorporeal circulation. It also discusses key diagnostic tools for PCCS including echocardiography, pulmonary artery catheters, vasoactive inotropic scores (VIS), and lactate clearance, which facilitate early recognition and management. Treatment pathways centred on temporary mechanical circulatory support (tMCS), tailored to clinical scenarios such as the inability to wean from CPB or refractory LCOS. The pivotal role of the multi-disciplinary Heart Team in decision-making, collaboration, and patient-centred care is highlighted. Finally, weaning protocols and considerations for long-term outcomes are discussed, underscoring the need for timely interventions and a personalized approach. Advances in PCCS management continue to evolve, aiming to improve survival and long-term outcomes for this high-risk population.

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Introduction

Post-cardiotomy heart failure, or post-cardiotomy cardiogenic shock (PCCS), is a critical and potentially life threatening condition characterized by persistent low cardiac output syndrome (LCOS) that manifests either as an inability to wean from cardiopulmonary bypass (CPB) or as severe cardiac dysfunction in the immediate post-operative period despite optimal medical therapy.[1,2] Similar to *classic* heart failure, PCCS presents with left, right, or bi-ventricular impairment and is often accompanied by pulmonary congestion. The aetiology of PCCS is multi-factorial and can stem from pre-existing heart failure exacerbated by surgical trauma or can develop acutely due to intra-operative factors such as inadequate myocardial protection or iatrogenic induced myocardial ischaemia, as well as to factors and conditions protracting or occurring in the early post-operative phase (uni- or bi-ventricular failure, tamponade, *de novo* ischaemia, and others).[2]

Several predisposing factors contribute to the development of PCCS, including advanced age, higher body mass index, pre-operative ventricular dysfunction, recent myocardial infarction, renal insufficiency, emergent or re-operative procedures, and prolonged bypass or aortic cross-clamp times.[2,3] These factors highlight the intricate inter-play between patient-specific vulnerabilities and surgical complexities, making PCCS a challenging condition to predict and manage.

The clinical and economic burden of PCCS is substantial. It is associated with increased morbidity, high short- and long-term mortality rates, and significant healthcare resource utilization. Its incidence ranges from 2 to 20%, depending on the underlying disease and the type of surgery. Persistent LCOS carries a grim prognosis with near-zero survival rates if not properly treated. However, timely application of temporary mechanical circulatory support (tMCS) has shown promise, improving survival rates to between 25 and 42%.[2,4-8]

Predicting outcomes for PCCS patients treated with tMCS remains a complex task. Scoring systems, such as the SAVE (survival after veno-arterial extracorporeal membrane oxygenation) and REMEMBER (predicting mortality in patients undergoing veno-arterial extracorporeal membrane oxygenation after coronary artery bypass grafting) scores, have been developed to aid in prognostication.[9-11] The SAVE score predicts survival to hospital discharge of patients supported by veno-arterial extracorporeal membrane oxygenation (VA-ECMO). It assesses factors such as age, body weight, shock aetiology, respiratory, and cardiac and organ function pre-ECMO support. However, this score was not meant to be specifically applied to PCCS.[9-11] Though the REMEMBER score was also created to predict in-hospital mortality of PCCS, it has only been validated for patients undergoing CABG. This score is calculated based on pre-ECMO parameters including age, type of coronary artery disease, inotropic score, and laboratory values. The REMEMBER score has demonstrated better predictive performance compared with alternatives such as SAVE, sequential organ failure assessment, ENCOURAGE, and EuroSCORE. However, its limited validation restricts its generalizability. Ultimately, the success of PCCS management hinges on early recognition, appropriate patient selection, and timely initiation as well as selection of tMCS. These elements remain central to improving outcomes and advancing care for this high-risk patient population.

Clinical scenarios in post-cardiotomy cardiogenic shock

Post-cardiotomy cardiogenic shock can manifest in two distinct clinical scenarios: either as the inability to wean from CPB or as refractory LCOS after CPB (intra-operatively or post-operatively in the intensive care unit). The central challenge in both cases is timely identification of patients whose cardiac function is unlikely to recover rapidly, necessitating prompt escalation to tMCS. Both clinical scenarios are reviewed in more detail below.

Scenario I: inability to wean from cardiopulmonary bypass

When patients fail to wean from CPB, a systematic re-assessment of potential contributing factors is essential to optimize the clinical situation and guide management decisions:[12-14]

- Electrocardiography: Evaluate for arrhythmias, ischaemic changes, or other abnormalities.
- Transoesophageal echocardiography: Assess valve competence, ventricular function, and regional movement disorders.
- Mechanical ventilation and bronchoscopy: Monitor tidal volumes, lung compliance, and identify signs of pulmonary congestion or atelectasis.
- Blood gas analysis: Identify metabolic derangements and signs of impaired ventilation or oxygenation.
- Bleeding and coagulopathy: Address surgical bleeding or coagulopathy through revision or supportive measures.
- Reperfusion: Prolonged reperfusion time and strategies to optimize cardiac unloading should be evaluated.
- Appropriateness of the surgical procedure: Evaluate whether residual valve dysfunction, incomplete or failing revascularization, or newly unfavourable haemodynamic conditions secondary to the surgical intervention might be responsible and amenable.

