Percutaneous Mechanical Circulatory Support Devices

Best practices for use in cardiovascular care.

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Percutaneous mechanical circulatory support (MCS) has seen rapid evolution in the last decade given the increased complexity of patients treated for acute myocardial infarction, chronic systolic dysfunction, decompensated heart failure, acute cardiogenic shock, as well as high-risk (HR) percutaneous coronary interventions (PCIs), and a strong belief that hemodynamic support can substantially improve outcomes in each of these settings. Medical therapies, including vasopressors and inotropes/vasodilators, remain the first-line treatment for shock despite a dearth of randomized trial data showing mortality benefit and, on the contrary, association with potentially negative physiologic effects, including tachycardia, arrhythmogenicity, and an increase in left ventricular (LV) afterload. These pharmacologic therapies increase myocardial oxygen demand in the most precarious of clinical settings, resulting in both acute and long-term declines of cardiac function. Although patients have traditionally been able to get out of the immediately critical setting with the use of such agents, long-term survival appears negatively affected due to these effects.

The potential benefits of MCS in a state of profound hemodynamic compromise, such as cardiogenic shock, include the ability to (1) maintain vital organ perfusion; (2) reduce intracardiac filling pressures; (3) reduce LV volumes, wall stress, and myocardial oxygen consumption; (4) improve coronary perfusion; (5) support the circulation during complex procedures; and (6) limit infarct size.[1] Accordingly, such devices may provide both short- and long-term benefits in both extricating the patient out of the acute decompensated setting but also preserving myocardial function and end-organ function such that long-term survival is improved.

MCS devices have been used to provide hemodynamic support in patients with complications of acute myocardial infarction (eg, ischemic mitral regurgitation, cardiogenic shock after large myocardial infarction, and primary PCI), severe heart failure in the setting of nonischemic cardiomyopathy (eg, fulminant myocarditis), acute cardiac allograft failure, right ventricular (RV) failure after transplantation, recurrent arrhythmias, and those with difficulty weaning from cardiopulmonary bypass after cardiac surgery. The devices described in this article can be viewed on a continuum of increasing hemodynamic support at the cost of more invasive vascular access and increased rate of complications. The development of newer and lower-profile MCS devices, in addition to novel devices that provide support to the right side of the heart, offers the potential to provide greater cardiac and systemic hemodynamic support and thus reduce morbidity and mortality among these HR patient subsets. Such devices may avoid progression to refractory shock, where surgical ventricular support devices may be necessary as a bridge to heart transplantation or permanent implant. Although those end therapies are reasonable options, they are limited by their own complications and survival, and there is growing sentiment that it may be best to avoid them unless no other options are available.

THE DEVICES

Current MCS devices include the intra-aortic balloon pump (IABP), the TandemHeart (left atrium to aorta assist) device (CardiacAssist, Inc.), the Impella (left ventricle to aorta assist) device (Abiomed, Inc.), and extracorporeal membrane oxygenation (ECMO). The initial search for percutaneous MCS led to the development of the IABP in

the 1960s, which still remains the most commonly used form of MCS in clinical practice. The IABP device is predominantly inserted via the femoral artery and consists of a double-lumen, 7.5- to 8-F catheter with a long polyethylene balloon attached at its distal end. The helium-inflated balloon is coupled to the electrocardiogram or pressure triggers to inflate during the onset of diastole and deflate at the onset of LV systole and is attached to a pump console to control the balloon. The IABP results in a modest increase in stroke volume, and as a result, an increase in cardiac output (~0.5–1 L/min), coronary artery perfusion, and diastolic blood pressure, while decreasing afterload and myocardial oxygen consumption. However, for the IABP to be effective, patients must have some degree of LV function and electrical stability, given that an increase in cardiac output with IABP is dependent on the augmented function of cardiac muscle itself.

TandemHeart

Currently, the only commercially available left atrial–aorta assist device is the TandemHeart. The TandemHeart device is inserted into the femoral vein and pumps blood extracorporeally from the left atrium, via a transseptally placed cannula, to the iliofemoral arterial system, therefore bypassing the left ventricle. The device has four main components: a 21-F transseptal cannula, a centrifugal pump, a femoral arterial cannula, and a control console. The size of the arterial perfusion cannula determines the maximal flow provided and can range from 3.5 L/min (15 F) to 5 L/min (19 F). The hemodynamic effects of redirecting blood from the left atrium include a reduction in LV preload and workload, filling pressures, wall stress, and myocardial oxygen demand. Currently, TandemHeart is approved by the US Food and Drug Administration (FDA) to provide extracorporeal circulatory support for up to 6 hours and CE Mark approval for use up to 30 days. It also has FDA approval to add an oxygenator to the circuit, allowing for concomitant LV unloading and oxygenation.

