Initiation and management of adult veno-arterial extracorporeal life support

Ahmet Kilic[1], Bassam N. Shukrallah[1], Arman Kilic[2], Bryan A. Whitson[1]

[1]Division of Cardiac Surgery, the Ohio State University Wexner Medical Center, Columbus, OH, USA; [2]Division of Cardiovascular Surgery, Hospital of the University of Pennsylvania, Philadelphia, PA, USA

Contributions: (I) Conception and design: All authors; (II) Administrative support: None; (III) Provision of study materials or patients: None; (IV) Collection and assembly of data: A Kilic, A Kilic; (V) Data analysis and interpretation: All authors; (VI) Manuscript writing: All authors; (VII) Final approval of manuscript: All authors.

Correspondence to: Ahmet Kilic, MD. Associate Professor of Surgery, Division of Cardiac Surgery, Department of Surgery, the Ohio State University Wexner Medical Center, 410 W. 10th Avenue, N-816 Doan Hall, Columbus, OH 43210, USA. Email: Ahmet.Kilic@osumc.edu.

Abstract: Extracorporeal life support (ECLS) for patients suffering from acute cardiopulmonary collapse is the penultimate therapy to provide hemodynamic stability. Although it can be a life sustaining as well as life-saving therapy, there are important factors that contribute to its success. In this review, we will describe the indications, management, pitfalls and limitations of ECLS.

Keywords: Cardiogenic shock; extracorporeal life support (ECLS); extracorporeal membrane oxygenation

Submitted Aug 15, 2016. Accepted for publication Aug 26, 2016.
doi: 10.21037/atm.2016.10.05
View this article at: http://dx.doi.org/10.21037/atm.2016.10.05

Background

Extracorporeal life support (ECLS) was initially developed to allow for the ability to perform open heart surgery while providing circulation, oxygenation and ventilation for the remainder of the body. Since inception, improvements in technology coupled with a better understanding of physiology have expanded the use of ECLS as a temporary therapy in the treatment of a spectrum of life threatening situations (1,2). In select situations where cardiopulmonary collapse would have resulted in immediate death, cardiogenic shock has become temporarily suspended until recovery, permanent life altering therapy or end of life discussions can be implemented. With the ability to possibly cheat death has come a host of questions as to when, how and who should have ECLS instituted. In addition to the technical details, debates of ethical and healthcare cost burden have come to the forefront. Nevertheless, ECLS as a last measure to support end organ function from cardiopulmonary collapse has saved countless lives and will continue to impact the way resuscitative medicine continues to evolve.

Initiation of veno-arterial extracorporeal life support (VA-ECLS)

Patient selection

ECLS is considered in those patients suffering from cardiopulmonary collapse with evidence of end-organ malperfusion that is not amenable to treatment with conventional inotropic, vasopressor or mechanical ventilation strategies. When used in strictly supporting the respiratory system with a working cardiovascular system, the preferred mode of ECLS is via a veno-venous configuration (VV-ECLS). This is beyond the scope of this article and henceforth will not be discussed in this present manuscript.

VA-ECLS is considered in those patients with cardiovascular collapse. Ongoing cardiogenic shock despite escalation of inotropes and pressors with ongoing evidence of continued end-organ hypoperfusion is an indication for VA-ECLS. The most common causes for these cases of refractory cardiogenic shock are fulminant myocarditis, post-cardiotomy shock, acute myocardial infarction, and post-heart transplant for early graft failure. Other

Table 1 Patient selection for VA-ECLS support

Indication
Post-cardiotomy support
Acute fulminant myocarditis
Acute myocardial infarction
Post-heart transplant for early graft failure
Refractory ventricular tachycardia or ventricular fibrillation
Hypothermia
Acute anaphylaxis
Pulmonary embolism
Peripartum cardiomyopathy
Contraindication
Age greater than 75 years
Active malignancy with expected survival less than 1 year
Severe peripheral vascular disease
End-stage renal disease on dialysis
Advanced liver disease
Current intracranial hemorrhage or other contraindication to systemic anticoagulation
Unwitnessed cardiopulmonary arrest with ongoing cardiopulmonary resuscitation
Witnessed cardiopulmonary arrest with cardiopulmonary resuscitation of greater than 30 minutes without return of spontaneous circulation

VA-ECLS, veno-arterial extracorporeal life support.

less common indications include refractory ventricular tachycardia or ventricular fibrillation unresponsive to conventional therapy, hypothermia, acute anaphylaxis, pulmonary embolism, peri-partum cardiomyopathy, sepsis-related cardiac dysfunction, and drug overdose.

