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Extracorporeal life support: Updates and controversies

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ABSTRACT

The use of Extracorporeal Life Support (ECLS) in children and adults has markedly increased during the past few years with over 4000 patients placed on ECLS every year in over 200 centers. This article focuses on updates to the physiology and mechanics of ECLS with use of magnetically levitated centrifugal pumps, hollow-fiber gas-exchange devices, and bi-caval dual-lumen catheters. We also explore controversies in management including indications, cannulation approaches, renal replacement, monitoring of anticoagulation, early ambulation, and termination of ECLS. Finally, we present changes in the systems that provide ECLS including the single-provider model and regionalization of care.

Introduction

The use of extracorporeal life support (ECLS) has increased dramatically over the past few years. In this article, we describe the various factors that have resulted in an increase in ECLS use. We describe technological advances and changes to the approach to ECLS including cannulation and management strategies as well as ongoing controversies.

Update on epidemiology

As of January 2014, of the 58,842 patients who have been managed using ECLS, over 10,000 are adults.[1] The dramatic increase in the use of ECLS starts with the rise of H1N1 viral pneumonia causing severe ARDS and respiratory failure.[2] Over a 3-month period from June 2009 to August 2009, 722 patients with H1N1 were treated at intensive care units in Australia and New Zealand, with 456 patients requiring mechanical ventilation.[3] Of these, 61 patients with confirmed influenza pneumonia were managed using ECLS for a median of 10 days with a 78% survival.[4]

Another major contributor to the rise in the use of ECLS is the conventional ventilatory support versus extracorporeal membrane oxygenation for severe adult respiratory failure (CESAR) trial. In the study, 180 adult patients with severe potentially reversible respiratory failure were randomized to conventional management or ECLS. There was a 63% survival in the ECLS treated group versus 47% in the conventional management group, translating to a one survivor for every six patients managed with ECLS.[5] Referral to an ECLS center was associated with an increase of 0.03 quality-adjusted life-years at 6-month follow-up.

Technological advances have not only simplified management of ECLS but also broadened the indications. Previous contraindications to ECLS have been reevaluated including prematurity, presence of intracranial hemorrhage (ICH), prolonged mechanical ventilation, and pre-ECLS cardiac arrest. ECLS may be successfully applied in the preterm newborn with EGA $>$ 30 weeks and birth weight $>$ 1 kg, although the incidence of ICH may be higher.[6,7] Development of ICH or extension of a previously present ICH was nonexistent when heparin administration was minimized and a proximal venous drainage cannula placed.[7,8] Reasonable outcomes have also been demonstrated when ECLS has been instituted in the setting of grade 1/2 ICH regardless of age group.[9] Mechanical ventilation pre-ECLS is no longer considered a contraindication to ECLS; although initiation of ECLS earlier in the course of respiratory insufficiency may reduce morbidity and mortality.[10]

Cardiac arrest is also not considered a contraindication and, in fact, may be an indication for ECLS at many centers.[11] The use of ECLS for cardiopulmonary resuscitation (ECPR) has increased with a survival rate of 30–40% on over 4000 patients per the ELSO registry.[1] In a series in Taiwan, over 45% of patients survived when ECPR was used as a strategy in children, with an average CPR duration of 40–50 min.[11] Predictive factors for mortality included higher pre-ECPR lactate levels and post-ECPR renal failure, and no difference in outcome was observed when in-hospital arrest was secondary to cardiac causes. In other series, over 70% survival to hospital discharge was seen for ECPR in patients who arrested in the ICU with good neurologic outcomes even with chest compressions during cannulation.[12,13] Predictive factors for mortality were post-ECPR lactate levels and serum ALT.[12] Using propensity-score

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analysis, adults who had ECPR had twice the survival of those who received CPR alone.[14] At our center, we have not routinely adopted ECPR except in post-cardiac surgery patients in the ICU.

Improvements in technology

Much of the expansion in the use of ECLS is due to novel advances in circuitry technology, which simplified the management, decreased complications, and provided more support to each individual patient. Components of the newer circuitry are associated with lower priming volume, provide less resistance to flow, and decrease hemolysis rates. Magnetically levitated centrifugal pumps have more efficient designs that are safer, more reliable, can be used for an extended time, reduce heat generation, and decrease hemolysis.[15–21] Newer hollow-fiber gas-exchange devices allow for lower priming volumes and have decreased plasma leakage, which enhances clinical application of these low-resistance lungs.[22–24]

Perhaps the largest change in ECLS technology is related to the introduction of bi-caval dual-lumen cannulas. Veno-venous ECLS is now most commonly provided in children and adults using bi-caval dual-lumen cannulas. These cannulas allow for increased venous drainage and additional support while using percutaneous single-site venous cannulation, rather than the traditional two-site cannulation. Thus, veno-venous ECLS can easily be performed in those patients who require gas exchange, but not cardiac, support. As a result, ligation of a carotid vessel is avoided. However, placement of these cannulas can be fraught with complications unless performed with appropriate ultrasound and fluoroscopic imaging. Furthermore, management of patients after cannulation includes monitoring via ultrasound and daily radiographs for migration or displacement of the catheters with timely repositioning when a problem is identified.