Impella

The Impella family of devices uses a nonpulsatile axial flow pump that propels blood from the left ventricle into the proximal ascending aorta, thereby unloading the left ventricle and increasing forward flow. The Impella MCS devices reduce myocardial oxygen consumption, improve arterial pressure, and reduce pulmonary capillary wedge pressure. These devices are available in three versions: a 12-F Impella 2.5 L device, a 14-F CP device (providing a flow rate of 3–4 L/min), and the 21-F Impella 5.0 L device. The 2.5 L and CP devices are implanted via the femoral artery, and the larger 5.0 L device is implanted via a surgical cutdown through axillary or femoral access. The device consists of a flexible pigtail catheter in the left ventricle that connects to a cannula, containing the pump inlet and outlet areas, motor housing, and pump pressure monitor. The Impella 2.5 provides a greater increase in cardiac output than the IABP, but less than the TandemHeart device, whereas the Impella CP and 5.0 devices are comparable to the TandemHeart device in terms of achieved hemodynamic support. The device has been approved by the FDA to provide up to 6 hours of partial circulatory support and is safe and effective in HR PCI; in Europe, the Impella 2.5 is approved for use of up to 5 days. Due to its direct unloading of the left ventricle, as opposed to indirect (left atrial) unloading of the TandemHeart, there is a theoretic advantage favoring the Impella due to constant unloading of the left ventricle even during the isovolumetric phases of the cardiac cycle, which should result in a slightly greater reduction in myocardial oxygen demand at similar flow rates. Recently, an RV Impella device, which is inserted via the femoral vein, was approved under an FDA investigational device exemption. This RV device could be used for RV myocardial infarction with cardiogenic shock, right-sided failure (eg, after open heart surgery or transplantation), or as part of a biventricular support strategy.

ECMO

ECMO provides a cardiopulmonary support strategy for patients requiring oxygenation and full circulatory support and can provide either venovenous support for oxygenation only (eg, in acute respiratory distress syndrome or pulmonary embolism) or venoarterial for both oxygenation and circulatory support. The venoarterial ECMO circuit is similar to a cardiopulmonary bypass circuit and is made up of a centrifugal, nonpulsatile pump for blood propulsion and a membrane oxygenator for gas exchange. The venous and arterial cannulae can vary in size but typically will be similar to the TandemHeart cannulae (20 F venous, 17 F arterial). Venoarterial ECMO can provide full circulatory support with flows sometimes > 6 L/min, depending on the cannula size. In some cases, venoarterial ECMO alone may not sufficiently reduce ventricular wall stress without the left ventricle being unloaded by concomitant IABP or Impella use. Although a point of controversy, many physicians opt to use concomitant LV unloading in cases of ECMO support to optimally reduce the myocardial oxygen demand. Oftentimes, ECMO is a form of escalating support after Impella or IABP use, and in this manner, the left ventricle is unloaded, and the two devices should remain in place during complete support.

TABLE 1. SUGGESTED INDICATIONS FOR PERCUTANEOUS MCS	
Indication	**Comments**
Complications of acute myocardial infarction	Ischemic mitral regurgitation
	Acutely depressed LV function
	Cardiogenic shock from RV infarction
	Ventricular septal defect
Severe heart failure in the setting of nonischemic cardiomyopathy	Acute decompensated heart failure
	Fulminant myocarditis
	Stress cardiomyopathy
	Peripartum cardiomyopathy
	INTERMACS profiles 1 or 2
	Bridge to destination ventricular assist device placement
	Bridge to recovery
Acute cardiac allograft failure	Primary allograft failure (adult or pediatric)
	Prolonged ischemic time
Posttransplant RV failure	Acute RV failure from recipient pulmonary hypertension, intraoperative injury/ischemia, and excess volume/blood product resuscitation
Patients slow to wean from cardiopulmonary bypass	Pulmonary hypertension
	Reduced cardiac output
Refractory arrhythmias	ECMO or biventricular support needed to tolerate refractory arrhythmias
	MCS devices unload the heart and reduce arrhythmia burden
Prophylactic use for HR PCI	Patients with severe LV dysfunction (ejection fraction < 20%–30%) and complex coronary artery disease involving a large territory
	Impella is FDA approved for this indication
HR or complex ablation of ventricular tachycardia	MCS use allows the patient to remain in ventricular tachycardia longer during arrhythmia mapping
HR percutaneous valve interventions	MCS devices provide stability for a more effective, high-quality procedure

INDICATIONS FOR PERCUTANEOUS MCS

Indications for MCS use in clinical practice include subsets of acute myocardial infarction, cardiogenic shock, and advanced decompensated heart failure, as well as HR PCI (Table 1).

