# Short-term mechanical circulatory support: Transitioning the patient to the next stage



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## CLINICAL VIGNETTE

*A 32-year-old man presented to the emergency department with acute cardiogenic shock: mean arterial pressure (MAP) 50 mm Hg despite initiation of high dose vasopressors, heart rate 130 beats/min, pulse pressure 10 mm Hg, and respiratory rate 35 breaths/min. Initial lab values showed elevated transaminases, creatinine 3.7 mg/dL, troponin 23 ng/mL, lactate 10 mg/dL. Bedside echocardiogram showed biventricular ejection fractions of 5% to 10% with normal left ventricular (LV) dimensions. Echocardiography showed no acute ischemia; however, frequent runs of ventricular tachycardia were occurring with 2 shocks required in the emergency department. The patient was transferred to the cardiac catheterization lab, placed on peripheral venoarterial extracorporeal membrane oxygenation (VA ECMO), and intubated. Coronary angiogram was normal and an endomyocardial biopsy was performed. A femoral intra-aortic balloon pump was placed for LV unloading. Biopsy returned as myocarditis and Coxsackie titers were consistent with acute infection. Urine toxicology was negative.*

*Over the first 3 days of VA ECMO support, the patient went onto continuous renal replacement therapy, liver enzymes downtrended, lactate levels normalized, and the patient remained neurologically intact. Pulsatility was minimal on the arterial line tracing. On day 4 an ECMO turndown study showed mild to moderate right ventricle (RV) dysfunction with LV ejection fraction of 10%. On 1 L/min ECMO support, MAP dropped to 50 mm Hg, pulmonary capillary wedge pressure to 20 mm Hg, and cardiac index dropped to 1.5. Given failure of turndown study, upper extremity arterial ultrasounds were performed to plan transition to subclavian Impella 5.0 device (Abiomed, Danvers, Mass). On day 5 the patient was transitioned to Impella 5.0 support and was extubated 2 days later. LV ejection fraction remained at 10% with several failures of Impella weaning at week 3 and ultimately a durable LV assist device (LVAD) was placed. The patient had recovery of renal function at 1 month post-LVAD and LV function normalized by month 8. Successful explantation of the LVAD was performed 1 year post-LVAD implantation after confirmation of cardiac recovery.*

### CENTRAL MESSAGE

Short-term mechanical circulatory support is an important tool for managing cardiogenic shock. The framework for decision making is critical in deciding the appropriate end goal and progressing care efficiently.

See Commentary on page 35.

## DISCUSSION

Studying the management of cardiogenic shock (CS) in a rigorous way has proven to be difficult. Randomization to a nondevice strategy for patients with refractory CS is not possible and so data to develop guidelines must be extrapolated from randomized trials of less sick patients, nonrandomized trials, and pooled institutional experience. CS is also complex: There is a spectrum of shock ranging from early end-organ dysfunction to multisystem organ failure with inflammatory cytokine-mediated vasodilation.[1] The etiology can be predominately left-sided, right-sided or biventricular, and the syndrome can occur in patients with chronic heart failure or those with normal cardiac function who experience an acute insult. Although the immediate goals of temporary support are to stabilize the patient and restore perfusion, the longer-term goal can vary based

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on the likelihood of recovery, the severity of myocardial injury, and candidacy for advanced therapies such as cardiac transplantation or LVAD placement. All of these factors contribute to the complexity and the wide variation in management of these patients.[2]

Use of short-term mechanical circulatory support (MCS) has risen dramatically over the past 2 decades.[3] Several modalities of short-term MCS are now in clinical use, including intra-aortic balloon pumps, Impella intravascular pump devices, and VA ECMO.[4] In addition to the widespread availability of these devices, use has also increased due to development of novel ways of utilizing existing support devices, and increasing collaborative experience and teamwork among cardiologists, intensivists, and cardiothoracic surgeons.[5]

The most potent of these acute modalities is VA ECMO, which remains the mainstay of therapy at our institution, and forms the basis of our decision-making process in short-term MCS. Because increasing numbers of patients are being placed onto short-term MCS for refractory cardiogenic shock, we review herein our institutional approach to decision making and management once VA ECMO has been initiated.