As the indications for VA-ECLS are quite varied with multiple disciplines involved, there are no standardized, absolute contraindications to VA-ECLS. It is important though to consider the futility of therapy in those patients who have advanced age (>75 years), life expectancy from end stage/active malignancy with less than 1 year, severe peripheral vascular disease, end-stage renal disease on dialysis, advanced liver disease, current intracranial hemorrhage or other contraindication to systemic anticoagulation, unwitnessed cardiopulmonary arrest with ongoing cardiopulmonary resuscitation, and witnessed cardiopulmonary arrest with prolonged cardiopulmonary resuscitation (>30 minutes) without return of spontaneous circulation. The indications and contraindications for VA-ECLS are summarized in *Table 1*.

ECLS circuit

The VA-ECLS circuit consists of a pump, a membrane oxygenator, a controller, cannulas for venous return from patient to circuit and arterial outflow from pump to patient, and tubing. The pump is usually a centrifugal pump that can generate up to 4,000 rotations per minute and flow up to 8 liters per minute. The oxygenator functions not only to oxygenate blood but also to eliminate carbon dioxide. The controller for the oxygenator has the ability to alter the fraction of inspired oxygen into the system as well as the sweep in liters per minute for the purpose of carbon dioxide removal. The controller displays information to the clinician and allows for adjustments to pump speed in rotations per minute and ultimately flow through the entire system.

The drainage cannula is inserted into the venous system of the patient and is typically a large diameter (21–25 French) and longer (up to 60 cm) than its arterial counterpart. The venous drainage cannula can be either single or multi-stage to facilitate drainage and hence inflow into the ECLS circuit. The return cannula is inserted into the arterial system, is typically 15–19 French in diameter, and is shorter with lengths of 20–25 cm when inserted peripherally.

Cannulation strategies

In determining the best method of cannulation strategy for the initiation of VA-ECLS, it is important to consider the indications for therapy, patient baseline characteristics and anatomic hazards that can lead to either a successful or futile attempt. The initiation of VA-ECLS in patients suffering from post-cardiotomy shock, inability to wean from cardiopulmonary bypass or in cases of emergent re-entry sternotomy in a recent cardiac surgery patient represents arguably the most straightforward cannulation decision. For these patients, VA-ECLS is most often instituted via insertion of cannulas directly into the aorta and right atrium in a central cannulation technique manner. In establishing access for VA-ECLS, the arterial cannula is placed in the ascending aorta and the venous cannula placed in the right atrium. This is carried out via standard manner

with purse-string sutures placed around the cannulas much akin to how cardiopulmonary bypass is instituted during routine on-pump cardiac surgery. In the emergency setting, most surgeons directly perform an aortotomy and atriotomy with immediate insertion of cannulas into the appropriate position with the aid of an assistant holding the cannulas in place to initiate VA-ECLS and expeditious hemodynamic support. Once appropriate circulatory support is established, pursestrings around the cannulas are placed to secure them in place and hence reducing the time the patient spends in extremis and hence reducing the chance of neurologic devastation. The chest is left open with packing material and cannulas tunneled away from the midline wound. In certain instances where aortic insufficiency may be present and/or left ventricular distension is seen on echocardiography, a left ventricular vent can be directly inserted into the left atrium and "y-ed" into the drainage cannulae.

