The Role of Mechanical Circulatory Support Devices in Pulmonary Embolism

A Comprehensive Review

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KEYWORDS

• Pulmonary embolism • Right ventricular failure • TandemHeart • ProtekDuo • VA-ECMO • ECMO • Catheter-directed therapy • Cardiogenic shock

KEY POINTS

- High-risk pulmonary embolism causes acute right ventricular failure and shock; mechanical circulatory support stabilizes hemodynamics by unloading the right ventricle and maintaining systemic perfusion.
- Percutaneous mechanical circulatory support includes Impella RP, ProtekDuo-based RVADs, and VA-ECMO, selected according to severity of shock, hypoxemia, ventricular involvement, and institutional expertise.
- Mechanical circulatory support is primarily used as a bridge to definitive therapy, enabling safer anticoagulation, catheter-directed thrombectomy or thrombolysis, surgical embolectomy, or myocardial recovery.
- Observational data suggest improved survival when mechanical support is initiated early, particularly before cardiac arrest, though randomized trials are lacking and evidence remains heterogeneous.
- Successful outcomes require multidisciplinary PE response teams, meticulous access planning, vigilant complication monitoring, and tailored weaning strategies based on hemodynamic recovery and right ventricular function.

INTRODUCTION

Pulmonary embolism (PE) represents a significant global health burden, ranking as the third leading cause of cardiovascular death after myocardial infarction and stroke. While low-risk PE carries an excellent prognosis with anticoagulation alone, high-risk PE (characterized by sustained hypotension, pulselessness, or profound bradycardia) and intermediate high-risk PE (characterized by right ventricular [RV] dysfunction and myocardial injury with elevated biomarkers in normotensive patients) present formidable challenges. Mortality rates for high-risk PE can exceed 50%, primarily driven by acute RV failure leading to cardiogenic shock and cardiac arrest. Traditional therapies—including systemic thrombolysis, surgical embolectomy, and, increasingly, catheter-directed therapies (CDT)—aim to reduce the thrombus

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Abbreviations	
ACT	activated clotting time
CDT	catheter-directed therapies
CO	cardiac output
CT	computed tomography
DPC	distal perfusion cannula
ECPR	extracorporeal cardiopulmonary resuscitation
LV	left ventricular
MCS	mechanical circulatory support
PA	pulmonary artery
PE	pulmonary embolism
PVR	pulmonary vascular resistance
RA	right atrium
RIJ	right internal jugular vein
RV	right ventricular
RVAD	RV assist devices
VA-ECMO	venoarterial extracorporeal membrane oxygenation

burden rapidly. However, systemic thrombolysis carries a significant risk (approximately 10%) of major bleeding, including a 1% to 3% risk of intracranial hemorrhage, limiting its use in many patients. Surgical embolectomy requires specialized expertise and cardiopulmonary bypass, and CDT, while effective, may not provide immediate hemodynamic stabilization in patients with refractory shock or those with cardiac arrest.

This therapeutic gap has fueled the growing utilization of percutaneous mechanical circulatory support (MCS) devices. These devices are not primarily thrombus-removing tools but are designed to support the failing circulation by unloading the RV and maintaining systemic perfusion. They provide critical hemodynamic stability, buying time for recovery, allowing institution of anticoagulation, facilitating safer delivery of thrombolytics (systemic or catheter-directed), or bridging patients to surgical embolectomy or other definitive interventions. This review aims to synthesize the most up-to-date information on the role of MCS devices in the management of acute PE, focusing on practical aspects for the interventional cardiologist, including device selection, implantation techniques, management strategies, complication avoidance, and integration within a comprehensive treatment algorithm.

RISK STRATIFICATION OF PULMONARY EMBOLISM

Multiple aspects need to be considered to appropriately risk-stratify a patient presenting with PE. As per the European Society of Cardiology guidelines, risk stratification depends on hemodynamic stability and the presence of right ventricular dysfunction by laboratory biomarkers (troponin, brain natriuretic peptide) or by imaging (transthoracic echo or computed tomography (CT)). CT findings of RV dysfunction include an abnormal right ventricle to left ventricle ratio of greater than 0.9. Echocardiogram evidence of right ventricular dysfunction includes quantitative assessment using parameters such as tricuspid annular plane systolic excursion and fractional area shortening. The 3 major categories into which patients are classified are low-risk, intermediate-risk, and high-risk PE. Low-risk PE patients are hemodynamically stable individuals without evidence of right ventricular dysfunction, as indicated by laboratory markers and imaging. Patients who are hemodynamically unstable, or require pressors to keep their blood pressures within normal range, and have evidence of right ventricular dysfunction are patients with high-risk PE.[1] In previous guidelines, these patients were defined as having massive PE.[2] Intermediate-risk PE patients are hemodynamically stable patients who can be further classified into subcategories: intermediate-low and intermediate-high risk. Intermediate low-risk patients are those with evidence of right ventricular dysfunction, as indicated by either laboratory markers or imaging evidence of right ventricular dysfunction. Intermediate high-risk PE patients have evidence of right ventricular dysfunction by elevated laboratory markers and by imaging.[1]

All patients without contraindication should be started on therapeutic anticoagulation. Patients with low risk and low intermediate risk can be managed conservatively with anticoagulation.

