When to use central mechanical support devices

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Feature Editor's Introduction—*The care of patients with refractory cardiogenic shock is one of life, and, sadly, frequently death. For many of these patients, mechanical circulatory support can provide rescue as a bridge to destination therapy or as the destination therapy itself. For every one of these patients, precise attention to detail is critical.*

The choices of which circulatory support device to use and its mechanism of delivery are the first steps in rescue therapy. These decisions are also the most critical, as all subsequent care is dictated by the benefits and limitations of both the type of support and its central or peripheral location. Unfortunately, choice of circulatory support device and the decision of peripheral versus central placement is a nonstandardized process, and strong evidenced-based recommendations to guide care are sparse.

When clear-cut evidence is lacking, it is important to perform a critical appraisal of all available options. In this edition of the Journal, *Drs Salna and Naka provide just this insight. Recognizing the available minimally invasive techniques for central placement and the limitations of peripheral cannulation, Salna and Naka outline clear and straightforward rationale for the consideration of central mechanical circulatory support and how to mitigate its common adverse sequelae.*

Understanding the physiologic effects of mechanical circulatory device placement, degree of cardiopulmonary relief, potential complications, and future long-term treatment modalities for refractory cardiogenic shock are vital to the care of these critically ill patients. Having the ability to centrally versus peripherally cannulate in the most minimally invasive fashion should be in every cardiac surgeon's armamentarium. This work by Drs Salna and Naka not only concisely reviews these minimally invasive central cannulation techniques but also provides the framework for when these techniques should be considered.

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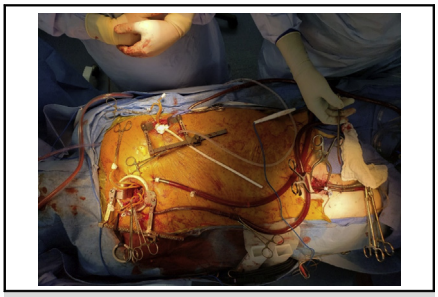

Conversion from femoral VA-ECMO to central MCS with right atrial and left ventricular apex drainage and aortic return.

CENTRAL MESSAGE

Central mechanical circulatory support can overcome the limitations of peripheral support and may be a necessary or adjunctive alternative.

See Commentary on page 27.

Cardiogenic shock is a state of critical end-organ hypoperfusion due to cardiac dysfunction, with the most common causes being myocardial infarction and acute decompensated heart failure. With a mortality rate of nearly 50%, there is great demand for aggressive therapies to manage patients in cardiogenic shock.[1] As the dosages of inotropes and pressors in a patient with shock rise, the decision to initiate temporary mechanical circulatory support (MCS), and the subsequent decision of which device to select, is not easy, and there are no clear-cut guidelines on which to rely. Complex, interrelated factors must all be taken into consideration, which range from patient-specific characteristics and organ function to a surgeon's technical abilities and available resources to the ultimate disposition of the patient—transplant versus long-term ventricular assist device versus recovery.

While there are many forms of temporary MCS devices available now for cardiogenic shock, including percutaneous options such as the Impella (Abiomed, Danvers, Mass) and the TandemHeart (Cardiac Assist, Inc, Pittsburgh, Pa) and more invasive options such as veno-arterial extracorporeal membrane oxygenation (VA-ECMO) or surgically implanted ventricular assist devices (VADs) such as the CentriMag (St Jude Medical, St Paul, Minn). The most common of these invasive options, VA-ECMO, is capable of providing cardiopulmonary support and is relatively easy

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to implant, most frequently inserted percutaneously through the ipsilateral femoral vein and artery. According to the Extracorporeal Life Support Organization, the rate of ECMO use around the world has surged over the past decade nearly 1200%.[2] Moreover, recent data have demonstrated reasonable survival to discharge rates with good neurologic outcomes even among those in refractory cardiac arrest who are treated with ECMO.[3]

WHY PERIPHERAL SUPPORT IS NOT ALWAYS APPROPRIATE

Cannula Sizes and Flow?

VA-ECMO is most commonly initiated peripherally—via a drainage cannula inserted into the femoral vein and an arterial return cannula into the ipsilateral or contralateral femoral artery. While this strategy is preferable due to the speed and safety of cannula insertion, it has its disadvantages (Table 1). Cannulating the femoral artery carries with it the risk of ipsilateral limb ischemia, greater difficulty with mobilization, poor upper body oxygenation, and increased left ventricular (LV) afterload. Cannulation of the axillary artery may reduce these complications but presents its own unique risks, including upper-extremity hyperemia and brachial plexus injury. There are situations, however, when peripheral VA-ECMO is not appropriate: either cannulation is not possible, troubleshooting complications has failed, or the provided support—either hemodynamically or through oxygenation—is inadequate.

