0003-4975 213
https://doi.org/10.1016/j.athoracsur.2025.01.038

Escalation and De-escalation of Temporary Mechanical Circulatory Support: Joint Consensus Report of the PeriOperative Quality Initiative and the Enhanced Recovery After Surgery Cardiac Society

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ABSTRACT

BACKGROUND Temporary mechanical circulatory support (tMCS) for cardiogenic shock (CS) is increasing despite knowledge gaps and variations in management practices. This document was created to provide clinicians with guidance regarding initiation, escalation, and de-escalation of tMCS in patients with CS.

METHODS An interdisciplinary, international expert panel using a structured literature appraisal and modified Delphi method derived consensus statements regarding triggers for prompt patient assessment and initiating tMCS in CS, assessing adequacy of support, readiness for tMCS weaning, and next steps in nonrecovery. Individual statements were graded on the basis of the quality of available evidence.

RESULTS The panel addressed 4 main questions aimed at initiation, escalation, and de-escalation of tMCS. On the basis of available literature review and expert consensus, 11 recommendations were formulated. Key principles included recognition of the need for patients with CS who have ongoing hemodynamic compromise, tissue hypoperfusion, and metabolic derangements to be considered for early tMCS initiation. An interdisciplinary shock team should be involved in management, with early referral when patient conditions require care beyond center capabilities. Discussions providing anticipatory guidance should be performed with patients and decision makers before initiating tMCS. Management of tMCS involves frequent, timely hemodynamic and tissue perfusion reassessments to determine the need for escalation or weaning. For patients unable to be weaned from tMCS, evaluation should include interdisciplinary assessment for advanced therapies, with palliation included as a consideration in care discussions.

CONCLUSIONS A practical guide to initiation, escalation, and de-escalation of tMCS is provided. Center-specific approaches that are based on local capabilities should be implemented.

(Ann Thorac Surg 2025;120:213-24)

The Supplemental Table and Supplemental Figure can be viewed in the online version of this article [https://doi.org/10.1016/j.athoracsur.2025.01.038 on http://www.annalsthoracicsurgery.org.

Accepted for publication Jan 19, 2025.

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Abbreviations and Acronyms

ADHF = acute decompensated heart failure
AMI = acute myocardial infarction
CPO = cardiac power output
CS = cardiogenic shock
ECMO = extracorporeal membrane oxygenation
ERAS = Enhanced Recovery After Surgery
IABP = intraaortic balloon pump
LV = left ventricular
LVAD = left ventricular assist device
MCS = mechanical circulatory support
PA = pulmonary artery
PC = palliative care
PCCS = postcardiotomy cardiogenic shock
PCI = percutaneous coronary intervention
POQI = Perioperative Quality Initiative
RV = right ventricular
SCAI = Society for Cardiovascular Angiography and Interventions
SVR = systemic vascular resistance
tMCS = temporary mechanical circulatory support
VA = venoarterial
VIS = vasoactive inotropic score

Temporary mechanical circulatory support (tMCS) provides short- to intermediate-term hemodynamic support for patients with cardiogenic shock (CS). Although several causes can result in CS, the most common are acute myocardial infarction (AMI), acute decompensated heart failure (ADHF) (specifically, decompensated chronic heart failure), and postcardiotomy cardiogenic shock (PCCS). Regardless of indication, tMCS may serve as a bridge to surgery, cardiac recovery, or advanced therapies (such as durable left ventricular assist device [LVAD] or cardiac transplantation) or as a bridge to decision, including palliation.

For related articles, see pages 194, 202, 225

Despite increasing worldwide tMCS use, there is little consensus regarding tMCS best practices, including escalation and weaning approaches. Although multiple algorithms exist, there is a need for practical guidelines focused on less experienced centers.[1-5] Furthermore, de-escalation strategies are characterized by marked variability regarding vasoactive medications and tMCS weaning. Our objective was to provide clinicians with expert guidance regarding initiation, escalation, and de-escalation of tMCS in patients with cardiogenic shock, by using a modified Delphi process that was based on expert consensus opinion.

This is the second document of 3 reports[6,7] linked through an executive summary.[8] These reports present the fundamental principles of patient and institutional factors that influence the use of tMCS. We acknowledge that this is a vast body of literature and have endeavored to distill it into practical guidance for providers caring for these vulnerable patients. To achieve this, we have organized the content into 3 distinct areas.

First, we provide an overview of the definitions of CS and the indications for tMCS. Next, we present an algorithmic approach for the escalation and de-escalation of tMCS for patients in shock. Third, we aim to apply enhanced recovery best practices for managing patients on tMCS in the intensive care unit.

Recognizing the rapid expansion of centers that provide tMCS therapies, particularly in the post-COVID-19 era, we acknowledge that centers vary in volume and capacity. Therefore, it is essential for the reader to adapt and contextualize this content to their specific center or health care system. These manuscripts intend to offer actionable guidance for centers with varied tMCS capabilities.

METHODS

The Perioperative Quality Initiative (POQI)[9] convened with the ERAS Cardiac Society on January 24 to 26, 2024, in San Antonio, Texas. Three working groups with tMCS expertise, representing surgery, anesthesiology, cardiology, critical care, and nursing from the United States, Canada, Germany, and the Netherlands, were assembled. Led by 2 co-chairs (D.T.E., A.D.S.), members performed literature searches; questions regarding controversies or lack of consensus were assembled by chairs (S.C. and A.E.S).