If repeated weaning attempts fail despite addressing these factors and optimizing medical therapy, an immediate transition to tMCS is warranted. These devices can provide haemodynamic stabilization, facilitate myocardial recovery, or serve as a bridge to permanent support devices or heart transplantation.

Scenario II: refractory low cardiac output syndrome after cardiopulmonary bypass

For patients who develop LCOS after initial successful weaning from CPB (either in the operating room or in the intensive care unit), additional tools and considerations are necessary to guide management:[15-17]

- Invasive cardiac monitoring: Devices, like PiCCO or Swan-Ganz catheters, provide detailed haemodynamic data, including cardiac output, ventricular filling

- pressures, and pulmonary artery pressures. These metrics are critical for tailoring therapeutic interventions.
- Selection of tMCS: The choice of tMCS modality (left, right, or bi-ventricular support) should be based on the type and severity of ventricular dysfunction. If the specific mechanism of pump failure cannot be determined, starting with bi-ventricular support and de-escalating to univentricular support should be considered.

Timing and cannulation are key principles for tMCS initiation in LCOS, which mirror those for other critical conditions. As such, early initiation of tMCS, ideally before significant end-organ injury or the onset of anaerobic metabolism (lactate level <4 mmol/L), is crucial. Moreover, central cannulation may be feasible in the intra-operative setting, providing rapid access to support, although it was shown to be associated with higher peri-operative mortality due to higher extent of post-operative bleeding.[18,19] *Table 1* provides treatment recommendations for high-risk patients with LCOS. Additional fundamental concepts surrounding pre-emptive tMCS in such conditions are addressed in a specific paragraph below.

Table 1 Approach recommendations for patients with high-risk for peri-procedural low cardiac output syndrome[a]

Recommendations	Class of recommendation[b]
It is recommended that the type and modality of tMCS should be discussed by an inter-disciplinary team (Shock Team) based on haemodynamic conditions, patient characteristics, and prognosis[20-22]	I
Significant comorbidities, advanced age, elevated lactate levels, and renal injury are risk factors associated with death and should be considered prior to initiation of tMCS[20,23,24]	IIa
In patients with structural cardiac anomalies (post-AMI VSD, papillary muscle rupture, or ventricular wall rupture) and haemodynamic, respiratory, or metabolic compromise, refractory to optimal medical therapy, the implantation of a pre-operative tMCS may be considered as a bridge to corrective procedure[25-28]	IIb
In patients at high-risk of post-procedural LCOS, intra-operative implantation of tMCS should be considered to facilitate CPB weaning and the peri-operative course as a bridge-to-recovery[23,29-33]	IIa
When the likelihood of myocardial recovery is low, post-procedural tMCS is recommended in patients eligible for HTx or dMCS[20,23]	I
When experiencing difficulty in weaning from CPB, early implementation of tMCS is recommended[20,24,34]	I
In patients in cardiogenic shock with irreversible cardiomyopathy, who are candidates for HTx or dMCS, tMCS may be considered as a bridging strategy[20,23]	IIb

AMI, acute myocardial infarction; CPB, cardiopulmonary bypass; dMCS, durable mechanical circulatory support; HTx, heart transplantation; LCOS, low cardiac output syndrome; tMCS, temporary mechanical circulatory support; VSD, ventricular septal defect.

[a]Adapted from the study by Lorusso *et al*.[35]

[b]I, is recommended/is indicated; IIa, should be considered; IIb, may be considered; III, is not recommended.

Right ventricular support

Right ventricular (RV) function is governed by three key factors: pre-load (volume status), contractility, and afterload. Managing RV dysfunction requires careful optimization of these parameters to stabilize haemodynamics and prevent further deterioration. Hypotension should be avoided, and inotropes, inodilators, or vasodilators (although typically avoided in patients with shock) should be used to support contractility and reduce RV afterload. Initial treatment of RV dysfunction or failure focuses on resolving the underlying cause, such as RV ischaemia, left heart failure, acute pulmonary embolism, pleural effusions, or ascites, while optimizing RV pre-load.[36,37]

Adequate oxygenation and RV perfusion pressure are essential for maintaining RV contractility. Inotropic agents, including dobutamine, milrinone, and epinephrine, are commonly used to support RV function. To reduce RV afterload, it is important to correct hypoxaemia, acidosis, hypercapnia, and hypothermia, as well as to avoid elevated intra-thoracic pressures that can increase pulmonary vascular resistance.[38,39] Pulmonary vasodilators, such as inhaled nitric oxide or iloprost, intravenous epoprostenol or milrinone, and oral agents like sildenafil or bosentan, can further reduce pulmonary vascular resistance.[40,41] However, their use must be carefully considered in patients with pulmonary hypertension due to left ventricular (LV) failure, as they may exacerbate LV volume overload. In such cases, bi-ventricular support should be considered.