Multiple guidelines have recommended systemic thrombolysis as a method of reperfusion. In patients with a contraindication for thrombolysis, surgical embolectomy is the alternative in centers that have the expertise.[3] Patients with intermediate-high risk PE have a higher rate of adverse outcomes, such as hemodynamic decompensation and short-term mortality. However, this patient population is heterogeneous, and identifying the one-third of patients that are at a higher risk of deterioration despite being normotensive is crucial.[4] These patients were found to have normotensive shock, which is defined as patients who have a cardiac index of less than 2.2 mL/min/m2 despite being

normotensive. With use of risk stratification scores such as composite shock scores, laboratory markers such as lactate, along with echocardiographic parameters like left ventricular outflow tract and right ventricular outflow tract velocity time integral, these patients can be identified noninvasively.[4,5] There is a wide variety in practice patterns in the management of this group of patients. Guidelines recommend catheter-based therapies (catheter-directed lysis or catheter-based thrombectomy) for high-risk PE patients who have a contraindication to systemic fibrinolytics and for patients with intermediate-to high-risk PE who have evidence of normotensive shock. Catheter-based therapies get a lower recommendation in the guidelines, given the absence of high-quality data when compared with standard therapy.

PATHOPHYSIOLOGY OF RIGHT VENTRICULAR FAILURE IN PULMONARY EMBOLISM AND THE RATIONALE FOR MECHANICAL CIRCULATORY SUPPORT

Understanding the hemodynamic consequences of high-risk PE is paramount to appreciating the role of MCS (Fig. 1).

Acute pulmonary artery obstruction with a large pulmonary embolus abruptly increases pulmonary vascular resistance (PVR), causing acute pulmonary hypertension, which leads to RV strain and failure. The thin-walled RV is unable to adapt to handle the sudden increase in afterload and dilates acutely. The right ventricle is unable to generate sufficient pressure to overcome the increased PVR, leading to an afterload mismatch.[1]

RV dilation causes a leftward septal shift, impairing left ventricular (LV) filling and thereby reducing preload and compliance, which leads to a decrease in LV stroke volume and cardiac output (CO).

Systemic hypotension coupled with an elevated RV end-diastolic pressure reduces the right coronary artery perfusion gradient, potentially causing RV ischemia, further exacerbating RV dysfunction in a vicious cycle.[6]

The reduced LV preload leads to systemic hypotension, hypoperfusion, and end-organ dysfunction, a constellation of which is called obstructive shock. Laboratory markers of myocardial injury (troponin) rise due to RV ischemia. Ultimately, this cascade can lead to cardiac arrest, often presenting as pulseless electrical activity.[1]

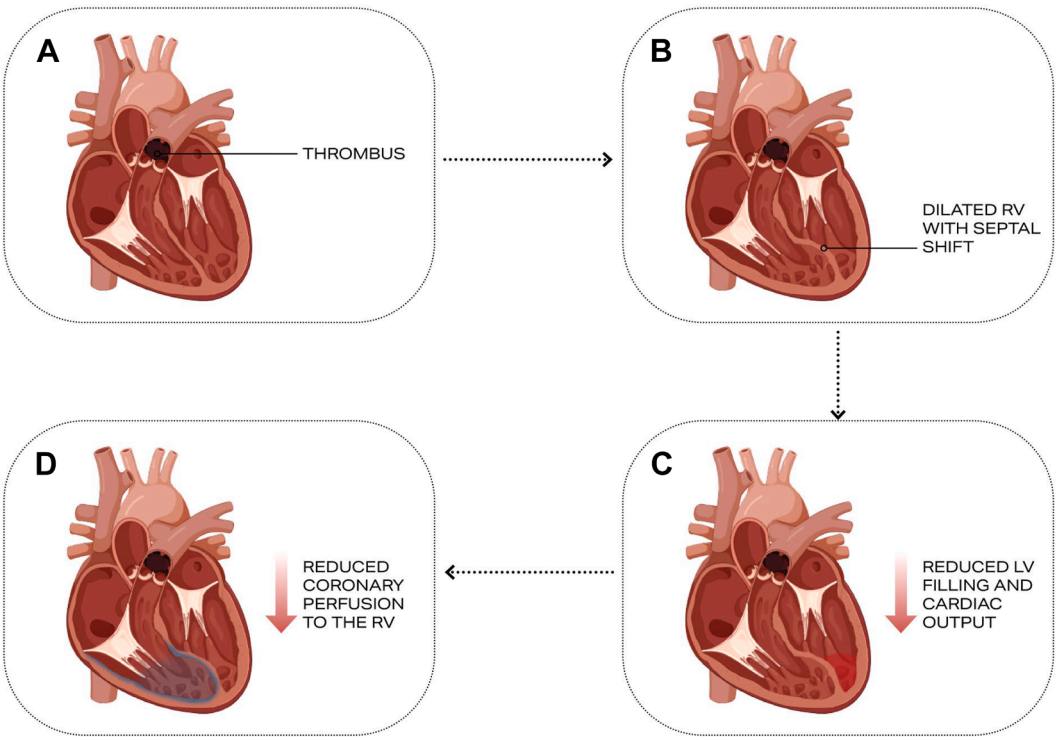

Fig. 1. Pathophysiology of acute PE and RV failure. (*A*) Large thrombus obstructing pulmonary arteries. (*B*) Dilated, hypokinetic RV with septal shift compressing the LV. (*C*) Reduced LV filling and CO. (*D*) Reduced coronary perfusion pressure to the RV. Arrows indicate pathophysiological flow and pressure consequences.

Rationale for Mechanical Circulatory Support

MCS devices interrupt the aforementioned pathophysiologic cascade in multiple ways:

Unloading the right ventricular

Reducing RV preload and decreasing wall stress may improve coronary perfusion pressure and potentially allow for recovery of RV contractility. Furthermore, reversing RV ischemia can lead to improved LV filling and improved stroke volume.

Maintain systemic perfusion

Providing adequate CO and blood pressure to perfuse vital organs and prevent multiorgan failure.