Consensus among working groups covered definitions of tMCS, types of devices, and the intended audience for recommendations. tMCS was defined as the use of short-term cardiovascular support devices, excluding durable LVADs. Specific devices included an intraaortic balloon pump (IABP), microaxial flow pumps (Impella, Abiomed) referred to as percutaneous ventricular assist devices, and venoarterial extracorporeal membrane oxygenation (VA-ECMO). TandemHeart (LivaNova) systems were not included given their limited use outside of specialty centers. The targeted audience was centers with limited tMCS use or access to heart failure therapies that may benefit from a management algorithm and guidance surrounding higher-level transfer.

This working group addressed 4 questions focusing on escalation or de-escalation of tMCS devices: (1) triggers for initiating tMCS in cardiogenic shock, (2) monitoring and assessing the adequacy of tMCS support, (3) assessing and

determining candidacy for tMCS weaning, and (4) What if the patient cannot be weaned from tMCS?

A Modified Delphi process shaped the recommendations, refining questions, and developing consensus as described[9,10] (Table 1). Recommendations emerged through open voting in plenary sessions, considering all members' inputs on working group statements. Moderators encouraged diverse views, incorporating dissent in the consensus. Iterative sessions solidified the consensus statements. During the final POQI conference session, all members from all 3 working groups voted to agree or disagree with statements and recommendations. Quality of evidence (QOE) was assessed, and designations were rendered on the basis of whether additional research on the topic is unlikely (High Quality), likely (Moderate Quality), or very likely (Low Quality) to have an important impact on the effect of the intervention. No human subject research occurred, eliminating the need for Institutional Review Board approval.

RESULTS AND COMMENT

SUMMARY OF RECOMMENDATIONS AND SUPPORTING EVIDENCE.

Table 1 is a summary of questions with relevant consensus recommendations and quality of evidence grading.

QUESTION 1: WHAT ARE THE TRIGGERS FOR INITIATING TMCS IN CS?

Statement 1.1: Patients with ongoing CS, as evidenced by tissue hypoperfusion and metabolic derangements due to cardiocirculatory compromise, should be considered for initiation of tMCS. QOE: Moderate

Definitions of cardiogenic shock are covered more comprehensively in Part 1 of this series.[6] However, in brief, cardiogenic shock is defined as "circulatory failure attributable to cardiac dysfunction that results in abnormal tissue perfusion." Objective markers of tissue hypoperfusion follow Society for Cardiovascular Angiography and Interventions (SCAI) clinical criteria.[11] Patients in SCAI stages C and higher (D and E) should be considered for tMCS initiation. This includes specific variables as outlined under "common triggers" in Figure 1. Earlier tMCS is advised on the basis of expected patient trajectories. The Altshock-2 Registry showed that 91% of patients not needing inotropes (SCAI-B) failed to improve with medical management, and 42% experienced worsened CS.[12] The mortality rate doubles when SCAI-B patients experience hemodynamic deterioration requiring support (SCAI-B to SCAI-C) compared with patients never requiring support.[13] The multicenter randomized Danish-German Cardiogenic Shock (DanGERShock) trial showed survival benefits with early microaxial flow pumps in CS after ST-segment elevation myocardial infarction (number needed to treat, 8).[14]

Patients in Figure 1 require advanced support beyond initial resuscitation to prevent end-organ damage. Measuring pharmacologic support with multiple vasoactive agent(s) is complex. The vasoactive inotropic score (VIS) allows treatment comparisons across various settings, increasing with the severity of CS, typically ranging from 10 to 30.[15] A VIS >10 should prompt early consideration of tMCS, thus helping centers plan for capacity assessments and potential transfer.

Statement 1.2: Perform complete hemodynamic assessment including pulmonary artery (PA) catheter or comprehensive echocardiography expeditiously (<6 hours) after identifying CS. QOE: Moderate

Data from more than 8500 patients in the Extracorporeal Life Support Organization (ELSO) registry demonstrate that delays in MCS initiation in patients with CS increase the risk of death by 11%/day.[16] According to the Cardiogenic Shock Working Group (CSWG) registry, the average transfer time to a higher level of care is 3.5 days.[17] Transfer times for patients with ADHF-CS average 117 hours compared with 40 hours for AMI-CS.[17] We recommend standardizing CS phenotypes, management protocols, and a "complete hemodynamic assessment" within 6 hours of CS diagnosis. This includes assessment of right ventricular (RV) and left ventricular (LV) function, organ perfusion and venous congestion markers, and hypoxemia. Mechanical support requirements can be assessed expeditiously, thereby improving overall survival.[18]

Statement 1.3: Centers should perform a self-assessment of ongoing capabilities, limitations, and capacity. Communication with local/regional shock programs for patients anticipated to need care beyond their capability is recommended. QOE: Moderate

Assessing center capabilities and establishing a network for prompt remote patient discussion and expedited transfer decrease time to support and improve survival. This model involves center assessment, a designated network, and predetermined interdisciplinary teams, proving successful across various health care systems.[19-22] A team-based approach with evaluation of center limitations and collaboration with advanced MCS centers is advised for managing patients with CS.