In the patient who is not status post recent cardiac surgery, peripheral VA-ECLS is the most common cannulation strategy. Peripheral cannulation requires vessels that can accommodate appropriate diameter cannulas for both drainage and perfusion. For these reasons and ease of access, the femoral artery and vein are the most frequently utilized vessels. Often times, peripheral access via the femoral vessels exists either through a resuscitative or diagnostic method and if in appropriate anatomic location, these can be guidewire exchanged after serial skin and subcutaneous dilation to cannulas to support VA-ECLS. It is essential that the wire is not bent or the cannulae be pushed with excessive force as this can cause a large retroperitoneal hematoma from vascular injury and not allow appropriate drainage or flow through the circuit. In the setting of significant resistance, there is often inadequate dilatation of the skin or subcutaneous tissue and additional, stiffer dilators can be utilized that do not routinely come in the cannula insertion kits. In addition, stiffer guidewires can be utilized to ease the transition to larger dilators and cannulas; however, appropriate judgement and attention to resistance is warranted in the non-image guided insertion of these stiffer guidewires.

There are multiple configurations that can be employed depending on the clinical scenario. The most common scenario is emergent VA-ECLS in the setting of active cardiopulmonary resuscitation. This is often during heroic measures to sustain life with a lack of pulse and pressure resulting in a hectic atmosphere. It is unreliable to use the usual measures to delineate venous versus arterial entry such as palpation of pulses, color of blood return, and presence of pulsatile flow. In this setting, the optimal configuration for cannulation is the ipsilateral femoral venous and femoral arterial access. If an intra-aortic balloon pump is in place, one can utilize the ipsilateral femoral venous access based on relative anatomy and the contralateral side for femoral arterial access.

Although ultrasound-guided cannula placement can be used in a "more controlled setting" to reduce the risk of vascular complications, in the setting of active cardiopulmonary resuscitation, this is often impossible. Once either venous or arterial access is established, one can use this as a relative anatomic guide for ipsilateral cannulation of the other vessel. The patient is commenced on VA-ECLS support after inserting the appropriate cannulae via the Seldinger technique previously described and after administration of systemic anticoagulation. The tip of the venous cannula should be in the distal inferior vena cava by the cavoatrial junction. This position can be confirmed by echocardiography or chest X-ray post-procedure. To further reduce the chance of vascular ischemia to the lower extremity of the femoral artery used, we routinely insert a 7 French armored (wire wound) catheter in the superficial femoral artery percutaneously by ultrasound guidance in an antegrade manner after the patient has been initiated on VA-ECLS support. This catheter is then connected to the femoral arterial VA-ECLS cannula to provide antegrade perfusion of the lower extremity with systemic anticoagulation and low-dose nitroglycerin to reduce the chance of distal limb malperfusion. Some groups do not routinely place this catheter but rather monitor lower extremity perfusion via oximetry, reserving catheter placement to those patients whose oximetry values decrease in that limb. Fluoroscopy is often helpful in percutaneously cannulating the superficial femoral artery in cases where it cannot be done with ultrasound guidance alone. Alternatively, a surgical incision can be made and the superficial femoral artery dissected out if percutaneous cannulation is unsuccessful.

Other methods of providing venous drainage access have been via internal jugular vein in cases of inferior vena cava thrombosis or inferior vena cava filters. Alternative arterial access sites are the right axillary artery via cut down and a chimney 8 mm graft sewn on in an end-to-side fashion. This method can also be performed on the common femoral arteries and can mitigate the need for distal superficial femoral arterial limb perfusion catheters. Whatever the method of cannulation is chosen, it is imperative to ensure

that cannulas are properly placed with distal perfusion to the limb that is being used for arterial access as well as ensuring that the cannulas are properly secured. Pursestring sutures at the insertion site can prevent migration of the cannulas both into and out of vessels. Pursestring sutures along the skin exit site, course of cannulas and connection sites with cannulas in tubing are also imperative in avoiding adverse events.

Management of VA-ECLS

Circuit management

Once VA-ECLS has been successfully initiated, it is important to remain vigilant about circuit management and proper function. The appropriate placement of cannulas should be confirmed and documented via abdominal and chest X-rays as soon as patient has been stabilized. This should be documented and checked on a routine basis with the distance of cannulas from entry site being marked every few hours to avoid slow migration of cannulas. Additionally, line pressures should be documented with respect to flow and trends noted. A slow but steady rise in line pressures could be the first sign of imminent failure of the circuit and development of a thrombus or malpositioned cannula. Ensuring appropriate oxygen flow and carbon dioxide removal with serial arterial blood gases should ensure a working oxygenator component of the circuit. Any fluctuations in measured flow despite a constant speed setting can signal trouble with either lack of preload, inability for appropriate drainage, resistance to outflow from the pump or clot in the circuit. Routine surveillance checks of the membrane oxygenator for build up of clot as well as ensuring enough laxity but no kinking of the tubing is a must for the maintenance of the circuit.