Bridge to therapy

Creating a window of opportunity for adjunctive therapies (anticoagulation, CDT, systemic thrombolysis, surgical embolectomy) to address the thrombus burden more safely and effectively.

OVERVIEW OF PERCUTANEOUS MECHANICAL CIRCULATORY SUPPORT DEVICES FOR PULMONARY EMBOLISM

The mechanical support devices for the right ventricle have evolved over the years. From surgically implanted pumps, such as the PA balloon counterpulsation pump, to rotary flow RV assist devices (RVAD) in the 1990s, to second and third generation surgical pumps used as RVADs, RV support devices have improved in the hemodynamic support they provide.[7]

Percutaneously placed devices offer a means for RV support without requiring surgical procedures. The ideal percutaneous MCS device for PE specifically addresses RV failure (Table 1). The 3 primary platforms are (Fig. 2).

Right Ventricular-specific Microaxial Pumps: Impella Right Pump (RP) and RP Flex (Abiomed)

Mechanism

A catheter-mounted microaxial pump is placed across the tricuspid and pulmonary valves. Blood is drawn from the right atrium (RA)/RV and expelled into the main pulmonary artery (PA), directly unloading the RV and increasing PA flow. It provides partial RV support (typically 3.5–4.0 L/min for RP, up to 4.5 L/min for RP Flex).

Insertion

Percutaneous via femoral vein (typically right, 22Fr sheath for RP, 23Fr sheath for RP Flex). It requires fluoroscopic and often echocardiographic guidance. The RP Flex uses a novel dual-bend catheter design and a precurved introducer sheath (FlexSheath) for potentially easier navigation and improved stability via right internal jugular vein (RIJ).

Key features

It requires a single vascular access site and provides direct RV to PA support. The inflow position of the cannula is in the inferior vena cava, and the outflow catheter resides in the PA.[8] It is relatively easy to position and requires systemic anticoagulation with an ACT (activated clotting time) of more than 160 to 180 seconds. It is Food and Drug Administration (FDA)-approved for up to a limited duration of 14 days, but it is often used for shorter-term use in PE. RP Flex offers improved positioning flexibility and flow potential.

Limitations

A prerequisite to the placement of the Impella RP is an unobstructed path between the femoral veins or juglar veins and the main PA. As flow is dependent on pulmonary afterload, an increased PVR can impede forward flow. Finally, it does not support gas exchange due to the absence of an oxygenator.[9]

Centrifugal Pumps with Dedicated Right Ventricular Cannula: ProtekDuo + TandemHeart (LivaNova/TandemLife) or CentriMag (Abbott)

Mechanism

A dual-lumen cannula (ProtekDuo: 29Fr or 31Fr OD) is inserted via the RIJ or less commonly, subclavian vein. The distal tip sits in the main PA. Blood is withdrawn from the RA via the proximal lumen and returned to the main PA via the distal lumen via an external centrifugal pump (TandemHeart or CentriMag). This provides a means to directly bypass the RV by providing flow from the RA to the pulmonary artery, effectively unloading the failing RV. It can provide high flows (up to 4.5–5.0 L/min). The TandemHeart pump is console-based. CentriMag uses a magnetically levitating centrifugal pump.

Insertion

It is placed percutaneously via RIJ vein (preferred) using Seldinger technique under ultrasound and fluoroscopy. It requires surgical cutdown or percutaneous closure for larger cannulas and requires systemic anticoagulation with an ACT of more than 180 to 200 seconds.

Key features

The single dual-lumen cannula simplifies the circuit and can provide high flows up to 4.5 to 5 L/min. The ability to place it via the RIJ frees the femoral vessels for other procedures such

Table 1
Comparison of key percutaneous mechanical circulatory support devices for pulmonary embolism

Type of Device	Impella RP/RP Flex	ProtekDuo + TandemHeart/ CentriMag	Venoarterial Extracorporeal Membrane Oxygenation
Mechanism	Microaxial RV-PA pump	Centrifugal RA-PA pump	Centrifugal Veno-Arterial pump + Oxygenator
Access	Femoral Vein/IJV (22–23Fr)	RIJ Vein (29/31Fr)	Fem Vein (19–25Fr) + Fem Art (15–19Fr) + DPC
Primary support	RV Unloading	RV unloading (RA-PA Bypass)	Biventricular + Respiratory
Flow (typical)	3.5–4.5 L/min	4.0–5.0 L/min	4.0–6.0 L/min
Oxygenation	No	Optional (add oxygenator)	Yes (integrated)
LV afterload	Neutral	Neutral	Significantly increased
Key advantages	Single access; easy mobility; direct RV-PA support	Single cannula; high flow; access via jugular. The femoral sites are free; ambulation possible (tandem); longer support	Full cardiopulmonary support; gold standard for arrest/ severe hypoxia; wide availability
Key disadvantages	Lower max flow; limited duration; femoral access only	Larger jugular cannula; requires cutdown/ closure; complex setup	Dual large-bore access; high bleeding/limb risk; LV distension; complex management;
Ideal patient	Isolated RV failure; Bridge to recovery/ CDT	Isolated RV failure needing higher flow/ longer support; Femoral access needed	Cardiac arrest; severe hypoxemia; biventricular failure; ongoing CPR

Abbreviations: CDT, catheter-directed thrombolysis; CPR, cardiopulmonary resuscitation.