For patients with ongoing RV failure despite maximal medical therapy, temporary mechanical RV support may be necessary. Right ventricular ventricular assist devices (VADs), such as the extracorporeal life support with pulmonary artery cannulation with single-lumen or double-lumen (Protek Duo) cannula, Impella RP, or surgically implanted RV assist device (RVAD) such as TandemHeart (TH-RVAD), can provide effective support by reducing the need for vasopressors and inotropes, improving oxygen delivery, and lowering serum lactate levels, which reflect better systemic perfusion.[42,43] Durable RVADs in these cases are not advisable, based on the more complex patient management, higher costs, and limited availability, making tMCS more suitable for

Table 2 Recommendations for temporary mechanical circulatory support implant for post-procedural low cardiac output syndrome[a]

Recommendations	Class of recommendation[b]
In patients with RV failure, intrinsic RV failure should be managed with optimization of the patient's heart rate (ideally sinus rhythm) optimizing volume status and reducing RV afterload with the pulmonary vasodilators and inotropic agents	I
LV failure may lead to pulmonary hypertension, which should initially be treated by LV support and eventually RV support	I
In patients with post-procedural LCOS and potential for haemodynamic recovery, tMCS is recommended[46-49]	I
In patients with post-procedural LCOS without potential for haemodynamic recovery, but eligible for dMCS/HTx, tMCS is recommended[26,34]	I
In patients with no likelihood of myocardial recovery and not eligible for dMCS/HTx, tMCS is not recommended[26,34]	III
For tMCS eligible patients who cannot be weaned from CPB despite optimal therapeutic measures, immediate transition to tMCS is recommended[24,47-49]	I

CPB, cardiopulmonary bypass; dMCS, durable mechanical circulatory support; HTx, heart transplantation; LCOS, low cardiac output syndrome; tMCS, temporary mechanical circulatory support.

[a]Adapted from the study by Lorusso *et al.*[35]

[b]I, is recommended/is indicated; IIa, should be considered; IIb, may be considered; III, is not recommended.

such situations. However, in cases of venous pulmonary hypertension secondary to LV failure, cautious use of pulmonary vasodilators and escalation to bi-ventricular support may be required to avoid further deterioration of LV haemodynamics.[44,45] *Table 2* provides treatment recommendations for patients with post-procedural LCOS.

Post-cardiotomy cardiogenic shock—pathophysiology

Post-cardiotomy cardiogenic shock, like other forms of cardiogenic shock, is characterized by severe myocardial contractile impairment leading to pre-cardiac blood stasis and organ congestion, reduced organ and tissue perfusion, and a mismatch between oxygen delivery and demand (*Figure 1*).[50] The extent of surgical damage is influenced by the complexity of the procedure and the patient's pre-existing cardiac anatomy, function, and comorbidities. These factors critically determine the heart's resilience to surgical stress.[51] Cardioplegia, intended to protect the heart during surgery, plays a pivotal role in mitigating ischemia-reperfusion injury. However, its efficacy can be compromised by conditions such as cardiac hypertrophy or limited functional reserve, potentially contributing to myocardial stunning.[51-53]

Extracorporeal circulation (ECC) triggers an inflammatory response proportional to its duration.[54] This response induces a cytokine-mediated myocardial hibernation and stunning and is regularly accompanied by systemic vasodilatation. Unlike classical acute myocardial infarction-related cardiogenic shock that typically presents with elevated systemic vascular resistance, PCCS is often associated with decreased systemic vascular resistance due to increased vasodilatation. Moreover, up to 50% of patients with PCCS experience vasodilatory shock, characterized by the dual challenges of myocardial stunning and systemic vasodilatation.[55] This unique haemodynamic profile underscores the critical role of tMCS in managing PCCS.

Effective management of PCCS requires not only restoration of cardiac output but also maintenance of adequate perfusion pressure to ensure end-organ perfusion. Post-cardiotomy cardiogenic shock most commonly arises after CABG or valve replacement surgery.[56] Importantly, the RV is implicated in most cases with 47% involve LV failure, 13% isolated RV failure, and 40% bi-ventricular failure.[56] These patterns are essential considerations when selecting the appropriate tMCS device for each patient.

Post-cardiotomy cardiogenic shock—diagnostics, immediate monitoring

Patients with evolving or manifest PCCS require meticulous monitoring to ensure timely diagnosis and stage-dependent interventions, which are crucial for patient survival. Four key pillars underpin the diagnosis and monitoring of PCCS and will be described below: echocardiography, pulmonary artery catheter (PAC) data, vasoactive inotropic score (VIS), and serial lactate measurements.