Anticoagulation

One of the first things concurrently with gaining access for VA-ECLS is to administer systemic heparin for an appropriate activated clotting time (ACT). It is important to get an appropriate systemic anticoagulation while de-airing the cannulas, cutting the tubing to desired length and initiating VA-ECLS. In the operating room setting, most centers use and ACT >220 seconds to ensure adequate blood thinness for the circuit. Out of the operating room, activated partial thromboplastin time (aPTT) >70 (depending on local laboratory normalization values) is desired for appropriate anticoagulation. This same value is kept with most patients on continuous unfractionated, intravenous heparin infusions. In patients with heparin induced thrombocytopenia, continuous bivalirudin can also be used. As a general rule, the higher the flow through the circuit the less chance for thrombus formation; however, the risk of stopping anticoagulation for clinical reasons must be weighed heavily with the risk of thrombus formation in the oxygenator and need for urgent replacement of the circuit and temporary cessation of VA-ECLS.

ECLS transportation

Patients on VA-ECLS represent a particular challenge for transportation and risk of cannula, circuit and tubing dislodgement. Whether it's transportation from site of VA-ECLS initiation to a tertiary care center or intra-hospital transportation for diagnostic and/or therapeutic measures, care must be reserved with multiple personnel taking part in the transportation. Regardless of the set up for VA-ECLS, critical care nursing, perfusion and a respiratory therapist at a minimum should accompany the patient. Particular attention to malpositioning of the cannulas, twisting or kinking of tubing, and maintenance of appropriate distance from patient to circuit must be adhered to during this standardized, highly orchestrated process.

Outcomes

There are an increasing number of studies looking at outcomes following VA-ECLS for refractory cardiogenic shock. According to the Extracorporeal Life Support Organization registry, 56% and 40% of adult patients survived ECLS for cardiac failure or in the setting of cardiopulmonary resuscitation, respectively (3). The survival rates to discharge or transfer in these cohorts were 41% and 30%, respectively. A single institution series of 179 patients supported on VA-ECLS demonstrated a 39% survival rate to discharge, with 45% surviving to 30 days (4). Myocardial recovery was demonstrated in 80% of survivors and 39% were transitioned to a more durable device. Older age and indication for support were predictors of mortality. A suprainstitutional network in Germany recently reported similar survival rates of 44% to discharge and 33% survival at 1.5-year follow-up in 115 consecutive patients undergoing VA-ECLS in refractory circulatory failure not related to cardiac surgery (5). An interesting conclusion of their study was the ability for rapid response initiation of

VA-ECLS in a defined regional setting with transportation subsequently to a tertiary center.

In the setting of a reversible insult such as acute fulminant myocarditis, a multicenter analysis demonstrated cardiac recovery and weaning from VA-ECLS in up to 76% of cases with survival to hospital discharge of 72% (6). A single institution series evaluating outcomes of VA-ECLS in the post-cardiac surgery setting in 233 patients demonstrated a lower survival rate to hospital discharge of 36% (7). A study comparing outcomes between 321 patients receiving conventional cardiopulmonary resuscitation and 85 patients receiving VA-ECLS in the setting of witnessed cardiac arrest demonstrated significantly improved hospital survival and 6-month survival with none or minimal neurologic impairment in the VA-ECLS group, particularly in cases of cardiac origin. Moreover, survival to discharge was 34% in the VA-ECLS group and 6-month survival with no or minimal neurologic impairment was 28% (8).

Aside from non-recovery of cardiac function and multi-organ failure, vascular complications are the most frequent cause of death in VA-ECLS. Bleeding is a major risk in VA-ECLS and can result from bleeding at the cannulation site, bleeding at a prior operative site, or hemorrhage elsewhere related to anticoagulation. In addition to systemic heparinization, platelet dysfunction and hemodilution of clotting factors contribute to the bleeding risk in patients supported with VA-ECLS. The rate of significant bleeding while being supported on VA-ECLS is approximately 40% (9). Malperfusion can also occur in patients on VA-ECLS with lower extremity ischemia (15–20%), the need for lower extremity fasciotomy or the development of compartment syndrome (10%) with a resulting 5% amputation rate (9). Acute kidney injury occurs in roughly 55% of VA-ECLS patients with 45% requiring renal replacement therapy (9). Neurologic complications have been reported in 10–15% with a stroke rate of 6% (9). Significant infection complicates 30% of VA-ECLS cases (9).