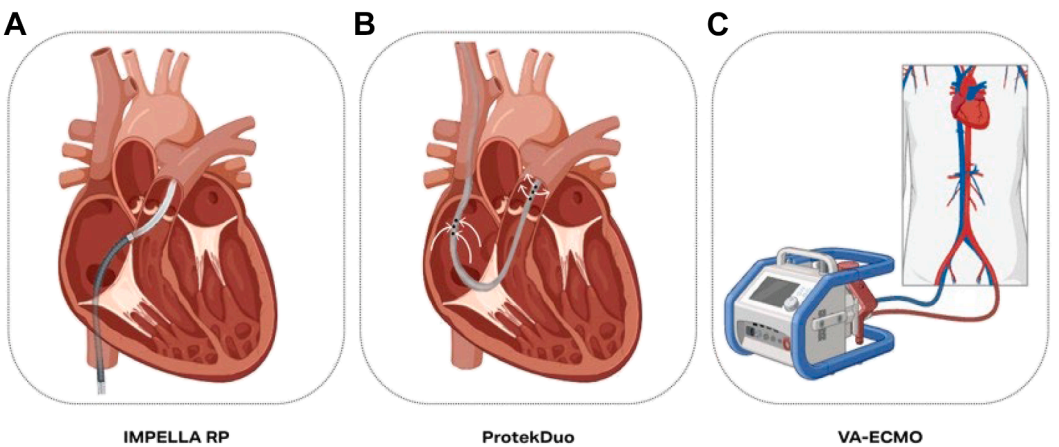

Fig. 2. Schematic of percutaneous MCS devices for PE. (*A*) Impella RP in RV outflow tract pumping to the pulmonary artery (PA). (*B*) ProtekDuo cannula in RIJ with tip in PA (*arrows* indicate right atrial drainage amd PA return). (*C*) VA-ECMO: Femoral vein drainage to pump/oxygenator, femoral artery return with distal perfusion cannula.

as CDT, diagnostics, among others. It also allows for potential ambulation (with TandemHeart Freedom Driver) while receiving mechanical support. It can be used for a longer duration, if needed, and an oxygenator can also be added in-line if needed (creating ProtekDuo oxy-RVAD).[10–12] CentriMag requires surgical placement and can be used for up to 30 days for support.[13]

Venoarterial Extracorporeal Membrane Oxygenation

Mechanism

Venoarterial extracorporeal membrane oxygenation (VA-ECMO) drains blood from the venous system (usually RA via the femoral vein) and pumps it through an oxygenator and heat exchanger before returning it to the arterial system (usually femoral artery). It provides complete cardiopulmonary support by (1) oxygenating blood, (2) removing CO2, and (3) providing biventricular support by indirectly unloading the RA/RV (reducing preload) and directly supporting systemic circulation (increasing afterload on the LV). It can provide flows of 4 to 6 L/min.

Insertion

It can be placed percutaneously (common) or surgically. It requires a venous drainage cannula (19–25 Fr) and an arterial return cannula (15–19 Fr), which are usually placed in the femoral vein and artery respectively. Additionally, a distal perfusion cannula (DPC) is essential to preventing limb ischemia. Apart from the cannulas, it requires a dedicated console, an oxygenator, and a perfusionist. Systemic anticoagulation with an ACT of 160 to 200 seconds is required for appropriate functioning of the device.

Key features

It provides complete cardiopulmonary support (circulatory flow and oxygenation). By unloading the RA and RV, it decreases RA, PA pressures, and LV preload. It increases the LV afterload by returning blood to the systemic circulation. With a preserved LV function, the CO remains unchanged or decreases slightly in comparison to someone with an impaired LV function, where in the increased afterload reduces the CO, leading to pulmonary congestion.[7] It requires meticulous management of oxygenation, ventilation, and LV distension. It is beneficial for patients with concomitant severe hypoxemia, cardiac arrest, or biventricular failure. VA-ECMO is associated with a higher risk of bleeding, limb ischemia, and neurologic complications as compared with isolated RVADs.

EVIDENCE REVIEW: CLINICAL OUTCOMES WITH MECHANICAL CIRCULATORY SUPPORT IN PULMONARY EMBOLISM

The mortality associated with high-risk PE remains high and approaches 30%.[14] There are no randomized controlled trials that have evaluated the use of MCS in comparison to other standard therapies in patients with PE. The evidence is currently limited to observational data that come from retrospective studies, registry-based data, case series and systematic reviews. The data need to be cautiously interpreted due to selection bias, heterogeneity in patient populations, the different devices used, other concomitant therapies that were used, and center and physician expertise.

Studies report survival rates ranging from 60% to 85% in patients receiving MCS (across device types) for massive PE or refractory shock, significantly better than expected historical controls. Survival is highest when MCS is initiated before cardiac arrest.

Right Ventricular Assist Devices

One of the most reported uses of RVAD was to support the RV when patients are unable to be weaned off cardiopulmonary bypass after surgical embolectomy. If patients became hypoxic, an additional oxygenator could also be added for additional support. The RVAD supports the RV by reducing preload and by providing continuous pulmonary flow.[15]

A systematic review of reports evaluated outcomes in patients with high-risk PE who underwent RVAD placement as compared to VA-ECMO. This review included 17 patients with RVAD, 164 patients with VA-ECMO. They found that all the patients with an RVAD were successful weaned off the device after an average of 3.9 ± 1.9 days and 94% of the patients were eventually discharged.[16] The RVADs included Tandem Heart and CentriMag among other. There were 8 patients with an Impella after mean duration of 3.4 ± 0.8 days. All the 8 patients were successfully weaned and survived till hospital discharge.

A single center study evaluated use of Protek Duo Oxy-RVAD in patients with cardiogenic shock and PE. They noted that all 4 patients were successfully weaned off after a mean duration of 8 ± 2.9 days. There was one patient that died due to hospital acquired pneumonia and not due to a device related complication.