Acute Myocardial Infarction

Data supporting the routine use of MCS devices in patients presenting with myocardial infarction without shock are lacking, and a meta-analysis of IABP use in acute myocardial infarction found no benefit and potential harm from a higher risk of stroke. The CRISP AMI (Counterpulsation to Reduce Infarct Size Pre-PCI Acute Myocardial Infarction) randomized controlled trial investigated whether routine IABP placement immediately before reperfusion reduced myocardial infarct size in patients presenting with an anterior ST-elevation myocardial infarction (STEMI).[2] The trial demonstrated no significant reduction in infarct size as assessed by cardiac MRI 3 to 5 days after PCI, and no significant difference in survival was observed at 6-month follow-up between groups. Therefore, currently there are insufficient data to support routine use of IABP as an adjunct to primary revascularization in the setting of large acute myocardial infarction. Whether the more powerful line of MCS can offer routine

benefit in uncomplicated acute myocardial infarction remains unknown.

Cardiogenic Shock and Advanced Heart Failure

Cardiogenic shock is associated with high morbidity and mortality in roughly 50% of patients due to profound hemodynamic compromise that results from decreased cardiac output and tissue hypoperfusion. The goal of utilizing MCS devices in cardiogenic shock is to stabilize critically ill patients and to bridge them to myocardial recovery or as a bridge for long-term destination therapy, such as a surgical LV assist device or cardiac transplantation. Early retrospective studies suggested a potential benefit of IABP placement, such as lower peak creatine kinase levels, lower major adverse cardiac events, and even lower mortality in those with acute myocardial infarction and cardiogenic shock. In the landmark IABP-SHOCK II trial, however, approximately 600 patients with cardiogenic shock complicating acute myocardial infarction (expected to undergo early revascularization and to receive optimal medical therapy) were randomized to IABP or no IABP counterpulsation.[3] At 30 days, there were no significant differences in mortality (39.7% vs 41.3%; $P = .69$) and no significant differences in secondary endpoints or in process-of-care measures, including the time to hemodynamic stabilization, the length of stay in the intensive care unit, serum lactate levels, the dose and duration of catecholamine therapy, and renal function.

The Impella-EUROSHOCK registry evaluated the safety and efficacy of the Impella 2.5 L device in 120 patients with cardiogenic shock after acute myocardial infarction.[4] Use of the Impella device resulted in a reduction of lactate levels at 48 hours, suggesting improved organ perfusion, with high (64%) mortality at 30 days in this patient population. In the small ISAR-SHOCK randomized trial comparing the Impella 2.5 L with the IABP in 26 cardiogenic shock patients, use of the Impella device resulted in a greater increase in cardiac index, while having similarly high (46%) 30-day mortality in both groups.[5] In the USpella registry of 154 PCI patients, early initiation of hemodynamic support prior to PCI with the Impella 2.5 was associated with more complete revascularization and improved survival in the setting of refractory shock complicating a myocardial infarction.[6] Currently, there are no studies available on the Impella CP device, which has mostly replaced the 2.5 L device in treating cardiogenic shock. Two small randomized trials that compared the TandemHeart to IABP in cardiogenic shock have been published, suggesting a greater increase in cardiac index and decrease in pulmonary capillary wedge pressure but no difference in

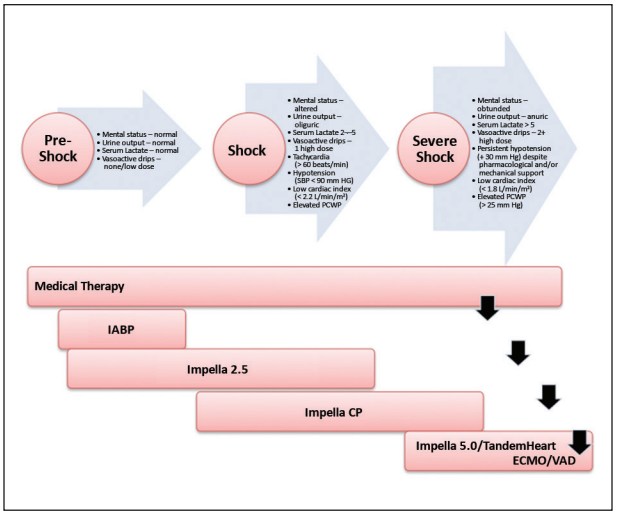

Figure 1. Suggested selection and escalation of MCS devices in cardiogenic shock based on severity of shock.