The use of VA ECMO for CS has increased exponentially over the past decade. The reasons for its popularity are multiple: VA ECMO provides full hemodynamic support, can support both ventricles, is widely available, can be placed quickly, allows for patient transport, and includes respiratory support by means of an oxygenator. VA ECMO can be placed through central cannulation or percutaneously through peripheral cannulae into the femoral vessels.[4,6,7]

## Possible Patient Pathways

Patients who are placed on VA ECMO for refractory shock can be divided into 2 categories: those with normal cardiac function who experience an acute myocardial insult, and those with chronic heart failure who reach a tipping point of acute decompensation (Figure 1). Reversible causes of cardiac dysfunction should be identified and treated appropriately, including cardiac catheterization for revascularization or myocardial biopsy to exclude giant cell myocarditis if suspected. For patients with chronic LV failure in refractory shock, the goal is to determine candidacy for and the safest pathway to advanced therapies. There are some patients who present with CS who have undiagnosed chronic heart failure; these patients may be candidates for longer-term recovery. To keep within the scope of this subject we will also omit elective indications for VA ECMO such as circulatory support for high-risk cardiac interventions as well as perioperative indications such as postcardiotomy shock, although the same basic principles of management and subsequent bridges to recovery are also applicable in those scenarios.

## Systemic Perfusion on VA ECMO

The success of VA ECMO for CS depends on the patient receiving adequate systemic perfusion. Optimal cannula function must be ensured, including verifying correct position and lack of obstruction in the circuit. A distal limb perfusion cannula should be placed if peripheral cannulation is used, to avoid distal lower limb ischemia. Consideration must also be paid to the development of so-called harlequin syndrome, in which native pulmonary hypoxia

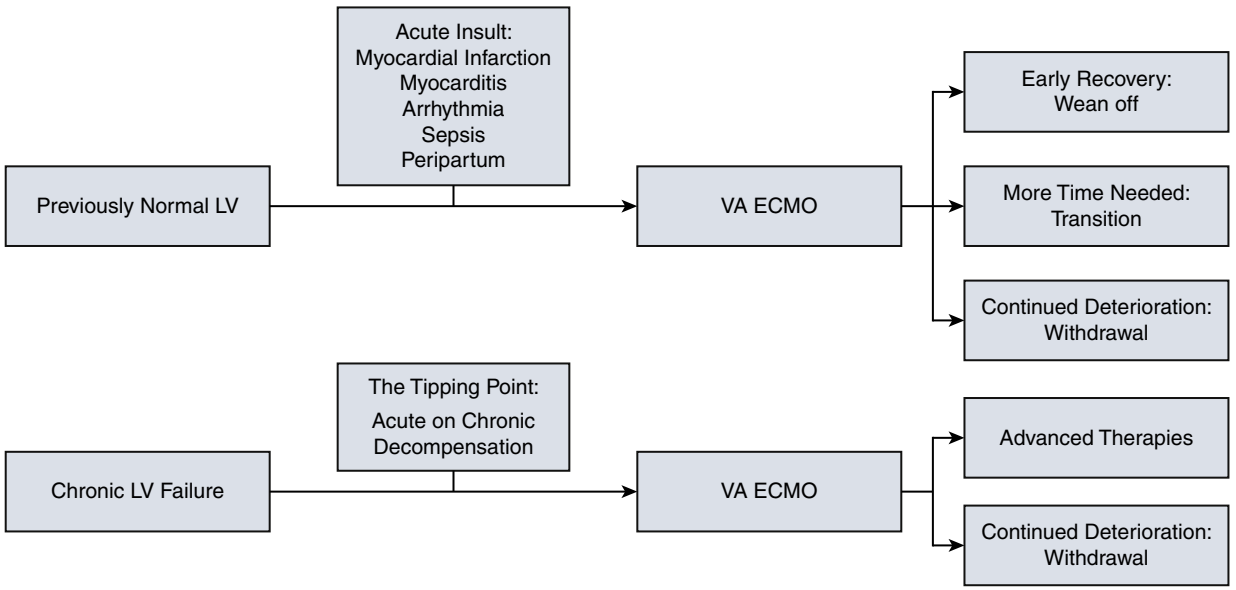


**FIGURE 1.** Simplified patient pathways for venoarterial extracorporeal membrane oxygenation (*VA ECMO*) in refractory cardiogenic shock. Patients in refractory cardiogenic shock are divided into 2 categories: previously normal cardiac function and chronic heart failure. Based on this classification, end-goals can differ as expectations of cardiac recovery differ. *LV*, Left ventricle.

combined with incomplete femoral ECMO perfusion leads to asymmetrical hypoxia of the upper body.[8] Either of these situations may necessitate conversion to central cannulation. Vasoplegia, if present, should be counteracted with vasopressors to ensure MAP >65 mm Hg. Bleeding should be controlled in order to minimize blood product usage. Lactate should be measured serially to ensure downward trend.