RECOVER RIGHT was a prospective study that noted Impella RP to be a safe and effective percutaneous device in reversing hemodynamic

instability in isolated right ventricular failure.[17] Successful use of Impella RP in patients was later shown in a case series of 2 patients. In both these patients, hemodynamics dramatically improved after placement of Impella after which the patients were successfully weaned off.[8] Another case series from the Detroit Medical Center showed successful improvement in cardiac index in 5 patients with PE and cardiogenic shock.[18]

Venoarterial Extra Corporeal Membrane Oxygenation

VA-ECMO remains the most commonly used MCS in patients with high-risk PE. In comparison to the RVADs, ECMO unloads the RV by bypassing it indirectly. In high-risk PE, ECMO is often used a bridge to reperfusion therapies or for stabilization after use of an advanced therapy. It is rarely used as an isolated treatment modality.

There has been an uptrend in the use of VA-ECMO in management of high-risk PE. Multiple registry-based studies and systematic reviews have evaluated the role of ECMO in high-risk PE. A systematic review by Boey el at included 39 observational studies with a mortality of ~43%. Mortality was lower (29%) when ECMO was combined with CDT as compared to when it was combined with systemic lysis (57%). Outcomes were also noted to be worse if there was presence of a cardiac arrest before initiation of ECMO.[19] Prognosis was noted to be worse in patients with a cardiac arrest and with markers of poor perfusion, such as an elevated lactate.[20] This highlights the importance of early initiation of ECMO before end organ damage.

While some studies have reported a potential benefit of extracorporeal cardiopulmonary resuscitation (ECPR) in patients with PE, these studies continue to have a high mortality despite use of VA-ECMO. A study in Netherlands evaluated efficacy of ECPR in patients with PE. Among 39 patients, 19 underwent ECPR and these patients had higher survival rates (26% vs 5%) in comparison to conventional CPR. These patients also had better neurologic recovery rates (21% vs 0%).[21] In a post hoc analysis of multicenter cohort study, that evaluated patients that underwent ECPR, looked at 78 patients that underwent ECPR for massive PE. They found that approximately 18% had a favorable neurologic outcome and also reported a high hospital mortality of 60%.[22] Post ECPR patients were also reported to have complications such as bleeding, renal failure requiring dialysis and heparin induced thrombocytopenia.[23] The high mortality rates across these studies points to the severity of critical illness in these patients and some of the mortality may also be related the complications that originate from VA-ECMO placement and end organ damage from cardiac arrest.

INDICATIONS FOR MECHANICAL CIRCULATORY SUPPORT IN PULMONARY EMBOLISM

Formal guideline recommendations specifically for MCS in PE are evolving, reflecting the rapid technological advancements and growing but still predominantly rely on observational evidence. Current guidance is often inferred or based on expert consensus within broader recommendations for high-risk PE management.

The European Society of Cardiology (2019) guidelines recommend the use of mechanical support devices, specifically VA-ECMO (class IIb, level C) in patients with high risk PE, hemodynamic collapse and/or cardiac arrest. They mention the use of VA-ECMO in addition to other therapies as opposed to use as a definitive modality of treatment. They acknowledge the use of Impella RP for hemodynamic support in high risk PE patients based on a couple of case reports but do not make a recommendation.[1] Consensus Statement from the PE response team (PERT) Consortium recognizes use of both ECMO and right ventricular assist devices in patients with cardiac arrest, refractory shock and with contraindications to or failure of systemic lysis. They strongly advocate utilization of PE response teams in patients with intermediate and high-risk PEs.[24] The Chest guidelines (2016 and 2021) recommend systemic lysis for patients with high risk PE and do not comment on mechanical circulatory support.[25,26] Scientific statement from AHA states that systemic thrombolysis is reasonable in patients with high risk PE (Class IIa, LOE B) without a specific mention of mechanical circulatory support.[2] Another AHA Scientific Statement acknowledges the use of VA-ECMO in patients with RV failure as a bridge to recovery or other treatment modalities.[27]

Patient Selection

When the acute increase in RV afterload impairs RV contractility, it decreases LV preload and ultimately leads to a decreased CO and circulatory collapse. Identifying these patients early and implementing early use of MCS should be considered, before there is irreversible end-organ damage or cardiac arrest. As previously noted, the presence of a cardiac arrest or with worsening markers of poor perfusion, worsens

the prognosis. Most of the data supporting the use of MCS are limited to observational evidence and with the majority of the data being about use of VA-ECMO. There are no randomized controlled data evaluating MCS in high risk PE patients. Due to the lack of definitive data, the decision regarding appropriate implementation of MCS should include a multidisciplinary team discussion among the members of a PERT.

The PE patients that are likely to derive the most benefit from early use of mechanical support devices are those with high risk PE with cardiogenic shock or shock refractory to medical therapies such as intravenous fluids or vasopressors and/or patients with failure of systemic lysis.[24] An extension of this patient population are patients with intermediate high risk PE that have evidence of clinical deterioration. This can include PE patients with RV dysfunction and elevated cardiac biomarkers that have clinical indicators of hemodynamic collapse. The benefit in these patients was noted when it was used as a bridge to another treatment modality that involves thrombus retrieval.[1]

In patients with cardiac arrest, either after quick return of spontaneous circulation or rarely when undergoing CPR, use of mechanical assist devices can also be considered if the arrest is witnessed with a confirmed diagnosis of PE and if the setting allows for rapid placement of mechanical support devices.

There are institutional variations in the use of MCS among patients with PE.[27] While some use it initially after diagnosing a patient with unstable PE, others use it as way of stabilizing patients after cardiac arrest. Fig. 3 shows an algorithm for managing high-risk PE patients who may require MCS.