TABLE 1 Summary of Questions With relevant Consensus Recommendations and Quality of Evidence Grading

Question	Recommendations	Quality of Evidence
1. What are the triggers for initiating tMCS in cardiogenic shock?	1.1 Patients with ongoing CS, evidenced by tissue hypoperfusion and metabolic derangements from cardiocirculatory compromise, should be considered for initiation of tMCS.	Moderate
	1.2 Perform complete hemodynamic assessment including PA catheter or comprehensive echocardiography expeditiously (≤6 hours) after identifying CS.	Moderate
	1.3 Centers should perform self-assessment of ongoing capabilities, limitations, and capacity. Communication with local/regional shock programs for patients anticipated to need care beyond their capabilities is recommended.	Moderate
2. How do we monitor and assess adequacy of current tMCS support?	2.1 The immediate goals of tMCS are stabilizing hemodynamics and restoring organ perfusion. Frequent reassessment and escalation of therapy for inadequate support are advised.	Moderate
	2.2 If patient clinical severity exceeds center capacity, call a regional referral center for timely transfer.	Moderate
	2.3 For improved continuous monitoring, a PA catheter should be maintained during ongoing tMCS.	Moderate
3. How do we best assess and determine a patient's candidacy for weaning from tMCS?	3.1 Assessment of cardiac recovery by biomarkers, imaging, hemodynamics, and clinical assessment helps determine suitability of de-escalation.	Moderate
	3.2 If prolonged cardiac support is necessary, consider alternative tMCS device to reduce complications.	Low
4. What if the patient does not have cardiac recovery/is unable to be weaned from tMCS?	4.1 Periodic reassessment (eg, every 48–72 hours; more frequently, if needed) should be performed reassessing patient's overall clinical trajectory and prognosis with goals of care discussions, family meetings, and shared decision making, including transfer to an appropriate center.	Low
	4.2 Eligibility for more advanced therapy options (ie, durable MCS, transplantation) should be considered in an interdisciplinary manner with workup initiated as indicated.	Low
	4.3 If advanced therapies are not an option and clinical recovery is not expected, palliative considerations should be discussed.	Moderate

CS, cardiogenic shock; PA, pulmonary artery; tMCS, temporary mechanical circulatory support.

QUESTION 2: HOW DO WE MONITOR AND ASSESS ADEQUACY OF CURRENT TMCS SUPPORT?

Statement 2.1: The immediate goals of tMCS are stabilizing hemodynamics and restoring organ perfusion. Frequent reassessment and escalation of therapy for inadequate support are advised. QOE: Moderate

In patients with CS, the MCS goals include (1) stabilizing hemodynamics restoring end-organ perfusion, (2) supporting heart recovery, and (3) allowing time for bridging to advanced therapies (durable LVAD or transplantation). This may require multiple devices, including device reconfiguration or exchange.

Once CS is diagnosed and tMCS need is identified, the likely disease origin and most appropriate device on the basis of local expertise or availability should be discussed. Before tMCS initiation, exit strategies should be considered. If the most appropriate device is not available or center capability is exceeded, referral center transfer should be initiated as soon as possible.

The choice of initial device depends on cause and shock severity, rate of hemodynamic deterioration, concomitant hypoxia, time to implant support, available devices, and the patient's stability for transfer. We will focus on the 3 most common causes (ie, AMI, ADHF, and PCCS) categorized into predominantly left-sided heart failure vs biventricular failure. Although other devices are available, we discuss the 4 most common and available MCS devices: IABP, extracorporeal membrane oxygenation (ECMO), and Impella CP and Impella 5.5 device use (Supplemental Table). Although important, isolated right-sided heart failure has been addressed previously by POQI (IX).[23]

After hemodynamic stabilization, planning for recovery or bridging to more advanced therapies is necessary. For patients undergoing peripheral VA-ECMO, optimizing LV unloading is particularly important because LV distention increases myocardial wall tension, thereby reducing coronary flow, which can hinder recovery. LV distention with a PA diastolic pressure >20 mm Hg increases the risk of pulmonary edema. Initial LV unloading may be improved with low- to moderate-dose inotropes and vasodilators, modifying ventilator variables (eg, increasing positive end-expiratory pressure for right-sided heart