Extreme Obesity

Patients with morbid (body mass index >35) or super (body mass index >40) can be adequately supported on peripheral VA-ECMO. However, peripheral cannulation can be extremely challenging due to excessive adiposity, even when surgical cutdowns are performed. In select patients, central cannulation can be considered a bailout option for initiation of hemodynamic support.

Severe Peripheral Vascular Disease

In patients with known severe calcific disease, femoral cannulation is neither safe nor, frankly at times, possible. We routinely began near-infrared spectroscopy tissue saturation monitors on the distal limb before femoral cannula insertion. If, after arterial cannula insertion, the ipsilateral leg saturation falls below 60%, we insert an 8-Fr arterial distal perfusion cannula into the superficial femoral artery.[4] However, in certain circumstances, when the femoral or axillary arteries are too diminutive or there is circumferential calcification in the vessels—2 factors that may impact the placement of an appropriately sized cannula—a central approach may be the safest configuration of ensuring sufficient hemodynamic support.

Need for Greater Upper Body Oxygenation

Femoral arterial cannulation provides oxygenated blood retrograde up the aorta. In patients who develop respiratory failure despite high ECMO flows and optimal ventilator settings, the left ventricle will begin to eject poorly oxygenated blood to into the ascending aorta and potentially to the coronary arteries, carotids, and upper extremities as well. As cardiac function recovers, this antegrade flow competes with the highly oxygenated retrograde ECMO flow, creating a mixing point in the descending aorta—the location of which can vary depending on the relative force of ECMO flow and native cardiac ejection. This phenomenon, known as "differential oxygenation" or "Harlequin syndrome," is best identified by trending arterial blood gases from a right

TABLE 1. Advantages and disadvantages of different types of VA-ECMO cannulation configurations

VA-ECMO cannulation	Advantages	Disadvantages
Peripheral	• Rapid initiation • Bedside cannulation • Avoidance of sternotomy/chest incision	• Partial biventricular support • Flow limitations • Differential hypoxia/competitive flow • Limb ischemia (femoral–femoral) • Nerve injury or ipsilateral upper extremity hyperemia (axillary cannulation) • Increased afterload–LV distension • Limited ambulation with femoral-femoral configuration
Central	• Facilitates ambulation • Superior flows and cerebral/upper body oxygenation • Antegrade flow • Biventricular unloading • Mini-thoracotomy facilitates HeartMate 3 (Abbott Laboratories, Chicago, Ill) insertion	• Necessity of sternotomy/chest incision • Greater risk of bleeding/tamponade • Risk of mediastinal adhesion formation • Greater risk of infection • Risk of pulmonary thrombosis

VA-ECMO, Veno-arterial extracorporeal membrane oxygenation; *LV*, left ventricular.

radial arterial line—as the blood delivered to the right hand reflects what is being seen by the brain. While the insertion of an additional venous reinfusion limb can aide in this circumstance, central ECMO is also an option of ensuring appropriately oxygenated antegrade blood flow to the brain and coronaries.

Insufficient Hemodynamic Support

The hemodynamic support offered by peripheral VA-ECMO is incomplete. In femoral ECMO, only partial biventricular support is offered with right ventricular offloading from the venous cannula. Retrograde aortic return, however, increases LV afterload and can predispose to distension and worsening cardiac function. For these reasons, it is imperative to maintain pulsatility to reduce the incidence of intracardiac or aortic root thrombus formation, which may subsequently result in emboli phenomena. Worsening LV distension can result in LV ischemia, mitral regurgitation, and pulmonary edema, occasionally necessitating a left apical surgical vent or percutaneous LV vent (eg, Impella; Abiomed, Danvers, Mass) be placed. We primarily use the Impella as an LV vent rather than a first-line hemodynamic support modality.

In biventricular failure, peripheral VA-ECMO may be insufficient in providing adequate biventricular support. In these instances, central ECMO with an LV vent or a CentriMag biventricular assist device with an oxygenator can be implanted in a right atrial–pulmonary artery and LV apex to ascending aorta configuration as a bridge to decision (myocardial recovery vs transplantation).

Bridge to Transplantation

The benefits of ambulation during venovenous ECMO, including its use as a bridge to lung transplantation, have been well documented.[5,6] While case series data have demonstrated ambulation with peripheral VA-ECMO to be feasible,[7] and the use of ambulatory VA-ECMO as a bridge to heart transplantation has been described in select cases,[8,9] these patients appear to have overall worse outcomes than those bridged with left ventricular assist devices (LVADs).[10,11] Nevertheless, femoral cannulas are at risk of kinking, or worse, dislodging, during any activity involving hip flexion, and therefore an upper-body configuration is preferable when mobilization is anticipated. A subclavian or central cannulation configuration through a minithoracotomy or upper hemi-sternotomy would both be viable strategies in this instance[12] (Figure 1).