It should be noted that VA ECMO raises LV afterload more so than other temporary MCS devices, which increases LV wall stress and does not lower myocardial work[9] in either central or peripheral configuration. Several strategies are available to provide LV decompression in VA ECMO: insertion of a second device (Impella), percutaneous transseptal cannula draining into ECMO venous circuit, direct placement of a LV vent, or simple atrial septostomy.[10,11] The importance of LV unloading in VA ECMO was recently established in a large meta-analysis of patients with a variety of forms of cardiogenic shock (N = 3997).[12] Patients who had ventricular unloading in that study had a 21% reduction in the relative risk of death (relative risk, 0.79; 95% confidence interval, 0.72-0.87). For patients at our institution for whom the goal is recovery and/or for whom a longer time of support is expected, upfront unloading is performed usually with a second device.

## Early Recovery: Wean Off

The pathway to early recovery occurs most often when there is an acute insult that is corrected quickly, such as myocardial infarction with timely revascularization. There is often rapid return of arterial waveform pulsatility and improved cardiac function once VA ECMO is initiated. On turndown of ECMO, pulsatility, and MAP are maintained and cardiac output and filling pressures remain normal. If the patient no longer requires an oxygenator, removal of ECMO should occur as soon as possible given the morbidity of the support (Table 1).

Our criteria for when to begin weaning VA ECMO are as follows: MAP >60 mm Hg without or with minimal vasoactive drips, pulsatile arterial waveform, activated clotting time between 180 and 200 seconds, normalized lactate level, and stabilized hepatic function. If acute kidney injury has occurred before the onset of ECMO, renal function may not correct quickly; however, weaning and decannulating ECMO should not wait for renal recovery. Once these parameters are met, we begin assessing native heart function with turndown studies.

A VA ECMO turndown study involves turning down ECMO support to assess underlying myocardial performance. At our institution this is performed under echocardiographic guidance. ECMO flow is decreased 1 L/min at a time, stopping for 5 minutes with each decrease to assess LV function, RV function, MAP, cardiac output, pulmonary capillary wedge pressure, pulse pressure, and heart rate. When ECMO flow has been weaned to 1 L/min, ECMO circuit inspired oxygen fraction ($F_{IO_2}$) is reduced and an arterial blood gas is obtained. The goal Arterial oxygen tension/$F_{IO_2}$ >200 at 1 L/min flow with a low sweep $F_{IO_2}$ and weaning ventilator settings.

## More Time Is Needed: Transitioning to Different Devices

If a patient has poor LV function and/or poor hemodynamic status on ECMO turndown, more time on support is needed. If such a patient is not a candidate for permanent advanced therapies, we transition to a subclavian Impella 5.0 as soon as possible. The reasons for this transition include the ability to ambulate the patient with this support device, the LV unloading this strategy affords, and the high morbidity of continuing ECMO for each additional day of support.

We recently presented a meta-analysis of subclavian or axillary Impella 5.0 for cardiogenic shock.[13] The analysis included 11 studies with a sample size of 190 patients. Over a mean of 13 days of support, the stroke rate was 2%, the rate of infection 9%, limb ischemia 0%, and bleeding 6%. In comparison, the adverse event rates reported in 2 large, recently published meta-analyses of ECMO for cardiogenic shock (Table 1) show average stroke rate on ECMO was 5% to 18%, infection 17%, and limb ischemia 25% to 40% over 3 to 5 days of support.