Echocardiography

Echocardiography is indispensable for diagnosing and managing PCCS. It provides rapid, essential anatomical and functional information, including assessment of LV and RV function, filling pressures, and regional wall motion abnormalities. Additionally, it identifies potentially reversible causes of low cardiac output, such as haematoma, pericardial effusion, or prosthetic valve dysfunction, informing strategic management decisions.[57]

Pulmonary artery catheter

Use of a PAC offers continuous, detailed haemodynamic monitoring, providing information on cardiac output, RV and LV filling pressures, pulmonary pressures, and mixed venous oxygen saturation. Advanced PAC models with rapid response thermistors provide additional insights into RV end-diastolic volume and the ejection fraction. These data are vital for identifying candidates for tMCS escalation, guiding tMCS therapy, and managing weaning strategies.[35] Evidence indicates improved outcomes in

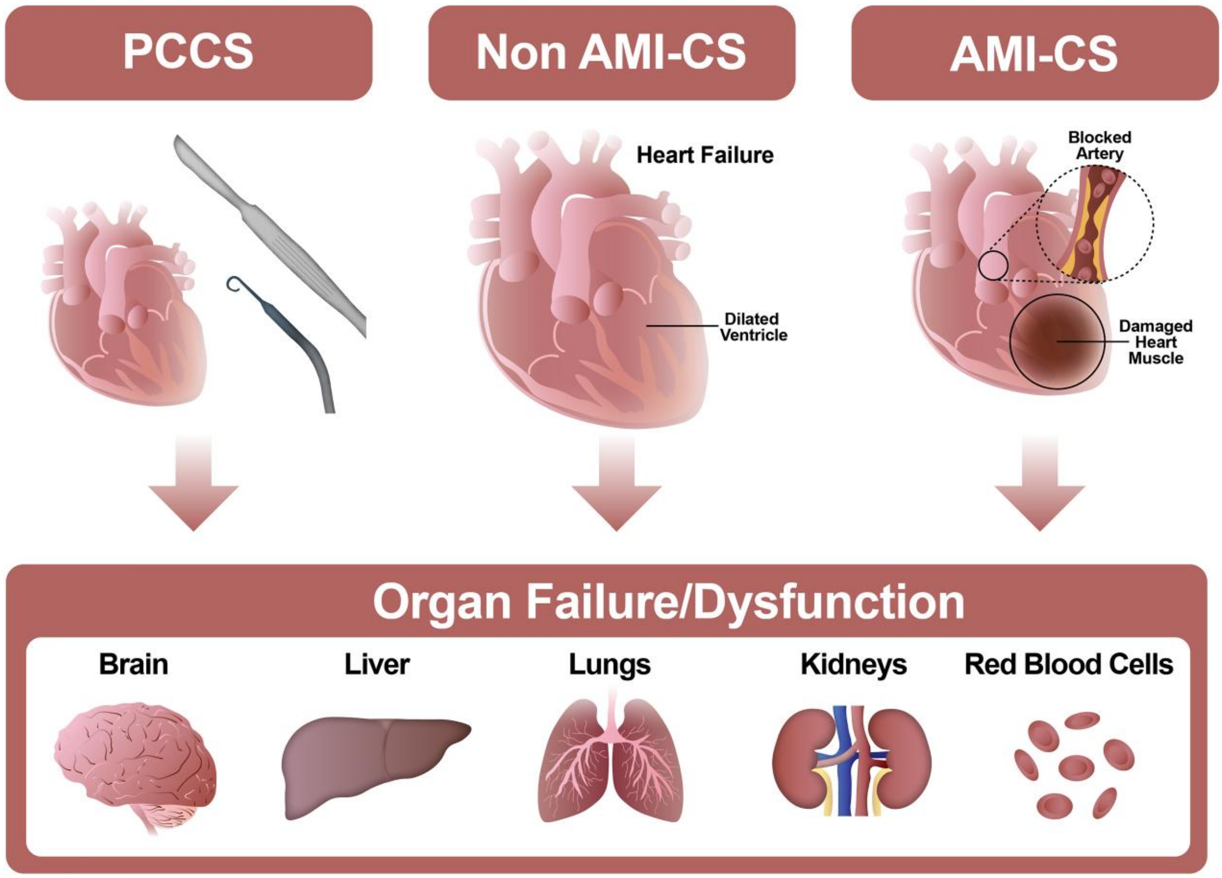

Figure 1 Cardiogenic shock and organ failure. PCCS, post-cardiotomy cardiogenic shock; AMI, acute myocardial infarction; CS, cardiogenic shock.

cardiogenic shock patients managed with PAC, underscoring its importance in both early diagnostic and long-term PCCS management.[58]

Vasoactive inotropic score

Vasoactive inotropic score quantifies inotropic and vasoactive support, serving as a surrogate marker for shock severity. While specific VIS cut-off values for PCCS are not yet validated, incorporating VIS into management algorithms has been associated with better survival outcomes in both PCCS and non-PCCS patients.[59,60]

Lactate

Despite its limited specificity, lactate remains an invaluable biomarker in PCCS management.[20,61-63] Absolute lactate values and clearance rates at 12 and 24 hours (h) are strongly correlated with mortality risk in PCCS patients treated with veno-arterial extracorporeal life support (ECLS).[62,64] Serial lactate measurements also facilitate prognostication and early decision-making. While specific short-term lactate clearance thresholds for PCCS have yet to be established (although the alerting threshold of 4 mmol/L has been proposed),[35] evidence from patients without PCCS suggests that 90-min lactate clearance is a valuable prognostic parameter and may guide early interventions.[65]