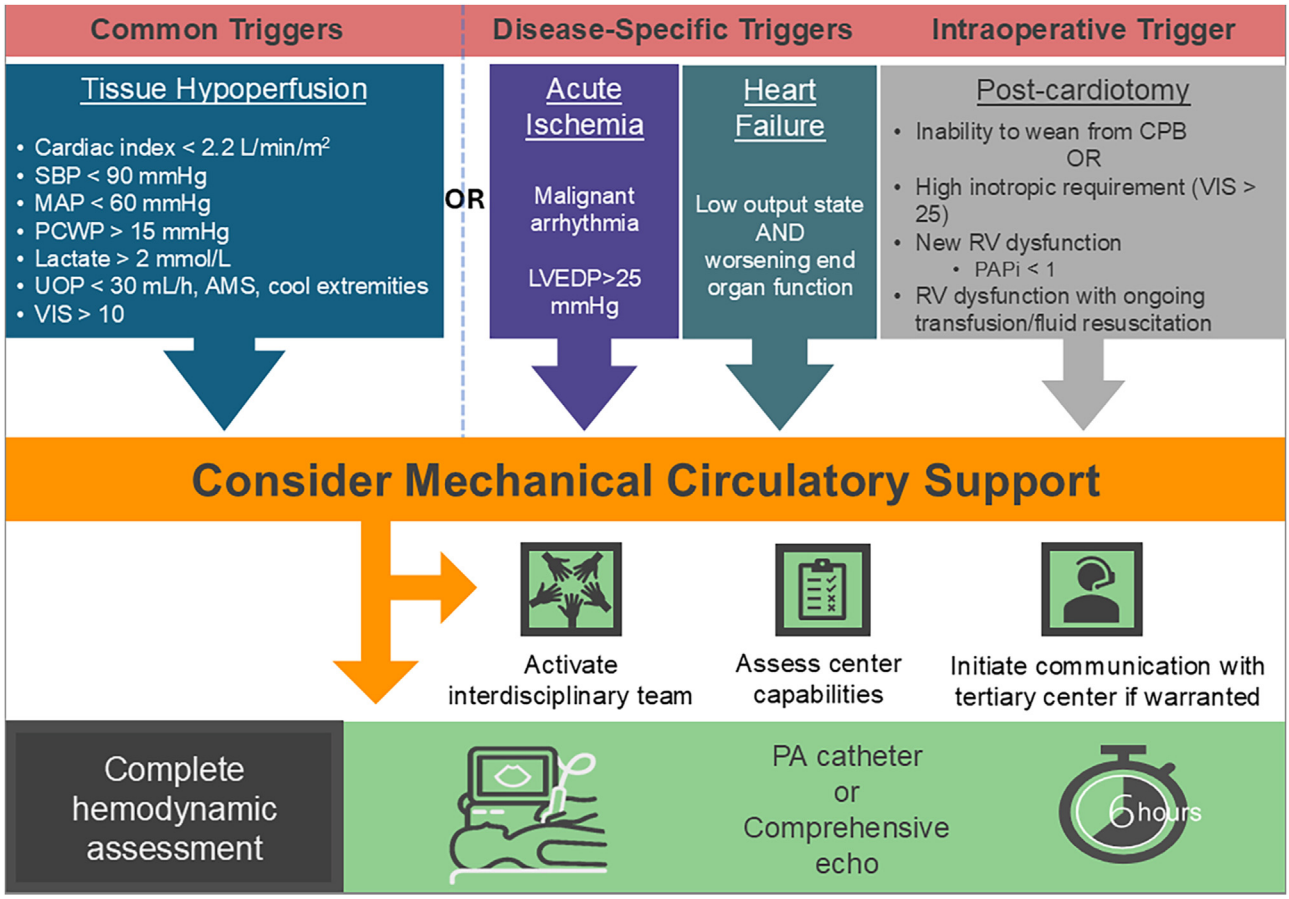

FIGURE 1 Triggers for initiation of mechanical circulatory support. Common triggers include markers of tissue perfusion and should prompt consideration for mechanical circulatory support. Disease-specific triggers may be present in the absence of common triggers and may also prompt consideration of mechanical circulatory support. Recognition of triggers should prompt interdisciplinary team discussion and consideration of available mechanical support or discussion with a tertiary center. Recognition of triggers should also prompt a complete hemodynamic assessment, which includes, but is not limited to, pulmonary artery (PA) catheter placement or comprehensive echocardiography (echo) within 6 hours or less. (AMS, altered mental status; CPB, cardiopulmonary bypass; LVEDP, left ventricular end-diastolic pressure; MAP, mean arterial pressure; PAPi, pulmonary artery pulsatility index; PCWP, pulmonary capillary wedge pressure; RV, right ventricular; SBP, systolic blood pressure; UOP, urine output; VIS, vasoactive inotropic score.)

drainage); further unloading may need atrial septostomy, additional left atrial or PA drainage, IABP, or Impella use.[24] LV unloading measures should be reassessed for efficacy, modification, or escalation. If prolonged MCS support is expected, focus on minimizing complications, durability of support, patient ambulation, and minimizing sedation. MCS reconfiguration may be necessary in these settings; for example, femoral VA-ECMO cannulation may be switched to an axillary position or an axillary flow device. Furthermore, it is worth emphasizing that VA-ECMO is associated with a higher rate of complications compared with other devices, and this rate increases with increasing duration. This must factor into decision making regarding use, time to weaning, and time to referral or transfer.

Predominant LV Failure. Patients with AMI-CS are often considered for PCI; patients undergoing tMCS with Impella CP may be most suitable for PCI support (Figure 2). IABP helps in less severe shock (SCAI-C) but may be inadequate for higher classes.[25] Although Impella CP may provide up to 4 L of flow, the overall hemodynamic effect is not additive to the native cardiac output by decreasing LV preload.[26] The net cardiac output increase may only reach 1 to 3 L depending on preload, afterload, and native ventricular contractility. In patients with the most severe degrees of shock or higher body mass index, this increase in flow may still be inadequate to normalize hemodynamics requiring escalation in MCS support. Peripheral VA-ECMO provides full hemodynamic support but may hinder myocardial

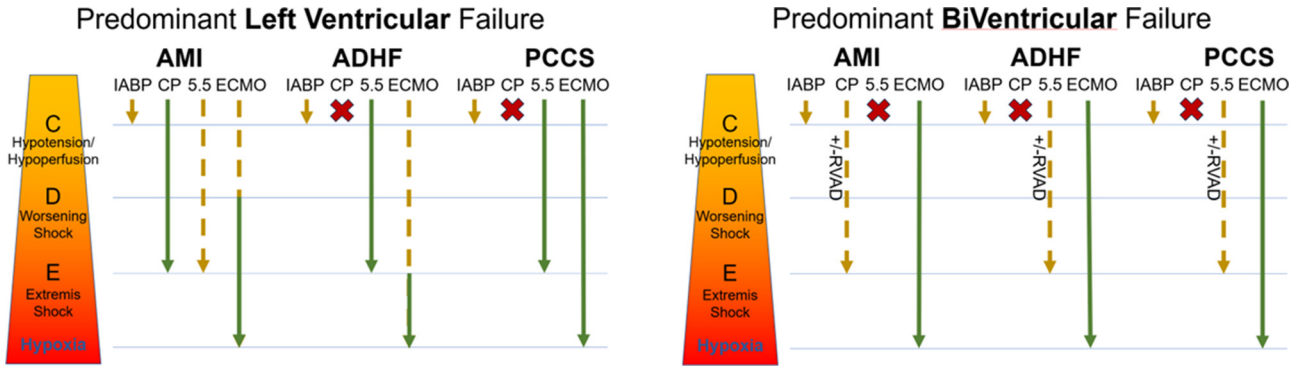

FIGURE 2 Device escalation options for patients with predominantly left ventricular/biventricular failure. Device options are provided for acute myocardial infarction (AMI), acute decompensated heart failure (ADHF), and postcardiotomy cardiogenic shock (PCCS). The dotted line indicates therapies that could be considered if only the device is available; the solid line indicates therapies that should be considered. (CP, Impella CP device [Abiomed]; ECMO, extracorporeal membrane oxygenation; IABP, intraaortic balloon pump; RVAD, right ventricular assist device.)