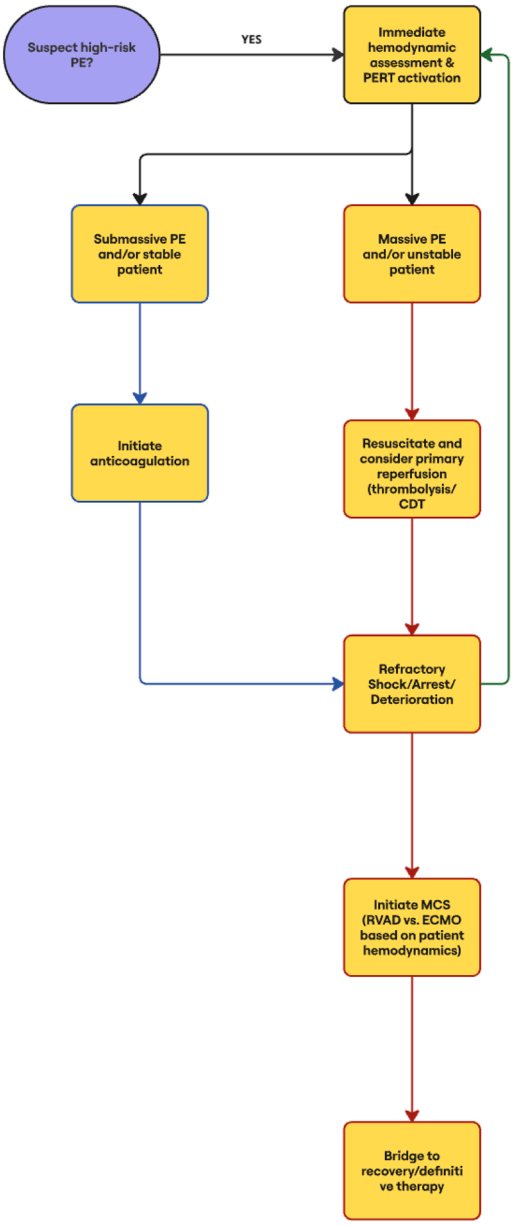

Fig. 3. Algorithm for management of high-risk PE incorporating MCS. Management algorithm for suspected high-risk PE, highlighting PERT activation, anticoagulation for stable patients, reperfusion for unstable patients, and escalation to MCS if refractory.

INTEGRATION OF MECHANICAL CIRCULATORY SUPPORT WITH OTHER THERAPIES

Multiple studies have established the benefit of bridging MCS with other reperfusion therapies. As VA-ECMO is the most commonly used MCS, most of the studies have evaluated benefit of VA-ECMO with systemic thrombolysis, catheter based therapies and surgical embolectomy.

In a critically ill patient with PE, MCS stabilizes hemodynamics while allowing safer and more deliberate use of advanced reperfusion therapies without the immediate threat of collapse during catheter manipulation or thrombolytic infusion.

Meneveau and colleagues evaluated outcomes in patients who underwent ECMO while being bridged to additional reperfusion therapies. They found that the 30 day mortality was 76.5% for patients that underwent ECMO and fibrinolysis, 29.4% for patients that underwent ECMO and surgical embolectomy and 77.7% for ECMO alone.[28] In another study of 136 patients of submassive and massive PE, Goldberg and colleagues evaluated the benefit of surgical

embolectomy and VA-ECMO in these patients. 43% of their patients with massive PE had undergone preoperative CPR. They found that RV function improved as measured by improvement in central venous pressure, pulmonary artery systolic pressure, fractional area change on echo, and RV/LV ratio.[29] In decompensating patients, VA-ECMO allows stabilization of hemodynamics while patients can be transferred to high volume surgical center for surgical embolectomy.

In a systematic review, mortality when ECMO was combined with catheter based therapies was lower than when it was used with systemic thrombolysis. This is probably due to worsening in the bleeding complications associated with VA-ECMO when used with full dose systemic thrombolysis.[19] Bleeding rates of 61% to 100% have been reported when patients were cannulated with ECMO after systemic lysis.[30]

Impella RP was successfully used along with catheter directed lysis in a couple of case series. In all the 7 patients from these case series, Impella RP stabilized hemodynamics after which catheter directed lysis was used for reperfusion. These patients were successfully weaned off the MCS and discharged in stable condition.[8,18] In patients undergoing surgical embolectomy, RVADs can be used to help wean the patients off cardiopulmonary bypass.[15]

Sometimes, other MCS may be used in combination. In patients with severe biventricular failure and profound shock, simultaneous use of an impella LV/CP with VA-ECMO allows unloading the LV while undergoing ECPR. This combined strategy is referred to as ECMELLA.[31] There are no standardized guidelines on when to use ECMELLA in preference to VA-ECMO and there are large institutional variations in its use.

PRACTICAL CONSIDERATIONS FOR MECHANICAL CIRCULATORY SUPPORT DEVICE SELECTION AND MANAGEMENT

Logistics: Access planning is crucial. Jugular-based ProtekDuo frees femoral veins for CDT. If using femoral Impella RP or ECMO venous drainage, CDT may need to use contralateral femoral or jugular access. Simultaneous MCS operation and CDT require careful coordination.

Device Selection

The choice of device selection depends on multiple factors. These include severity of shock, presence of isolated RV or biventricular failure, the presence of hypoxemia, and the need for additional support or access sites. It also largely depends on the presence of experienced personnel that are familiar with the devices and its protocols. The availability of a perfusion is crucial to the incorporation of VA-ECMO in the protocols.