Treatment options and decision-making

The treatment of PCCS requires a nuanced and vigilant approach, as treatment strategies remain debated and largely based on expert consensus. Post-cardiotomy cardiogenic shock management is time sensitive and should often start pre-operatively with thorough risk assessment and close monitoring of systemic perfusion. Preparing for the potential need for tMCS in high-risk patients is critical, alongside intra-operative monitoring of myocardial function post-CPB. Insights gained during the procedure can help anticipate and mitigate the risk of PCCS.

Initial management often involves optimizing inotropic and vasopressor therapy to stabilize cardiac function. However, many patients fail to stabilize, necessitating timely escalation to tMCS. Intra-operative transition to tMCS from CPB is common, particularly in patients unable to achieve adequate myocardial recovery. In cases of post-CPB cardiac deterioration after initial weaning, tMCS implantation is initiated post-operatively. Importantly, tMCS should be introduced before severe end-organ malperfusion, or ischaemia ensues, as these conditions are key predictors of mortality in PCCS. Early MCS initiation, however, has been associated with markedly improved outcomes.[35,66,67]

Despite its debated efficacy, an intra-aortic balloon pump (IABP) is often considered as an early intervention due to its ease of use and favourable safety profile. However, the benefits of IABP remain controversial, and its limited capacity to reverse shock often necessitates escalation to more robust options like ECMO.[68-70] Veno-arterial ECMO is a cornerstone treatment for PCCS, though the choice of cannulation site remains a topic of debate. A recent matched meta-analysis reported that central ECMO cannulation was linked to higher in-hospital mortality compared with peripheral cannulation (64.5 vs. 70.8%, $P = 0.027$).[19] Current consensus guidelines from the European Association for Cardio-Thoracic Surgery, Extracorporeal Life Organization, the Society of Thoracic Surgeons, and the American Association for Thoracic Surgery recommend peripheral cannulation as the preferred method for initiating or transitioning to ECMO in PCCS patients.[35] Furthermore, recent single-centre studies highlight the benefits of combining ECMO with micro-axial pump devices like the Impella for ventricular unloading in eligible patients. This approach has been shown to significantly reduce early mortality and is emerging as a promising strategy for improving outcomes in these patients.[5,71,72]

Effective PCCS management extends beyond tMCS alone. It requires careful management of bleeding risks, optimization of coagulation parameters, and proactive mitigation of potential complications associated with tMCS. A comprehensive, multi-disciplinary, and holistic approach that integrates these considerations is essential for improving outcomes in this high-risk patient population (*Figure 2*).

Practicing a new concept of temporary mechanical circulatory support in cardiac surgery: prophylactic cardio-circulatory assistance to reduce post-cardiotomy cardiogenic shock

Current cardiac surgery practice is facing a substantial change in the patient profile. Indeed, more urgent/emergent cases, older patients, surgical candidate with more pre-operative comorbidities, and more complex procedures such as re-operations, multiple interventions, patients with more compromised cardiac function, and more frequent chronic cardiovascular diseases are increasingly performed. As such, these clinical scenarios are challenging for the surgical team and the other professionals care takers in the peri-operative phases. There is mounting evidence that the concept consistently applied to high-risk patients undergoing percutaneous coronary intervention (PCI), known as *protected PCI*,[73,74] may be beneficial in cardiac surgery patients as well.

The prophylactic approach used in *protected PCI* might be applied differently in the scenario of cardiac surgery. Indeed, in interventional cardiology, this pre-emptive cardio-circulatory approach is mainly used during the planned PCI procedure to prevent or reduce shortcomings, such as LCOS or even myocardial ischaemia. In cardiac surgery, however, this prophylactic approach might be extended from the immediate pre-operative to the early post-operative phases.

In some cases, potential surgical candidates might approach the surgical procedure in sub-optimal or even critical haemodynamic, respiratory, and metabolic conditions putting the intra-operative and post-operative course for complication occurrence at greater risk. In such situations, it has been shown that a prophylactic, pre-conditioning approach, meant to stabilize and correct haemodynamic organ function and metabolic impairment, might favour the post-operative course.[29,30] Following a similar concept, patients undergoing cardiac surgical procedures with a high-risk profile for peri-operative LCOS might benefit from timely support beginning in the operating room and a limited peri-operative time (usually 24–48 h) allowing a smoother recovery from the surgical stress.[35,46] This is even more important in cases of unexpected intra-operative cardiac dysfunction, in which timely prophylactic support applied in a protected environment, and avoidance of vasoactive drugs (inotropes and vasoconstrictors) known to be associated with unfavourable peri-operative events would be beneficial.[35] The patient selection, strategy planning, and peri-operative management should account for a careful and dedicated multi-disciplinary team discussion which, in very complex and high-risk patients, should include also a palliative team involvement to assess escalation or futility in case of severe complications and need for more advanced heart therapies.[35] Conditions related to pre-emptive approach are shown in *Tables 1* and *2*.