recovery from high afterload, and it carries the risk of other complications (pulmonary capillary, left-sided heart and aortic root stasis, pulmonary edema, and thromboembolic events).[27] In some centers, Impella 5.5 may be first-line tMCS for AMI; however, surgical-cardiology coordination may be challenging, to avoid PCI revascularization delay.

Patients with ADHF may better tolerate lower cardiac index (CI >1.8) and blood pressure than patients with other causes of shock. The focus in ADHF is often on bridging to advanced therapies, emphasizing durable devices that allow patient mobility. An IABP may be sufficient in a patient with ADHF with SCAI C or D shock, but for more advanced shock levels, Impella 5.5 is the preferred device over Impella CP and ECMO given the axillary insertion site and better durability.[28]

In patients with PCCS, the objective is not only to support separation from cardiopulmonary bypass, but also to aid myocardial recovery.[29] ECMO is the primary device used due to its availability and complete support. Patients with severe LV dysfunction and peripheral VA-ECMO may need LV venting to avoid LV distention. The Impella 5.5 (axillary or direct aortic) can be used for salvage or planned for patients at higher PCCS risk.[30,31] The ongoing IMpella-Protected cArdiaC Surgery Trial (IMPACT) trial aims to define prophylactic Impella 5.5 use in high-risk cardiac surgery.[30]

Although PCCS is similar to nonoperative CS in many ways, there are key differences influencing support initiation after cardiac surgery. Whereas hemodynamic and biologic markers are similar, the VIS is typically higher (Figure 1). RV function and ability to tolerate anticipated postoperative volume should be considered when planning tMCS. In PCCS there are survival advantages to early support and high mortality in patients whose condition worsens over the first 24 hours.[29,32,33]

In cases of LV failure with pulmonary edema and hypoxia or hypercapnia, VA-ECMO is likely the most appropriate initial device. An LV venting strategy should be used to achieve a PA diastolic pressure <20 mm Hg. Notably, a right upper extremity arterial catheter, should be maintained to monitor for differential hypoxia in the setting of concomitant respiratory failure. If refractory, addition of a venous outflow limb to establish venous-arteriovenous ECMO may be considered. Alternatively, in patients with LV failure with hypoxia or hypercapnia supported by a non-ECMO device, venovenous ECMO can act as an adjunct for pulmonary support. Detailed tMCS management practices are outlined in Part 3 of this series.[7]

Predominant Biventricular Failure. In CS with biventricular failure, left-sided heart failure leads to pulmonary congestion and higher RV afterload, decreasing RV ejection fraction.[34,35] Often, supporting the left ventricle alone may be sufficient in biventricular failure.[36] In stage C shock, an IABP may be sufficient because the increased coronary perfusion benefits the right ventricle (Figure 2). ECMO can bypass both ventricles and normalize systemic perfusion. With isolated LV support, reassessment of the right ventricle is essential. When left-sided flow increases, RV failure may manifest with a septal shift toward the left ventricle or an inability to increase LV device flow. However, if lower flows are tolerated with adequate systemic perfusion,

over the course of hours and days with diuresis, inotropes, and pulmonary vasodilators, RV function may improve, allowing increased LV flows.[3,37] In situations where the right ventricle is not tolerating isolated LV tMCS, support of the right ventricle can be accomplished with either VA-ECMO or a temporary RV assist device (either with or without oxygenator).[23,38,39]

Statement 2.2: If patient clinical severity exceeds center capacity, call a regional referral center for timely transfer. QOE: Moderate

Once the patient is undergoing initial support, frequent assessments for adequacy of support are recommended. If tMCS has not achieved adequate hemodynamic support, escalation of device support is recommended. If such a device is not locally available, referring the patient to a different center may be appropriate (Supplemental Figure).[21,22]

Statement 2.3: For improved continuous monitoring, a PA catheter should be maintained during ongoing tMCS. QOE: Moderate

PA catheter-based monitoring in CS shows a survival benefit through comprehensive hemodynamic assessments in multicenter registries and the Detroit Cardiogenic Shock Initiative.[20,40] This initiative showed that patients with AMI-CS who were prospectively enrolled into a highly protocolized, algorithmic treatment plan had a significant improvement in survival to device explantation (85% vs 51%), with 76% discharged from the hospital.[20]

A PA catheter provides vital information in hemodynamic monitoring, including right- and left-sided filling pressures, mixed venous saturation, systemic vascular resistance (SVR), PA pulsatility index (PAPi), and cardiac power output (CPO) to assist in tMCS consideration and management.[41] We recommend using a Fick calculation from mixed venous saturation to assess cardiac index in patients with CS who are undergoing tMCS. Furthermore, rising mixed venous saturation and a drop in SVR can also indicate transition to a vasodilatory state (eg, sepsis).

QUESTION 3: HOW DO WE BEST ASSESS AND DETERMINE A PATIENT'S CANDIDACY FOR WEANING FROM TMCS?