30-day mortality. Multiple case reports, case series, or case-control studies have suggested a potential benefit of ECMO in patients with cardiogenic shock or cardiac arrest, but the weight of evidence thus far is meager.

In our opinion, IABP or the Impella 2.5 L can be considered in patients with borderline hemodynamic parameters, particularly when PCI is likely to exacerbate ischemia (Figure 1). In patients with profound cardiogenic shock, early initiation of more powerful MCS devices (Impella CP or TandemHeart) before PCI is strongly recommended, particularly if fluid resuscitation and pharmacologic support do not result in rapid hemodynamic improvement. In this setting, the Impella CP is often chosen due to the desire to avoid transseptal puncture, which adds time and risk in a complicated, tenuous patient. For patients who continue to deteriorate despite Impella CP or TandemHeart, ECMO or surgical cutdown for delivery of an Impella 5.0 should be considered, and in these patients, an Impella or IABP should be left in place to unload the left ventricle and protect the heart. Patients with biventricular failure may benefit from early support with ECMO or a combined right and LV Impella device. Patients in persistent shock may remain on percutaneous support until their hemodynamic status improves, sometimes for days or even weeks.

High-Risk PCI

The term *HR PCI* refers to PCI in those with patient-specific, lesion-specific, or clinical presentation–specific features, where aspects of coronary manipulation may result in transient or permanent impairment of myocardial perfusion that cannot be tolerated by the patient

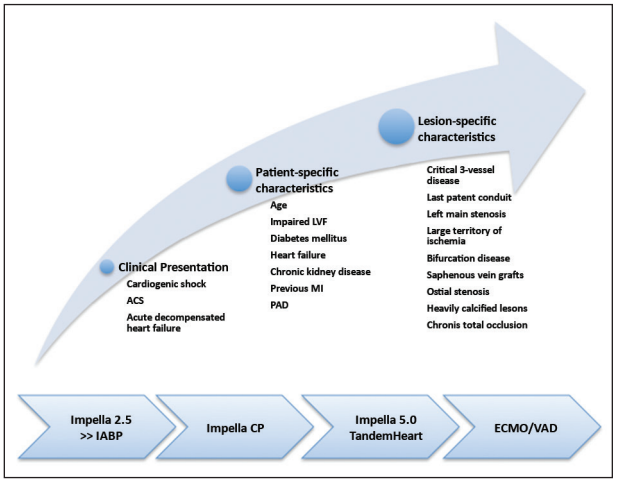

Figure 2. Suggested use and choice of MCS devices based on clinical presentation and patient- and lesion-specific characteristics.

without developing worsening hemodynamics, shock, or death. Patient-specific variables include increased age, impaired LV function, heart failure, diabetes mellitus, chronic kidney disease, previous myocardial infarction, and peripheral artery disease. Lesion-specific variables include left main stenosis, complex bifurcation disease, saphenous vein grafts, ostial stenoses, heavily calcified lesions, chronic total occlusions, and lesions that supply a large territory of ischemia. Clinical presentations include acute coronary syndrome, particularly myocardial infarction, or cardiogenic shock (Figure 2).

In a large analysis from the NCDR database, IABP was used in approximately 10% of HR PCI and was not associated with lower mortality. In the UK randomized clinical trial of 301 patients, BCIS-1, routine IABP use in HR PCI failed to improve mortality, but reduced periprocedural hypotension.[7] The PROTECT 2 trial was the largest randomized clinical trial of HR PCI using MCS devices. Four hundred fifty-two symptomatic patients with complex three-vessel disease or unprotected left main and severely decreased LV function were randomized to IABP or the Impella 2.5 device.[8] The primary endpoint was a composite of 11 adverse events at 30 days and was not significantly different between the groups (Impella, 35.1% vs IABP, 40.1%), with greater differences in the per-protocol population (Impella, 34.3% vs IABP, 42.2%; $P = .09$). At 90 days, a trend toward decreased events was observed in the intent-to-treat population (Impella, 40.6% vs IABP, 49.3%; $P = .07$), with greater and significant differences in the per-protocol population (Impella, 40% vs IABP, 51%; $P = .02$). This late benefit may have been the result of more stable procedural hemodynamics, an ability to perform more complex PCI (eg, rotational atherectomy), and more complete revascularization with the Impella device. In addition, subsequent analyses showed the impact of a learning curve associated with the introduction of the new Impella device and improvement in outcomes in later stages of the trial.[9] No randomized trials comparing the TandemHeart device exist, while single-center retrospective studies have reported on feasibility and safety of this device in HR PCI with improvement in procedural hemodynamics during support. However, as in cardiogenic shock, many institutions prefer to utilize the less-invasive Impella device, given the associated randomized controlled trial data and ease of use. In addition, the FDA has recently approved an indication for the Impella 2.5 device as safe and effective in the setting of HR PCI, making it the only device approved for this setting.