The role of the Heart Team in decision-making for patients with post-cardiotomy cardiogenic shock

Percutaneous insertion

The Impella CP device is normally inserted percutaneously via the left or right femoral artery. As in elective cases, careful planning of the access site is essential even in emergencies to minimize complications. This can be achieved using vascular ultrasound, computed tomography (CT), or conventional angiography. While pre-procedural CT is often not feasible in emergencies, ultrasound-guided puncture of the femoral artery or angiographically guided insertion is recommended.[75] A recent study comparing fluoroscopy-guided with ultrasound-guided access for large-bore transfemoral procedures found no significant reduction in clinically relevant bleeding or vascular access site complications with ultrasound-guided puncture.[76] Limitations of ultrasound include its unavailability in some catheterization laboratories and reduced visualization in patients with obesity. Therefore, combining ultrasound-guided puncture with angiographic visualization is recommended using a 4-6 Fr femoral sheath and catheter to map the femoral bifurcation and iliac arteries before inserting the Impella sheath. Following femoral artery puncture, serial pre-dilation with dilators from the Impella kit is recommended, followed by an insertion of the 14 Fr Impella sheath over a stiff guidewire. The device is then advanced over the guidewire positioned in the left ventricle apex via a 5 Fr pigtail catheter. In cases where femoral access is unsuitable and for using Impella 5+, surgical trans-axillary insertion of the Impella device is used.[77] This procedure requires surgical cutdown and fluoroscopic or echocardiographic guidance (*Figure 3A-C*).

The management of acute and chronic heart failure, particularly in patients with PCCS, remains a complex