We perform upper extremity vascular ultrasounds early in the patient's ECMO course to assess subclavian size. Exclusion criteria for transition to a subclavian 5.0 Impella include subclavian dimension <7.0 mm, continued need for an oxygenator, presence of an LV thrombus, severe RV

**TABLE 1. Comparison of left ventricular support devices[7,12-14]**

| Type of mechanical circulatory support | Ventricle supported | LV unloading | Mobility on support | Stroke rate (%) | Limb ischemia rate (%) | Bleeding rate (%) | Infection rate (%) | Average length of support (d) |
|---|---|---|---|---|---|---|---|---|
| VA ECMO | Bi-V, LV, RV | No | No* | 5-18 | 25-40 | 16-33 | 17 | 3-5 |
| Subclavian Impella 5.0† | LV | Yes | Yes | 2 | 0 | 6 | 9 | 13 |
| Intra-aortic balloon pump | LV | Yes | Yes | 0-2.4 | 0-4 | 8-20 | 9-15 | 2-4 |
| TandemHeart‡ | LV | Yes | No | 0-6 | 11-33 | 28-41 | 6-21 | 3-5 |

*LV*, Left ventricle; *VA ECMO*, venoarterial extracorporeal membrane oxygenation; *Bi-V*, biventricular; *RV*, right ventricle. *Some centers have begun ambulating patients on VA ECMO. †Abiomed, Danvers, Mass. ‡Livanova, Arvada, Colo.

dysfunction refractory to volume loading or inotropic challenge, or more than mild aortic insufficiency.

### Bridge to Advanced Therapies

For patients with chronic heart failure who deteriorate and require VA ECMO support, expectations are low for a full recovery to normal cardiac function. Instead, our goal is to provide short-term MCS for recovery from fulminant shock with intention of transitioning to long-term circulatory support either with durable LVAD or heart transplantation. The same principles above apply in terms of weaning VA ECMO and monitoring for recovery of neurologic and end-organ function. After stabilization and determination of patient's or family's wishes, there can be consideration of a pathway to transplant in the United States under the current United Network for Organ Sharing allocation system or bridging with durable LVAD, although these patients are the highest risk for both therapies.[15,16] Occasionally the decision is made to change support to another temporary device to allow the patient to wake up, fully assess his or her choices, evaluate RV function, and allow for further end-organ recovery. However, such a device-to-device strategy does carry risk of prolonged delay and more intensive care-related complications, not to mention a likely very long hospital course and continued high risk of mortality.

Much has been written in the literature about criteria for heart transplant, and we will not expound in detail on such criteria. At our institution, such patients who are deemed not to be candidates for transplant are then planned for LVAD as either bridge to destination or bridge to candidacy. Whether LVAD is used as bridge to transplant or destination therapy in refractory cardiogenic shock, we use the same principles in our decision-making algorithm.

When considering durable LVAD placement, it is important to minimize risk of infection. However, it is important to note that leukocytosis may persist in these MCS patients even without infection. If infectious workup is negative in the presence of leukocytosis, the risk-benefit balance may be tipped toward LVAD placement rather than staying on temporary support.

### Algorithm for Pathways Off VA ECMO for Cardiogenic Shock

Our algorithm for possible patient pathways off VA ECMO is highlighted in Figure 2. The concept of support on time means that the patients were placed on MCS before the development of the metabolic sequelae of cardiogenic shock such as shock liver and acute kidney injury. In cases where MCS is placed early in the course of cardogenic shock, renal function, liver function, and neurologic function will remain intact or normalize very quickly. Such patients may be candidates for going directly to durable LVAD or transplant if cardiogenic shock develops on the backdrop of a chronically failed LV. In many of these latter situations, chronic heart failure patients may have already undergone