Future directions

VA-ECLS is an important modality in the armamentarium of clinicians who treat patients with acute, medically refractory circulatory failure. Despite improvements in technology and patient management, there remains a significant risk of mortality and morbidity in patients supported with VA-ECLS. There will undoubtedly be further advancements in technology, refinements in treatment algorithms and regional ability to initiate immediate VA-ECLS for patients presenting with acute heart failure. A healthy understanding of the indications and management will be essential in continuing to optimize survival while reducing the complication rates of this technology.

Other barriers for success, such as incomplete offloading or decompression of the left ventricle are currently being addressed. The idea of reducing myocardial wall stress and oxygen demand and ultimately improving the chance of ventricular recovery is a tantalizing one. A better understanding of the concurrent use of VA-ECLS with percutaneous ventricular support systems [intra-aortic balloon pump, Impella (Abiomed, Danvers, MA, USA)] in providing ventricular unloading in patients supported on peripheral VA-ECLS is needed.

Furthermore, educating the first line respondents such as emergency room, critical care and interventional cardiology physicians regarding the benefits of early initiation of this technology is paramount to increase survival from acute cardiogenic shock. Despite the ongoing challenges in improving results of VA-ECLS support, this technology has undoubtedly saved thousands of critically ill patients who would have likely died otherwise.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

References

1. Sakamoto S, Taniguchi N, Nakajima S, et al. Extracorporeal life support for cardiogenic shock or cardiac arrest due to acute coronary syndrome. Ann Thorac Surg 2012;94:1-7.
2. Chen YS, Lin JW, Yu HY, et al. Cardiopulmonary resuscitation with assisted extracorporeal life-support versus conventional cardiopulmonary resuscitation in adults with in-hospital cardiac arrest: an observational study and propensity analysis. Lancet 2008;372:554-61.
3. Extracorporeal Life Support Organization. ECLS Registry Report. Available online: https://www.elso.org/Registry/Statistics/InternationalSummary.aspx

4. Truby L, Mundy L, Kalesan B, et al. Contemporary Outcomes of Venoarterial Extracorporeal Membrane Oxygenation for Refractory Cardiogenic Shock at a Large Tertiary Care Center. ASAIO J 2015;61:403-9.
5. Aubin H, Petrov G, Dalyanoglu H, et al. A Suprainstitutional Network for Remote Extracorporeal Life Support: A Retrospective Cohort Study. JACC Heart Fail 2016;4:698-708.
6. Lorusso R, Centofanti P, Gelsomino S, et al. Venoarterial Extracorporeal Membrane Oxygenation for Acute Fulminant Myocarditis in Adult Patients: A 5-Year Multi-Institutional Experience. Ann Thorac Surg 2016;101:919-26.
7. Elsharkawy HA, Li L, Esa WA, et al. Outcome in patients who require venoarterial extracorporeal membrane oxygenation support after cardiac surgery. J Cardiothorac Vasc Anesth 2010;24:946-51.
8. Shin TG, Choi JH, Jo IJ, et al. Extracorporeal cardiopulmonary resuscitation in patients with inhospital cardiac arrest: A comparison with conventional cardiopulmonary resuscitation. Crit Care Med 2011;39:1-7.
9. Cheng R, Hachamovitch R, Kittleson M, et al. Complications of extracorporeal membrane oxygenation for treatment of cardiogenic shock and cardiac arrest: a meta-analysis of 1,866 adult patients. Ann Thorac Surg 2014;97:610-6.

Cite this article as: Kilic A, Shukrallah BN, Kilic A, Whitson BA. Initiation and management of adult veno-arterial extracorporeal life support. Ann Transl Med 2017;5(4):67. doi: 10.21037/atm.2016.10.05