Impella RP functions well in patients with preserved LV function, ruling it out as an etiology for the patient's shock. In patients with isolated RV failure due to high-risk PE, Impella RP can be used as a bridge to other catheter-based therapies. Theoretically, as it requires venous cannulation, it can potentially be used after systemic lysis.[30] Protek-duo, TandemHeart can be used in patients that require prolonged duration of support. It is a good option in patients with shock and hypoxemia as an oxygenator can be added for oxygenation. Furthermore, as it spares the femoral veins, it can be combined with be catheter based therapies that require femoral access. VA-ECMO is preferred in patients with persistent shock and hypoxemia due to biventricular failure and in patients with ongoing CPR to provide ECPR. If VA-ECMO results in LV congestion, an additional device such as an Impella LV/CP may be required to offload the LV.

Insertion and Cannulation Tips

Access planning before insertion of MCS is crucial. Simultaneous use of MCS and CDT require careful consideration. Protek-Duo is a jugular based MCS that frees the femoral veins for CDT. If Impella-RP or VA-ECMO is used, the contralateral femoral veins or the jugular may need to be accessed for CDT. The absence of deep vein thrombosis should be also be confirmed before accessing the vein. Using ultrasound to guide access minimizes complications, improves success rates and improves patient safety.[32] Fluroscopy and echocardiography is used to confirm appropriate position of MCS (Protek Duo tip in PA, ECMO wire in RA, and Impella RP)

A heparin bolus is usually given precannulation (unless contraindicated) with a target ACT guided by the device protocol. A DPC for VA-ECMO is placed prophylactically in femoral arterial cannulation to decrease limb ischemia.[33] Limb perfusion is monitored clinically. All the cannulas and sheaths should be robustly secured to prevent dislodgement.

Management of the Patient on Mechanical Circulatory Support

Patients' hemodynamics should be closely monitored. Frequent echocardiograms are used to not only assess the RV and LV function but to assess the position of the cannulas and to

Table 2
Major complications of mechanical circulatory support in pulmonary embolism: prevention and management

Complication	Risk Factors	Prevention Strategies	Management Strategies
Bleeding	Large-bore access, anticoagulation, thrombolytics, uremia, and thrombocytopenia	Meticulous access technique (using US guidance); avoid excessive anticoagulation early (esp postarrest); monitor ACT/aPTT closely; correct coagulopathy/platelets preprocedure; consider lower ACT targets if high risk	Local compression; reversal agents (protamine, PCC, platelets, FFP); Endovascular/surgical repair; Reduce/ stop heparin temporarily; Transfuse PRBCs as needed
Limb Ischemia (VA-ECMO)	Large arterial cannula, PVD, Vasopressors, Low CO, No DPC	Mandatory DPC placement, US-guided access, appropriate cannula size, monitor perfusion (pulses, Doppler, and NIRS)	Ensure DPC patency/flows, optimize CO/ BP, fasciotomy, cannula repositioning/ change (eg, switch to central), and revascularization surgery
Hemolysis	High device RPMs, high pressure gradients (kinks, malposition), small cannulas, and thrombus	Optimize device position, avoid excessive RPMs for flow needs, ensure adequate cannula size, maintain therapeutic anticoagulation	Reduce RPMs, Reposition cannula/ device, Treat underlying cause (eg, thrombus), hydration, alkalinize urine, and consider device exchange if severe
Infection	Prolonged support, multiple lines, large cannulas, and immunosuppression	Strict aseptic technique, early removal of unnecessary lines, timely dressing changes, and antibiotic prophylaxis per protocol	Culture-directed antibiotics, source control (dressing change, and line/ cannula removal if source)
LV distension (ECMO)	High afterload, severe MR/AR, poor LV function, inadequate LV ejection	Monitor echo/PA pressures; Maintain some LV EF; inotropes; IABP; LV venting (Impella, atrial septostomy)	Add LV unloading (Impella - *ECMELLA*); Increase inotropes; consider septostomy; Reduce ECMO flows if possible
Device malfunction	Pump thrombosis, mechanical failure, and power issues	Maintain anticoagulation; monitor power source/battery; monitor device parameters (flow, power, and pulsatility)	Troubleshoot alarms; reposition device/ cannula; exchange device if malfunction confirmed.
Cannula malposition	Migration, initial malposition	Secure cannulas well; confirm position with imaging (using echocardiogram/ fluoroscopy); monitor parameters	Imaging confirmation; reposition under fluoroscopy/echocardiographic guidance
Neurologic event	Hypotension, hypoxia, CPR, embolism (air/clot), and hemorrhage	Optimize hemodynamics/oxygenation during CPR/cannulation; meticulous air removal; anticoagulation	Neuroimaging (CT head); Neurosurgical consultation; Reverse anticoagulation if hemorrhagic; and supportive care

Abbreviations: MR, mitral regurgitation; AR, aortic regurgitation; BP, blood pressure; PRBC, packed red blood cell; RPM, revolutions per minute; US, ultrasound.

evaluate for LV distension while on VA-ECMO. Pulmonary artery catheter is extremely valuable in to monitor parameters such as pulmonary artery pressures, pulmonary capillary wedge pressure, CO and mixed venous oxygen. Lactate is monitored as a marker of hypoperfusion.

Continuous unfractionated heparin infusion is standard. The ACT that should be targeted depends on the device protocol and patient bleeding risk. As these patients are on continuous unfractionated heparin, they should be closely monitored for heparin induced thrombocytopenia. Direct oral anticoagulants are often avoided in these acute critically ill situations.

Weaning

There are no standardized criteria for weaning MCS in patients with PE. Echocardiogram and invasively obtained parameters are used as a cornerstone to evaluate LV and RV recovery. Echocardiographic parameters that evaluate RV function include fractional area change, TAPSE, and a 3-dimensional ejection fraction. A 3-dimensional EF of greater than 25% was found to be associated with successful weaning from VA-ECMO in a small cohort study.[34] Hemodynamic stability off pressors or on minimal doses of pressors, adequate oxygenation along with improvement with RV function are important parameters that determine successful weaning. Progressively decreasing the level of support depending on the MCS while evaluating hemodynamics and RV function will determine the appropriate time for device removal. If minimal support is tolerated for several hours, device removal can be considered.