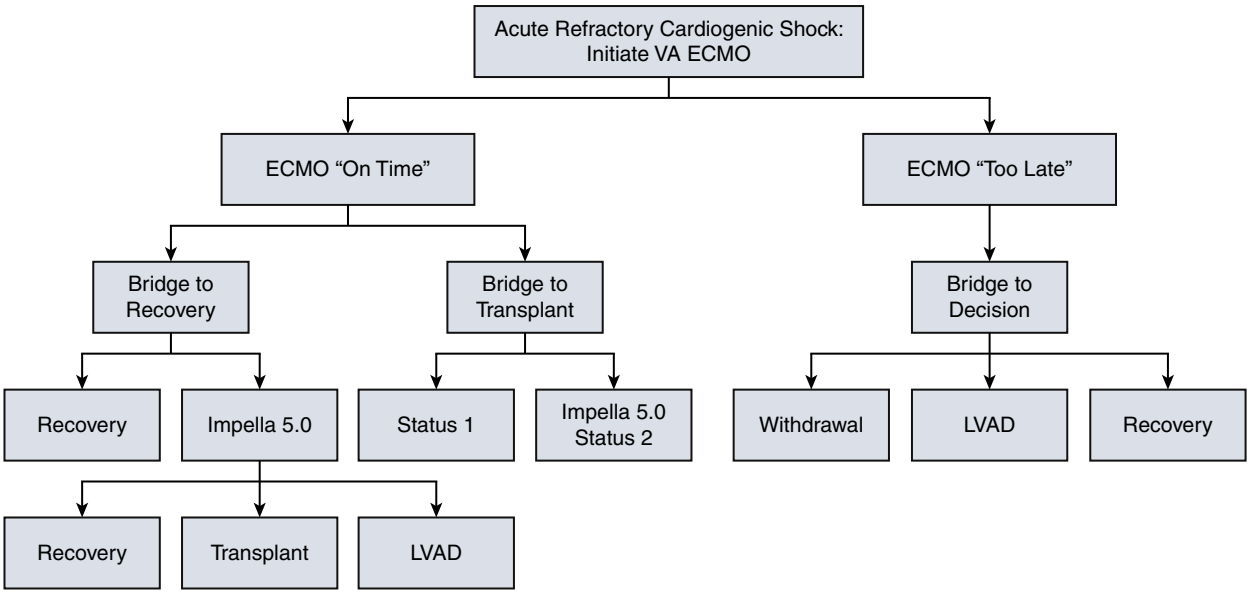


**FIGURE 2.** Decision-making algorithm for venoarterial extracorporeal membrane oxygenation (*VA ECMO*). Once VA ECMO has been initiated for refractory cardiogenic shock, decision making hinges on patient response to circulatory support. ECMO placed in a timely manner (ie, On Time) will show preserved or recovered neurologic and end-organ function, and the subsequent choice of bridge to recovery versus bridge to transplant depends on recovery or lack thereof of cardiac function. ECMO placed too late will show continued deterioration of end-organ function and, critically, neurologic function. In these patients, the bridge to decision pathway is pursued with prompt family discussions on goals of care. *LVAD*, Left ventricular assist device. Impella 5.0, Abiomed, Danvers, Mass.

evaluation for either LVAD or heart transplantation even before acute decompensation.

### Bridge to Decision

There are several clinical situations that can lead to a transition in the goals of care. Complications can arise from the ECMO circuit, such as bleeding or thrombosis. Patients who have sustained severe hypoxic injury may have irreparable neurologic sequelae that result in dismal prognosis for future quality of life. Even with excellent cardiopulmonary stability on MCS, irreversible end-organ injury may progress. Lack of return of cognitive function portends a particularly poor prognosis, as does progressive shock liver refractory to maximal medical therapy.

Such a framework of parameters for assessing treatment success allows for clearer communication with family when discussing situations of futile care. Thus, the evidence of the patient's response to our treatment algorithm can often help the family gain a clearer understanding of the patient's grave state, and help them reach the difficult decision to withdraw such measures in futile cases.

## CONCLUSIONS

The implementation of shock teams is presently under study with the goal of identifying cardiogenic shock early and thus being able to implement timely interventions to reduce mortality. In a recent large meta-analysis of VA ECMO for cardiogenic shock, 50% of patients were receiving cardiopulmonary resuscitation by the time VA ECMO was placed, indicating that early signs of cardiogenic shock are often missed.[7] In addition, patients who are receiving cardiopulmonary resuscitation by the time MCS is initiated have a higher mortality compared with other patients who require such support,[7,17] again underscoring the importance of earlier identification of cardiogenic shock. The shock team approach involves early hemodynamic assessment, multidisciplinary teams, and matching the level of support to the level of shock. Early investigation of this approach has demonstrated a reduction in mortality[18]; further study of this team-based model will be required to develop evidence-based guidelines and for replication across hospital systems.

Short-term mechanical circulatory support has become more widespread in recent years. It is imperative to have a solid framework for decision making once short-term MCS is initiated because prompt interventions are critical. VA ECMO is a powerful tool in the fight against refractory cardiogenic shock, but early initiation and prompt decision making are critical to success in managing VA ECMO and transitioning patients to the next stage of care. Multidisciplinary shock teams hold promise in pushing the field forward and ultimately improving outcomes for patients.

### Conflict of Interest Statement

Dr Cogswell is a consultant and member of the Speakers Bureau for Abbott Labs and Medtronic and is a national principal investigator for Nupulse. She has a spouse employed by Medtronic. Dr John is a consultant and has received research grants from Abbott Medical and Medtronic. All other authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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