Statement 3.1: Assessment of cardiac recovery by biomarkers, imaging, hemodynamics ,and clinical assessment helps to determine suitability of de-escalation. QOE: Moderate

MCS De-escalation. Biomarkers, hemodynamics, and imaging help evaluate the response to tMCS and help determine transitioning to de-escalation. The decision to de-escalate or remove MCS, or both, should be driven by invasive hemodynamic monitoring (PA catheter), echocardiography, and hemometabolic variables (Table 2).[2,42] End-organ function should show significant improvement or recovery. In the awake patient, successful weaning is suggested by improved dyspnea, energy level, and appetite. Patients should be on minimal oxygen settings and low-dose inotropes (VIS <9; eg, milrinone, 0.25 μg/kg/min, or dobutamine, 5-7.5 μg/kg/min). Patients should maintain CPO >0.6 with echocardiographic improvement. Once achieved, the de-escalation algorithm (Figure 3) can be followed. Device complications requiring immediate removal do not fall under the de-escalation pathway. For any device-related complication that requires immediate removal, interdisciplinary team discussion regarding replacement or ineligibility for additional tMCS should take place.

As de-escalation is initiated, frequent monitoring is essential for determining success of weaning. Device-specific weaning is described in Table 3.[43,44] At times, transitioning from 1 type of tMCS to another better promotes recovery or reduces complications. For example, weaning from VA-ECMO to single LV or RV tMCS placed in the upper body, such as axillary Impella for LV support or ProtekDuo (LivaNova) for RV support, may provide prolonged assistance, reduce complications, and promote ambulation and rehabilitation.

Although improvements in blood pressure, serum lactate levels, and end-organ function indicate adequate tMCS support, these improvements may not signify cardiac recovery. Indeed, recent systematic review and multicenter studies have shown that successful weaning from VA-ECMO may still result in an in-hospital mortality ranging from 15% to 25% with multiorgan failure or persistent cardiac compromise.[45,46] Comprehensive monitoring is key to making informed decisions about the patient's potential for successful de-escalation.

Successful Weaning From MCS: Strategies for Myocardial Recovery and Hemodynamic Improvement. An early weaning strategy is advised when there is evidence of myocardial recovery during reduction of tMCS flow. A Doppler echocardiographic LV outflow velocity-time integral >10 to 12 cm is the most widely used variable to track LV recovery.[47] Other variables, such as a lateral S wave >6 cm/s, have also been suggested as predictors of myocardial recovery and successful weaning.[48]

Sometimes, weaning can be facilitated by using pharmacologic unloading strategies to reduce afterload and increase contractility. Using comprehensive assessment of hemodynamics,

TABLE 2 Key Hemodynamic and Hemometabolic Assessment variables During Escalation and Weaning

Variable	Frequency of Assessment	Goals
Hemodynamic		
Cardiac power output	q2–4h	Goal >0.6 Watts
Cardiac index	q4–6h	>2.2 L/min/m^2
Pulmonary artery pulsatility index	q4–6h	>1
Mean arterial pressure	Continuous	>65 mm Hg, <80 mm Hg
Pulmonary artery diastolic pressure/pulmonary capillary wedge pressure	Continuous	<18 mm Hg
Central venous pressure	Continuous	<12 mm Hg
Hemometabolic		
Liver function tests, creatinine	q6–8h	Down trending
Urinary output	Hourly	0.5 mL/kg/hr
pH	q2h	7.35–7.45
Lactate	q2h	<2 mmol/L

including SVR, CPO, mean arterial pressure, filling pressures, and PAPi, will allow optimization of the weaning process.[3,49] During the tMCS weaning process, focusing on pulse pressure is essential. Initiation of continuous flow tMCS can lead to the disappearance of pulse pressure, and its reappearance indicates improvement in cardiac performance.

A Criteria-Based Guide For tMCS Weaning Success. Successful weaning from tMCS is multidimensional, with hemometabolic, hemodynamic, and end-organ functional criteria. Hemometabolic stability includes lactate clearance (<2 mg/dL), improving liver and renal function (unless dialysis-dependent), and blood pH of 7.35 to 7.45. Hemodynamic goals include CPO >0.6, a CI >2.2, central venous pressure <12 mm Hg, PA diastolic pressure or pulmonary capillary wedge pressure <18 mm Hg, and VIS <10.[1] For end-organ function, ventilation variables include extubation readiness or minimal ventilatory settings, satisfactory radiographic appearance, and improved echocardiographic cardiac function. On meeting these criteria and optimization of goal-directed medical therapy focusing on preload, afterload, and contractility, tMCS is weaned to minimal settings before removal.[1]

Statement 3.2: If prolonged cardiac support is necessary, consider alternative tMCS device to reduce complications. QOE: Low

Failed Weaning From MCS: A Guide to Intervention, Transition, and Terminal Care. Failed weaning scenarios from tMCS can occur for various reasons; identifying and addressing the causes are important. These may include irreversible cardiac damage, valvular disease, ongoing arrhythmia, suboptimal fluid status, or new or worsening organ dysfunction. Optimization of stroke volume is crucial and involves the careful manipulation of preload, afterload, and contractility. If weaning continues to fail, a measured approach to subsequent steps is essential. These strategies may include a longer run on the existing device, providing additional recovery time. Alternatively, transitioning to a different tMCS with the possibility of mobilizing the patient may reduce the risk of complications. Occasionally, an upgrade to more durable circulatory support may be appropriate. A ventricular-specific strategy promoting minimization of sedation and rehabilitation should be considered. Furthermore, longer-term MCS selection should also minimize risk of complications (eg, leg ischemia or stroke).