Emerging Indications

Given the large number of patients undergoing coronary, electrophysiologic, and valve procedures, new applications of MCS are continuously evolving and may include patients undergoing percutaneous aortic valvuloplasty or aortic valve replacement, patients with LV dysfunction undergoing prolonged electrophysiologic procedures (eg, complex ventricular tachycardia ablation), and patients with RV failure, particularly in the setting of myocardial infarction, heart failure, or cardiogenic shock. A dedicated Impella device for RV support is now approved as part of an investigational device exemption. The RECOVER RIGHT study will examine the feasibility, safety, hemodynamic, and clinical improvements of this device in patients with RV failure refractory to medical treatment, such as RV failure after LV assist device implantation, cardiotomy, or myocardial infarction. In the meantime, however, it is likely that this device will be used in the setting of acute inferior myocardial infarction with RV involvement, after open heart surgery RV failure, such as in patients with severe pulmonary hypertension, and other forms of profound RV failure. Algorithms to determine optimal clinical use for this device will be needed.

THE GUIDELINES AND CONSENSUS OPINION

Despite limited evidence of clinical benefit, IABP has received a class IIa indication for use during STEMI complicated by cardiogenic shock in the 2013 ACCF/AHA guideline statement on STEMI management.[10] Those guidelines gave a class IIb indication for alternative LV assist devices for circulatory support in patients with refractory cardiogenic shock. In the recent large

NCDR registry study of patients undergoing PCI in the setting of cardiogenic shock between 2009 and 2013, MCS devices were being used in approximately 50% of patients, with the majority of patients still receiving IABP.[11] Importantly, since the publication of the IABP-SHOCK II trial, the use of IABP in cardiogenic shock has been slowly declining,[11] whereas the use of other MCS has been rapidly increasing.[12] The 2011 ACC/AHA/SCAI guideline for PCI recommends consideration of percutaneous MCS in two clinical settings: (1) as an adjunct to HR PCI (class IIb) and (2) for cardiogenic shock in patients presenting with STEMI (class Ib). More recently, a 2015 SCAI/ACC/HFSA/STS clinical expert consensus statement on the use of percutaneous MCS devices in cardiovascular care has been published, incorporating data from recent trials.[1] Earlier placement of MCS devices in cardiogenic shock is now recommended. In patients with profound cardiogenic shock, Impella 2.5, Impella CP, or TandemHeart are seen to be of greater benefit compared with IABP and should be the first option. Furthermore, when oxygenation is impaired, adding an oxygenator to a TandemHeart circuit or using ECMO should be considered, with the latter being more widely available and utilized in clinical practice. The consensus statement guides clinicians to consider MCS in HR PCI, particularly in patients undergoing multivessel, left main PCI or last patent conduit PCI in the setting of decreased LV function or elevated filling pressures. The Impella is suggested in this setting based on the weight of data from randomized trials and its FDA approval specifically for this indication.

For cardiogenic shock and severe heart failure, device selection is determined by the severity of presentation, degree of shock (eg, mental status, urine output, serum lactate, number of vasoactive drugs), complexity of coronary anatomy, ischemic time, likelihood of hemodynamic compromise during PCI, technical operator/institutional expertise, and ease of device insertion and monitoring (Figure 2). A heart team model using multidisciplinary teams that include interventional cardiologists, cardiothoracic surgeons, and heart failure specialists should be encouraged, similarly to the heart team approach for transcatheter aortic valve replacement patients. Cath lab drills may be helpful to prepare the team for the rapid insertion of MCS devices in critical situations. Clinicians need to weigh the risks of these devices (eg, more invasive vascular access) and balance them against potential and proven benefits of MCS, especially for the most powerful devices and for the sickest patients. Given insufficient randomized data comparing different MCS strategies in complex clinical scenarios, further randomized controlled trials and registries are still needed to help clinicians make decisions in gravely ill patient populations. However, due to clinical experience and device availability, it is likely that Impella devices and ECMO will continue to emerge as the preferred strategies in most patients. ■

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