WHY USE CENTRAL ECMO?

The aforementioned examples are select examples of when we believe the optimal alternative cannulation configuration is using central MCS, which we define as having at least one cannula in the mediastinum. Central mechanical support, traditionally with a right atrial venous drainage cannula and an ascending aortic arterial return cannula, has the advantages of more physiologic antegrade flow with ascending aortic cannulas, full biventricular support with the potential for greater flows than in peripheral ECMO, the avoidance of differential hypoxemia, and the greater potential for patient mobilization.

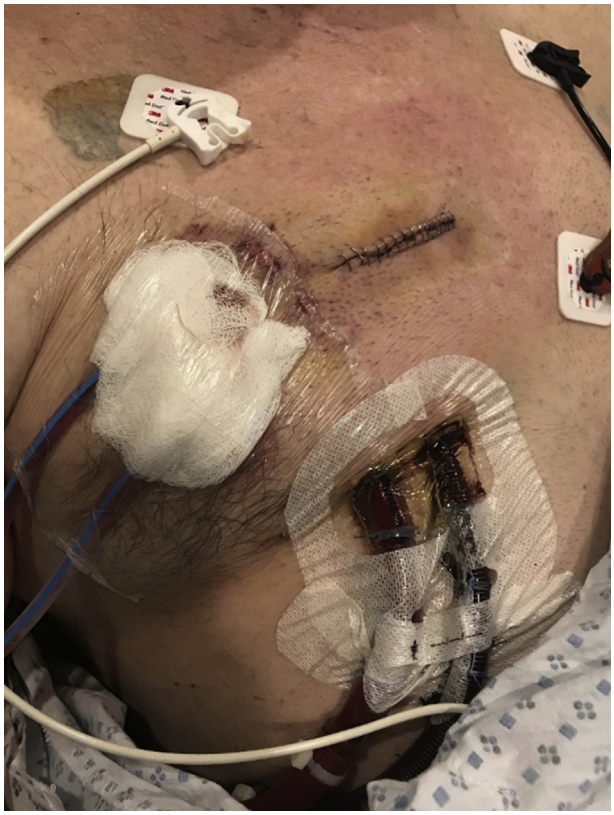

FIGURE 1. Central mechanical circulatory support with right atrial drainage and ascending aortic return via a right mini thoracotomy.

The major disadvantage of central ECMO is the invasive nature of cannulation. While alternative access exists for the initiation of central VA-ECMO, the involvement of the mediastinum predisposes to bleeding, adhesion formation, and an increased risk of infection.[13]

CENTRAL ECMO CONFIGURATIONS

Right Atrial-Ascending Aorta

The most common central MCS configuration is right atrial drainage with ascending aorta return and is most commonly employed in postcardiotomy shock (PCS) when a patient is unable to be weaned from cardiopulmonary bypass. In PCS, this configuration is easily adapted using the pre-existing cannulas and affords the opportunity to administer protamine when the patient is placed on ECMO. The obvious disadvantage of right atrial-ascending aorta cannulation is the need for eventual formal decannulation and chest closure in the operating room. It is our routine practice to use peripheral VA-ECMO in PCS, reserving central MCS

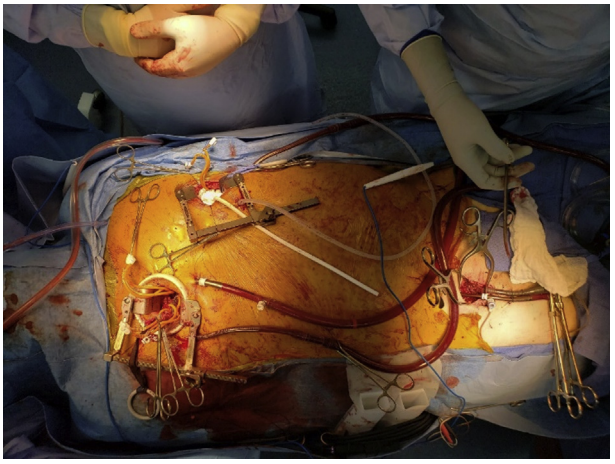

FIGURE 2. Conversion from femoral VA-ECMO to central MCS with right atrial and left ventricular apex drainage and aortic return.

for patients with PCS who have significant bleeding, thereby prohibiting chest closure, severe biventricular failure, or poor upper-body oxygenation. In the non-PCS setting, we have employed this cannulation strategy using a right anterior minithoracotomy in the second or third interspace to access the necessary structures (Figure 2).