QUESTION 4: WHAT IF THE PATIENT DOES NOT HAVE CARDIAC RECOVERY/IS UNABLE TO BE WEANED FROM TMCS?

Statement 4.1: Periodic reassessment (eg, every 48-72 hours; more frequently if needed) should be performed to reassess patient's overall clinical trajectory and prognosis with goals of care discussions, family meetings, and shared decision making, including transfer to an appropriate center. QOE: Low

Assessment of clinical trajectory and prognosis includes both current state of cardiac function and device dependency, as well as the patient's overall clinical status (Supplemental Figure). For example, worsening multiple organ system dysfunction may affect overall prognosis as well as candidacy for future therapies. Ongoing assessment and discussions with decision makers should include expected trajectory and next steps. The ability to discontinue tMCS support at any time should be made clear in conversations with patients and decision makers and is particularly important to reemphasize in circumstances where patients and surrogates no longer wish to continue support or for those in whom other nonsurvivable organ dysfunction is present.

Statement 4.2: Eligibility for more advanced therapy options (ie, durable MCS, transplantation) should be considered in an interdisciplinary manner with workup initiated as indicated. QOE: Low

Ongoing assessments of eligibility for advanced therapies is necessary, especially in patients with

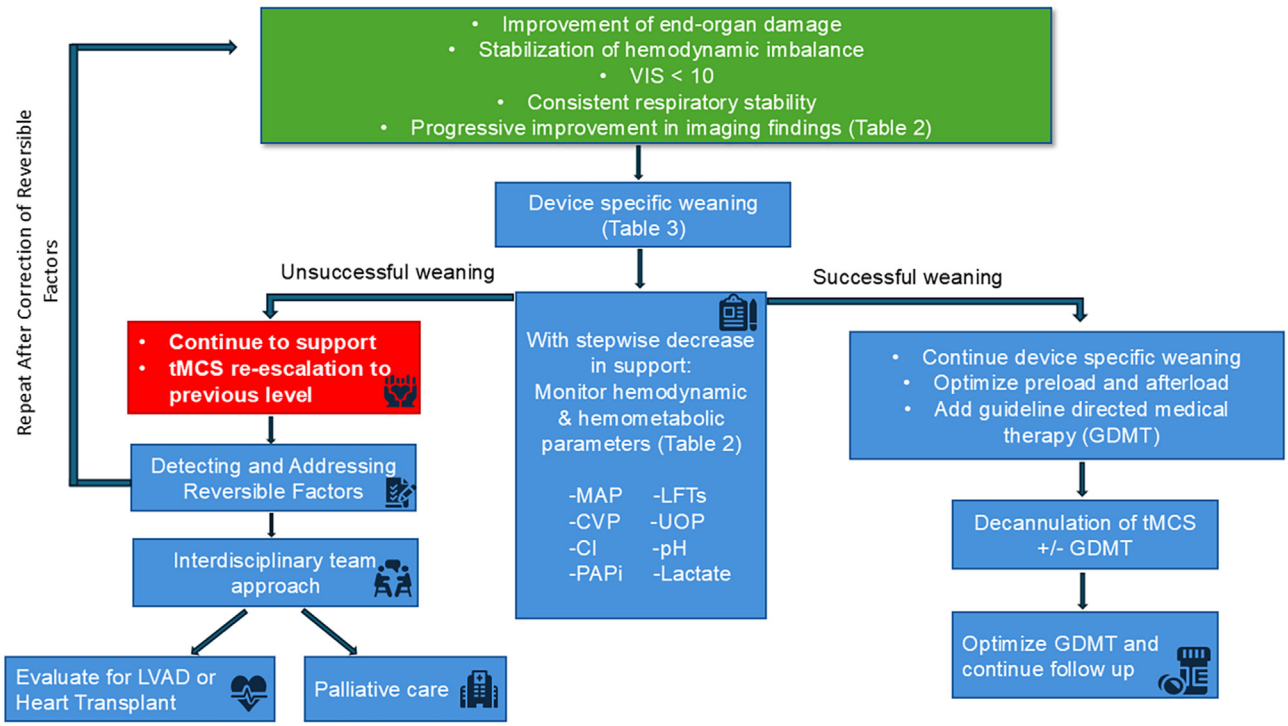

FIGURE 3 Weaning strategy for temporary mechanical circulatory support (tMCS) devices. Approach to successful and unsuccessful weaning for mechanical circulatory support. After resolution of shock and improvement in end-organ function, begin device weaning in stepwise fashion. With each decremental wean, reassess hemodynamic and hemodynamic variables. Successful weaning is achieved when hemodynamic and hemometabolic variables remain stable at minimal support. After medical optimization, decannulation and further titration of goal-directed medical therapy should follow along with continued monitoring of hemodynamic and hemometabolic variables. In the event of unsuccessful weaning, return to previous level of tMCS support and address reversible factors of weaning failure. In the event of repeated inability to wean, an interdisciplinary approach is required for consideration of advanced therapies vs palliation. (CI, cardiac index; CVP, central venous pressure; GDMT, guideline-directed medical therapy; LFTs, liver function tests; LVAD, left ventricular assist device; MAP, mean arterial pressure; PAPi, pulmonary artery pulsatility index; UOP, urine output; VIS, vasoactive inotropic score.)

unsuccessful weaning. Referral to regional networks with expertise in advanced heart failure management is appropriate for patients in centers without advanced therapy capabilities. Referring teams are not responsible for determining potential candidacy for advanced therapies, and a

TABLE 3 Device-Specific Weaning Approaches: Frequency of Weaning and Unique Considerations for Various Devices