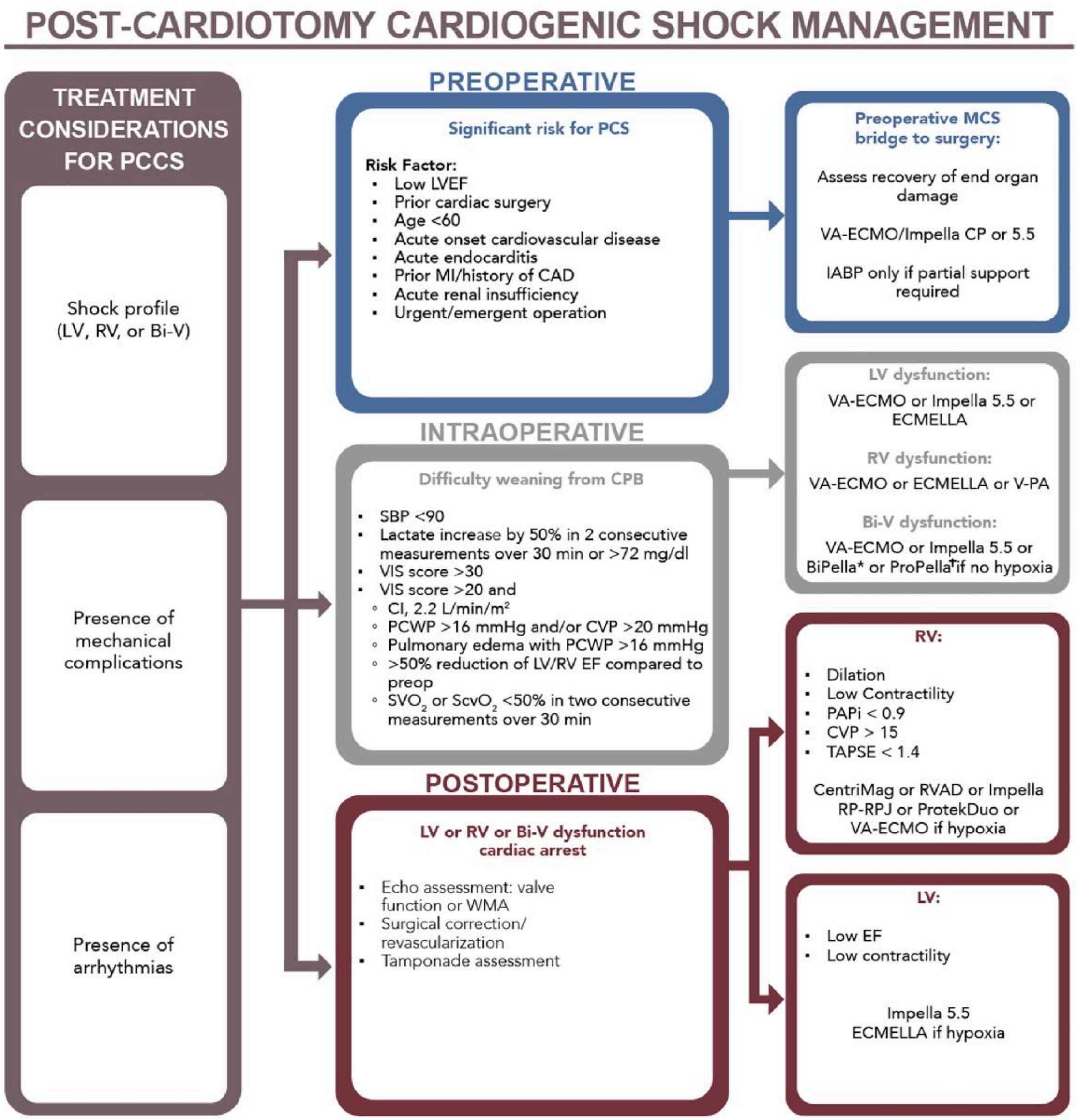

Figure 2 Post-cardiotomy cardiogenic shock management. PCCS, post-cardiotomy cardiogenic shock; LV, left ventricular; RV, right ventricular; Bi-V, bi-ventricular; PCS, post-cardiotomy shock; LVEF, left ventricular ejection fraction; MI, myocardial infarction; CAD, coronary artery disease; SBP, systolic blood pressure; VIS, vasoactive inotropic score; CI, cardiac index; PCWP, pulmonary capillary wedge pressure; EF, ejection fraction; SVO_2, mixed venous oxygen saturation; $ScvO_2$, central venous oxygen saturation; WMA, wall motion abnormality; MCS, mechanical circulatory support; VA-ECMO, veno-arterial extracorporeal membrane oxygenation; IABP, intra-aortic balloon pump; ECMELLA, combined extracorporeal membrane oxygenation and Impella; V-PA, venous pulmonary artery; PAPi, pulmonary artery pulsatility index; CVP, central venous pressure; TAPSE, tricuspid annular plane systolic excursion; RVAD, right ventricular assist device; CBP, cardiopulmonary bypass.

and widely debated challenge. Advanced age and comorbidities elevate the risk profiles of these patients, pushing the boundaries of traditional treatment paradigms. Over the past two decades, advancements in treatment modalities such as ECLS for short-term support and LV assist devices as destination therapy have significantly improved patient outcomes. More recently, micro-axial pump flow devices like the Impella have demonstrated efficacy in providing haemodynamic support for patients with severe LV dysfunction, enabling timely interventions in critical care settings.

Given the multi-faceted nature of these cases, the Heart Team model has become integral to modern cardiac care. The multi-disciplinary approach, comprising of cardiologists, cardiac surgeons, interventionalists, and anaesthesiologists, facilitates comprehensive patient assessments and consensus-driven decision-making. By leveraging the collective expertise of multiple specialities, the Heart Team enables personalized treatment pathways tailored to each unique condition of patients. This collaborative model is increasingly recognized as best practice in managing complex cardiac cases, including PCCS.

The Heart Team approach is instrumental in achieving optimal possible outcomes for high-risk cardiac patients. By fostering inter-disciplinary collaborations, it enables

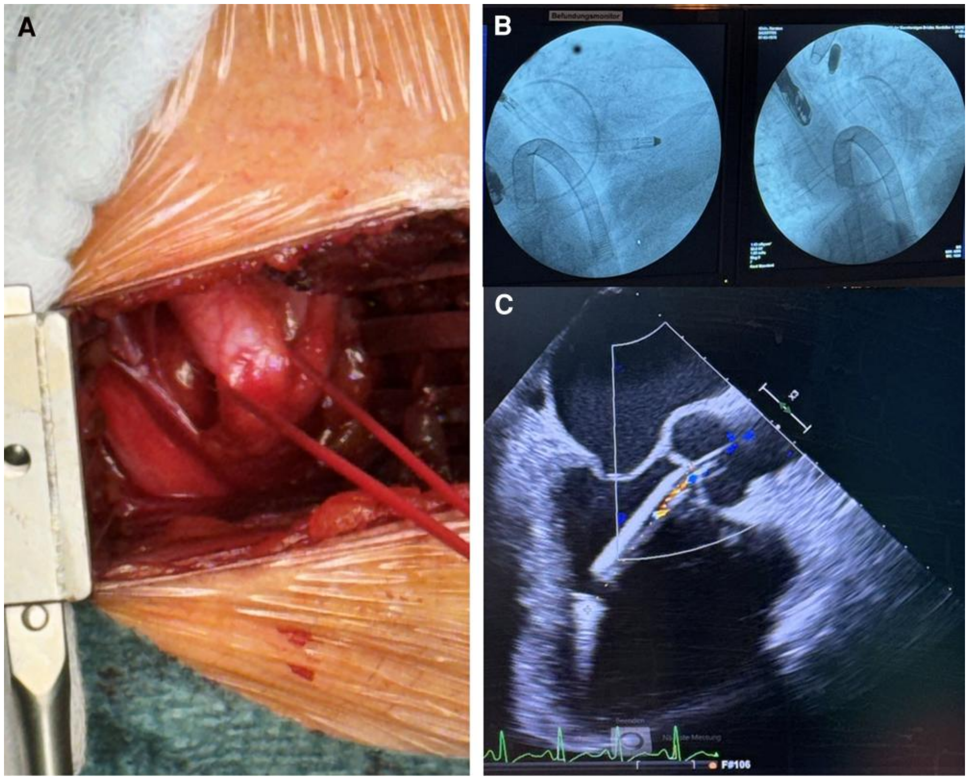

Figure 3 Surgical trans-axillary insertion of the Impella 5.5 device. Surgical trans-axillary Impella insertion by surgical cutdown (*A*) and fluoroscopy (*B*) and/or echocardiographic (*C*) guidance.