When veno-arterial ECLS is required, the internal jugular vein and common carotid artery are traditionally used. There is an increased risk of neurologic injury when the common carotid is ligated for access, although the rate of injury does not vary with age. Interestingly, when stroke rates are compared to those without carotid ligation, the difference is only approximately 1.4% higher; therefore, carotid artery cannulation should be considered the mainstay of access when veno-arterial ECLS is required in this population with a high risk of mortality.

In older children and adults, the femoral artery may be used for cannulation in lieu of the carotid artery when veno-arterial ECLS is required. Femoral artery cannulation may be associated with ipsilateral ischemic limb injury due to obstruction of femoral blood flow by the cannula. In adults, a distal perfusion pressure less than 50 mmHg measured at the ankle can lead to critical limb ischemia.[25] Lower extremity ischemia may be avoided by placement of a distal reperfusion cannula such as in the posterial tibial artery or the distal femoral artery.[26,27] Alternatively, a “stove pipe” end-to-side graft may be placed onto the femoral artery with the cannula placed into the end of the graft.[28] Thus, obstruction of the femoral artery is avoided, though this approach can be time-consuming and technically demanding. At our center, we routinely place a posterior tibial artery cannula in those children who require a femoral artery cannulation.

The other complication of femoral arterial cannulation is the “cool head, warm legs” syndrome seen with mixing of hypoxic blood pumped from the native heart with highly oxygenated blood provided from the ECLS circuit via the femoral artery. Placement of an additional internal jugular vein cannula allows variable flow of arterialized blood through the femoral arterial or internal jugular venous cannulas. Known as veno-arterial-venous (V-AV) ECLS, flow through the femoral artery can be emphasized when enhanced hemodynamic support is required or through the internal jugular venous cannula as further gas exchange is required. While V-AV may be highly effective, this configuration can be difficult to manage, as the flow to each of the vessels must be carefully titrated. Frequently, the patient is transitioned to a veno-venous ECLS via the femoral–jugular veins with removal of the arterial cannula once the heart has fully recovered.

Finally, thoracic cannulation for VA ECLS has been described for severe sepsis.[29] Approximately 10% of patients with septic shock were managed with VA ECLS via central cannulation. By using thoracic cannulation, larger cannulas were placed, allowing for increased flow and greater hemodynamic support. The survival rate was 73% in patients who were cannulated using a sternotomy in this series, without severe disability on long-term follow-up. Sepsis and multiorgan failure should be considered an indication for ECLS,[30] and thoracic cannulation might provide additional support.

Providing the most updated care using ECLS requires extensive investment in resources including standardized protocols and training and continuous adoption of newer management strategies. Many countries, partially forced by the H1N1 epidemic, have regionalized centers to provide ECLS, resulting in improved outcomes.[4,31–34] A tiered system may allow optimization of care for those with ARDS, thus allowing the sickest patients to be cared for at locations with dedicated resources to provide ECLS. Such regionalization might also serve as the basis for a pandemic plan.[35]

Management controversies

As ECLS technology advances, as the indications for ECLS broaden, and as use increases, it is natural that new approaches to and sometimes controversies in the management of ECLS have developed. Prominent areas of change and controversy surround the optimal methods and monitoring of anticoagulation, the use of renal replacement therapy, early patient mobilization on ECLS, the appropriate caregiver model, the need for team-based training, and indications for futility and discontinuation of ECLS.

There are advocates and opponents for each of the tests for monitoring anticoagulation. Proponents of the activated clotting time (ACT) argue that it provides a broad, inclusive exam of clotting time that takes into account many factors such thrombocytopenia, factor depletion, and inflammation in addition to heparin levels.[36] At our center, we primarily use ACT to guide heparin administration. Thromboelastography (TEG) uses the viscoelastic properties of the blood to look at the initiation of clotting through the dissolution. When using TEG, the reaction time represents the time to initial fibrin formation, affected by heparin among other things. The use of activated partial thromboplastin time (aPTT) on recalcified citrated plasma allows titration of heparin using values on the intrinsic clotting pathway. As the reagent used at an institution may vary, the actual values are not comparable; however, the aPTT can be used to delineate between low and moderate levels of anticoagulation better than ACT when heparin is used.

In an international survey administered to members of ELSO, unfractionated heparin was universally used as the mainstay for anticoagulation on ECLS, with monitoring focused on ACT in 97% of the respondents.[37] Antithrombin III levels, anti-factor Xa assay, and TEG were also commonly employed to monitor anticoagulation. As each of these tests examines various aspects of the coagulation system, they cannot be directly compared.[38] However, antiXa levels correlated with heparin dose better than do either the aPTT or ACT.[39,40]

In patients for whom unfractionated heparin cannot be used due to antithrombin III deficiency or heparin-induced