Device	Weaning Level	Weaning Frequency	Lowest Level	Unique Considerations
IABP	1:2	2 h	1:4	Alternative approach: weaning by serial balloon deflation while maintaining 1:1 ratio.[43]
PVAD Impella (Abiomed)	Decrease p-level by 2	6–8 h	P-2	Recognize hemolysis, which may require alternative MCS strategy.
VA-ECMO	1.5–2 L/min	12–24 h vs days	2 L/min (lower flows for supervised short durations)	Echocardiography: RV/LV function; LV function (LVEF >20%–25%, velocity-time integral >10 cm, and lateral mitral annulus peak systolic velocity >6 cm/s) during reduced flow (1–2 L/min) Weaning may alternatively be accomplished by establishing a shunt between ECMO arterial and venous catheters and gradually increasing recirculation ratio, thereby reducing flow to patient.[44]

ECMO, extracorporeal membrane oxygenation; IABP, intraaortic balloon pump; LV, left ventricular; LVEF, left ventricular ejection fraction; MCS, mechanical circulatory support; PVAD, percutaneous ventricular assist device; RV, right ventricular; VA-ECMO, venoarterial extracorporeal membrane oxygenation.

complete assessment is not required before referral. Interdisciplinary assessment, discussion of comorbid conditions, and social support are routinely performed during evaluation.

Critical decisions regarding advanced therapy options are best approached through a collaborative, interdisciplinary team, ensuring comprehensive evaluation and planning. Equally important is patient and family inclusion in these discussions, affirming their integral role in shared decision making. This process provides a transparent review of prognosis and exploration of all treatment options.[3]

Statement 4.3: If advanced therapies are not an option and clinical recovery is not expected, palliative considerations should be discussed. QOE: Moderate

For patients with tMCS who have a poor prognosis and who are not candidates for advanced therapies, a terminal wean from the device may be considered. This involves a deliberate decision to remove life-sustaining treatment after extensive discussions to ensure alignment with the patient's wishes and ethical practices. The patient is made as comfortable as possible, often with palliative care (PC) specialists for pain and symptom management. Removal of the tMCS device is done in a controlled manner, focusing on maintaining the patient's dignity and comfort.[50,51]

PC plays a crucial role in caring for critically ill patients with end-stage heart failure and their families, with emotional support, defining goals of care, and managing symptoms and future expectations. The joint American Heart Association/American College of Cardiology/Heart Failure Society of America guidelines make PC a Class I recommendation for all patients with heart failure and a Class 2a recommendation for tMCS candidates.[52] We recommend inclusion of PC services for all patients requiring tMCS. This is further expanded in Part 3 of this 3-part series.[7]

PC does not hasten death, as some caregivers commonly think. It does clarify goals, including decisions on discontinuation of life-prolonging treatments and exploring end-of-life preferences. Although all patients requiring tMCS should involve PC services early, we recommend re-engaging PC services as an additional resource for prognosis discussion, caregiver support, and, if needed, transitioning to withdrawal and comfort measures.[53]

In conclusion, timely initiation and escalation of MCS for cardiogenic shock are essential to improve patient outcomes. If the initial strategy is insufficient, device escalation may be necessary. Collaboration across a multidisciplinary group with an understanding of local capabilities and expertise and coordination with tertiary referral centers is critical for management. Timely and appropriate de-escalation of tMCS, transition to durable therapies, or palliation should be provided to a center's best abilities.

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FUNDING SOURCES

Andrew D. Shaw reports article publishing charges provided by PeriOperative Quality Initiative (POQI). Roberto Lorusso reports a relationship with Medtronic that includes: funding grants; and with LivaNova that includes: funding grants. All other authors declare that they have no funding sources.

DISCLOSURES

Lauren M. Barron reports a relationship with Abiomed that includes: speaking and lecture fees. Roberto Lorusso reports a relationship with Xenios that includes: consulting or advisory; and with Abiomed that includes: speaking and lecture fees. Scott C. Silvestry reports a relationship with Abiomed that includes: consulting or advisory; with Abbott Vascular that includes: consulting or advisory; and with Medtronic that includes: consulting or advisory. Michael Z. Tong reports a relationship with Abiomed that includes: consulting or advisory; with Abbott Vascular that includes: consulting or advisory; and with LifeNet Health that includes: consulting or advisory. Daniel T. Engelman reports a relationship with Edwards Lifesciences that includes: consulting or advisory; with Renibus Therapeutics that includes: consulting or advisory; with Alexion Pharmaceuticals that includes: consulting or advisory; with Medela AG that includes: consulting or advisory; with Arthrex that includes: consulting or advisory; with AtriCure that includes: consulting or advisory; and with Pharmacosmos AS that includes: consulting or advisory. Andrew D. Shaw reports a relationship with Alexion Pharmaceuticals that includes: consulting or advisory; with Chugai Pharmaceutical Co that includes: consulting or advisory; with Alexion Pharmaceuticals includes: consulting or advisory; with Retia Medical that includes: consulting or advisory; with Renibus Therapeutics that includes: consulting or advisory; with Novartis Pharmaceuticals that includes: consulting or advisory; with RenalGuard Solutions that includes: consulting or advisory; and with Fresenius Medical Care that includes: consulting or advisory. Subhasis Chatterjee reports a relationship with Edwards Lifesciences that includes: consulting or advisory; with La Jolla Pharmaceutical Company that includes: consulting or advisory; with Eagle Pharmaceutical that includes: consulting or advisory; and with Baxter Pharmaceutical Products that includes: consulting or advisory. All other authors declare that they have no conflicts of interest.

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