Advanced age, high lactate, low mean arterial pressures, worsening oxygenation while weaning off ECMO and renal failure requiring renal replacement therapy are markers of increased mortality.[34]

Complication Surveillance

A multidisciplinary team involving an intensivist led critical care team, cardiology (interventional, heart failure, and electrophysiology), vascular medicine, cardiothoracic surgery, neurology (if a central nervous system event is suspected) and nursing is crucial to the success of MCS in such critically ill patients.

Daily rounds should include vigilant monitoring for common complications, including bleeding from access sites and other locations such as the gastrointestinal (GI) tract or intracranial space; limb ischemia assessed by pulses, extremity color and temperature, and near-infrared spectroscopy (NIRS); hemolysis evaluated using plasma-free hemoglobin (Hb), lactate dehydrogenase (LDH) levels, and urine color; infection assessed by fever, white blood cell (WBC) count, and cultures; and arrhythmias. Any suspicion of cannula migration or malposition should be confirmed with echocardiography or fluoroscopy.

Complications and Their Management

Prompt recognition and management of complications are crucial to the success of MCS and are summarized in Table 2.

FUTURE DIRECTIONS

The field of MCS for PE is evolving. Technological advancements in devices have led to ease of insertion, better pump management and more patient mobility. This is attributed to smaller and more portable devices.[35] With newer materials, improved hemocompatibility, has led to surface coatings that reduce risk of thrombosis and inflammation, potentially allowing for lower anticoagulation targets. More research is required with regard to specific devices types and their effects in the high risk PE population. While randomized controlled trials are desperately required in this field, they are challenging to organize in this patient population.

Use of MCS with other advanced reperfusion therapies and early use of MCS in comparison to standard therapies and comparison of specific devices with other devices should be evaluated in prospective cohorts. Another area that requires more data is recognizing the subset of population among intermediate-high risk PE patients that are an increased risk of deterioration. Knowledge of biomarkers and more refined scoring systems will help risk stratify these patients better.

SUMMARY

MCS devices have revolutionized the management of the most lethal forms of PE. By providing hemodynamic stability through RV unloading and systemic perfusion support, percutaneous MCS platforms (Impella RP/RP Flex, ProtekDuo with TandemHeart/CentriMag, and VA-ECMO) offer a lifeline for patients with massive PE, refractory shock, high-risk and intermediate high-risk PE with deterioration, and PE-related cardiac arrest. They allow time for RV recovery while other therapies such anticoagulation, systemic thrombolysis or surgical embolectomy can be administered.

The evidence, though predominantly observational, consistently demonstrates improved

survival compared to historical expectations in these critically ill populations. However, MCS is not without significant risks. They are associated with multiple risks, such as bleeding, vascular complications, hemolysis, and infection, necessitating meticulous management by a highly skilled multidisciplinary team including interventional cardiologists, cardiac surgeons, intensivists, perfusionists, and specialized nurses.

Device selection requires careful consideration of patient factors (severity of shock, hypoxia, RV/LV function), center expertise, and device availability. VA-ECMO provides full cardiopulmonary support and is preferred in arrest or severe hypoxia, while isolated RVADs offer targeted support with potentially lower complication profiles in isolated RV failure. Integration with CDT is particularly synergistic.

As technology advances with smaller, more efficient devices and clinical research matures, particularly with prospective registries and hopefully RCTs, the role of MCS in PE will continue to be refined. For now, the early involvement of a PERT is paramount to rapidly identify appropriate candidates and implement MCS within a comprehensive treatment strategy. For the interventional cardiologist, proficiency in percutaneous MCS insertion and management is becoming an increasingly essential skill in the battle against high-risk PE, transforming what was once a near-uniformly fatal condition into one with a fighting chance for survival.

CLINICS CARE POINTS

- Pearls: Early RV support saves lives: Initiate MCS before cardiac arrest or severe lactic acidosis to improve survival and neurologic outcomes, especially in refractory shock.
- Device selection must be physiologic: Choose isolated RVADs (Impella RP, ProtekDuo) for isolated RV failure; reserve VA-ECMO for profound hypoxemia, biventricular failure, or arrest.
- MCS is a bridge, not definitive therapy: Use MCS to stabilize hemodynamics while planning reperfusion (CDT, thrombolysis, surgical embolectomy), not as standalone treatment.
- PERT activation improves coordination: Early multidisciplinary PE Response Team involvement streamlines device selection, access planning, and reperfusion strategy.
- Echo and PA catheter guide care: Serial echocardiography and invasive hemodynamics are essential for assessing RV recovery, cannula position, LV distension, and weaning readiness.
- Pitfalls: Delayed escalation to MCS: Waiting for hypotension, arrest, or multiorgan failure markedly worsens prognosis; normotensive shock still warrants early consideration.
- Underestimating bleeding risk: Large-bore access, anticoagulation, and thrombolytics amplify bleeding—especially with VA-ECMO—necessitating strict ACT targets and access-site vigilance.
- Ignoring LV distension on VA-ECMO: Increased afterload can worsen LV congestion; failure to unload the LV (Impella/IABP) risks pulmonary edema and low output.
- Poor access planning: Femoral crowding can preclude CDT; jugular-based ProtekDuo may preserve femoral access and reduce complications when planned upfront.
- Inadequate limb protection: Omission of prophylactic distal perfusion cannula during femoral arterial ECMO increases limb ischemia and morbidity.

DISCLOSURE

No disclosures.

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