the selection and implementation of the most appropriate therapies, whether interventional, surgical, or hybrid. For patients with advanced valvular or coronary disease with impaired LV ejection fraction (LVEF), the Heart Team's input is crucial in refining treatment strategies and aligning them with the latest advancements. This model not only enhances survival rates but also aims to improve the quality of life for patients by promoting precise, innovative, and co-operative care planning.

Patients with complex coronary artery or valvular diseases, particularly those with impaired LV function undergoing elective, urgent, or emergent procedures, represent a significant proportion of the global burden of PCCS and heart failure. These conditions contribute to millions of deaths annually, emphasizing the importance of identifying optimal therapeutic strategies. However, despite advancements, controversies persist regarding the best approach for managing such high-risk cases. Catheter-based interventions have emerged as a viable alternative to traditional surgery for certain cardiac pathologies, though their efficacy in complex cases remains a topic of debate. To address these challenges, the Heart Team approach must continue to evolve. Supporting innovation, embracing emerging technologies, and refining collaborative strategies are essential for advancing patient care.

Weaning

Weaning from tMCS is a critical yet challenging step in device management. Early explantation is preferred when feasible, carefully balancing the risks of continued tMCS support (e.g. limb ischaemia, stroke, haemolysis, bleeding, and deconditioning) against its benefits. However, only 30–70% of patients with cardiogenic shock undergoing tMCS therapy can be successfully weaned.[78] This highlights the importance of a standardized weaning protocol with criteria to predict successful weaning outcomes. Unfortunately, data supporting such protocols from large cohorts remain limited.[79]

Except for specific scenarios like drug intoxication or hypothermia, the first weaning attempt is generally delayed until at least 72 h post-tMCS implantation. This delay allows for recovery of end organs and the potentially stunned myocardium. The underlying aetiology of cardio-circulatory dysfunction must be compatible with myocardial recovery (e.g. acute myocarditis or acute myocardial infarction).

Step 1: assessing readiness to wean

Daily assessment of readiness to wean is essential to determine whether patients are candidates for weaning. Readiness is defined by clinical, haemodynamic, metabolic, and imaging improvements resulting from tMCS-induced perfusion support and ventricular unloading.[79] While the acceptable degree of pharmacological support during weaning is debated, low levels of catecholamines, indicative of improved intrinsic myocardial function, are associated with improved outcomes.

Echocardiography input is indispensable during this stage. Key parameters and thresholds for indicating readiness for weaning include the following: aortic velocity time integral ≥10 cm, LVEF >20–25%, and lateral mitral annulus peak systolic velocity >6 cm/s.[80]

Step 2: weaning trials

Once readiness is established, the second step involves an intentional and controlled reduction in blood flow delivered by the tMCS device, referred to as a weaning trial. This step evaluates the native heart's ability to maintain adequate circulatory support. Typically, a weaning trial is deemed successful when a patient has minimal tMCS support for greater than 8 h indicating readiness for permanent device removal.

Step 3: optimizing weaning outcomes

Pharmacological agents like levosimendan have shown potential to improve weaning success in patients with ECMO, and their integration into weaning strategies is under discussion.[81] Invasive monitoring tools, such as the Swan–Ganz catheter, may also offer valuable insights into LV pre-load (pulmonary capillary wedge pressure) and RV afterload (mean pulmonary artery pressure), although more evidence is needed to establish their role during weaning.

For patients deemed unsuitable for tMCS removal, a multi-disciplinary team discussion is crucial to optimize patient conditions and re-assess treatment strategies. Repeating the weaning trial after 48 h should be considered. When prospects for successful weaning are poor, especially in patients on ECMO for more than 1-week, alternative pathways, such as palliation, escalation or modification of support, or long-term VAD or heart transplant should be considered.[82]

Conclusions

Post-cardiotomy cardiogenic shock represents a significant challenge in cardiac surgery, requiring prompt diagnosis and tailored interventions. Effective management hinges on understanding the multi-factorial pathophysiology, employing advanced diagnostic tools, and initiating tMCS to stabilize patients and prevent end-organ damage. Multi-disciplinary collaboration via the Heart Team model is critical for optimizing treatment pathways and improving outcomes, while the advances in tMCS devices, diagnostic modalities, and individualized weaning protocols continue to refine care strategies, offering improved survival and quality of life for patients with PCCS.

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