Left Ventricular Apex–Axillary Artery

For patients with pure cardiogenic shock who do not exhibit any signs of compromised gas exchange requiring an oxygenator, the venous cannula can be removed from the femoral vein and inserted into the left ventricular apex through a minithoracotomy.[14] This configuration also liberates the femoral vessels and improves the potential for ambulation.

It must be noted that although this strategy can effectively regulate LV unloading, significant LV decompression may cause the aortic valve to stop opening, which may result in stasis of blood in the proximal aorta. Therefore, it is important to frequently monitor the arterial line for pulsatility and aortic valve opening using echocardiography. As apical cannulation can compromise the architecture of the LV apex, this approach is best suited to those patients who are candidates for bridge-to-durable VAD (using the pre-existing minithoracotomy as the access incision) or transplant. We very rarely use central ECMO as a bridge to transplantation due to historically poor outcomes.

Hybrid Configurations

In patients who require the full biventricular support of central MCS with persistent LV distension, we opt for a hybrid approach with femoral venous and LV apical drainage cannulas and a single axillary artery return cannula (Figure 3). This approach not only avoids a median sternotomy, thereby reducing the risks of bleeding, adhesion formation, and infection, but also facilitates future durable LVAD implantation via the minithoracotomy.

To facilitate ambulation in these patients, a right upper minithoracotomy or hemisternotomy can be performed to permit minimally invasive right atrial and ascending aortic cannulation and a small left minithoracotomy can be performed for left ventricular apex venting.

Surgical Biventricular Assist Device

In patients with refractory biventricular failure, independent MCS circuits may be required to assist each ventricle. One of the most common circumstances in

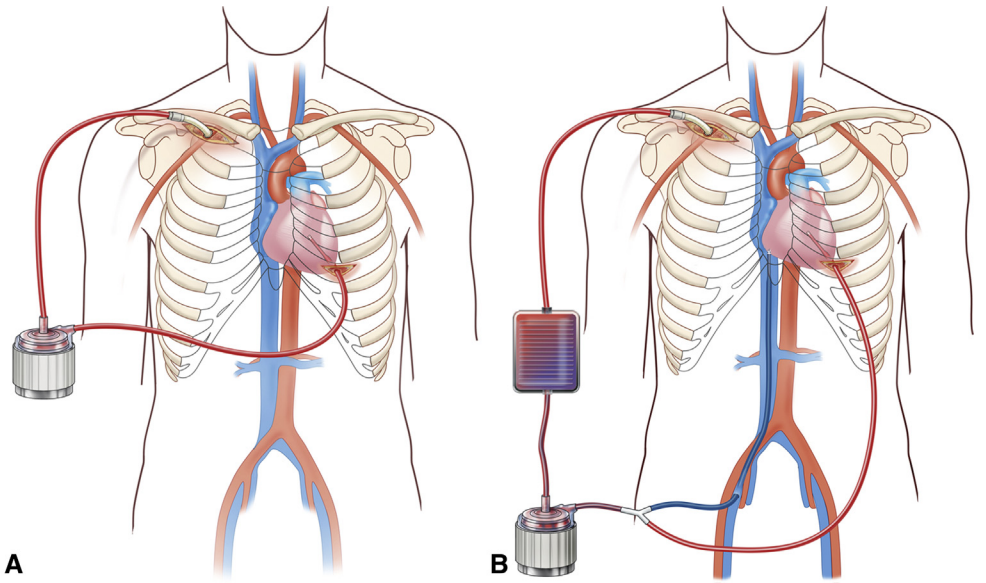

FIGURE 3. A, Left ventricle apical drainage with right axillary arterial return cannulation. B, Left ventricle apex with right femoral vein drainage and right axillary arterial return providing biventricular support and oxygenation. Adapted, by permission of Oxford University Press, from Takeda and colleagues.[14]

which this may occur is after LV assist device placement, where subsequent right ventricular failure can portend extremely poor outcomes.[15,16] To prevent the development of right heart failure, a temporary right VAD can be inserted at the time of LVAD implantation via the right atrium and pulmonary artery,[17] or the percutaneous double-lumen microaxial Protek Duo (TandemLife, Pittsburgh, Pa) can be placed to provide central right ventricular support after chest closure.[18]

CONCLUSIONS

In summary, central MCS is a valuable addition to the arsenal against cardiogenic shock. Despite its more invasive insertion, it overcomes many of the limitations of peripheral cannulation, including complete biventricular support, antegrade flow, and the facilitation of ambulation. In summary, we believe the primary indications for initiation of central MCS are as follows: (1) relative contraindications to peripheral cannulation (eg, access issues due to severe peripheral vascular disease or extreme obesity); (2) need for greater upper-body oxygenation (due to differential hypoxia with peripheral support); and (3) the need for full biventricular support.

Conflict of Interest Statement

Dr Naka reports financial grants from Abbott. Dr Salna 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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