The role of extracorporeal mechanical assists (ECLS et al.)

Stephan M. Ensminger, Thomas Puehler, Michael Benzinger, Michiel Morshuis, Lukasz Kizner, Jan F. Gummert

Herz- und Diabetes-Zentrum NRW, Klinik für Thorax- und Kardiovaskularchirurgie, Universitätsklinikum der Ruhr-Universität Bochum, Bad Oeynhausen, Germany

Abstract

Extracorporeal mechanical assist earlier named extracorporeal circulation (ECC) has evolved markedly over recent years. ECLS (extra corporeal life support) is employed for the management of life threatening heart or heart and lung failure, when no other treatment option is likely to be successful. Mostly it is instituted in an emergency or urgent situation after failure of other treatment modalities. ECLS is used as temporary support, usually awaiting the recovery of organs. It can also be used as a bridge to a more permanent supporting device or cardiac transplantation (bridge-to-decision-patient). ECLS is implanted in a veno-arterial configuration (either peripheral or central cannulation) for the treatment of heart failure. This is usually seen post-cardiotomy, post-heart transplant and in severe cardiac failure due to almost any other cause (e.g. cardiomyopathy, myocarditis, acute coronary syndrome with cardiogenic shock).

In contrast ECMO (extracorporeal membrane oxygenation) is used for respiratory failure and usually involves peripheral cannulation using the femoral veins +/- internal jugular vein if required. The indications for ECMO are respiratory failure, most commonly due to adult respiratory distress syndrome (ARDS), as a consequence of pneumonia, trauma or primary graft failure following lung transplantation. ECLS is also used for neonatal and paediatric cardiac and respiratory support. In this review, the technical aspects of ECLS and ECMO cannulation and the different pump systems are outlined. In addition, indications, complication rates and outcomes are discussed.

Key words: extracorporeal mechanical assist, extracorporeal membrane oxygenation, mechanical circulatory support, heart failure, short term support

Abbreviations

ECMO Extracorporeal membrane oxygenation
MCS Mechanical circulatory support
ARDS Adult respiratory distress syndrome
ECLS Extracorporeal life support

Introduction

After initially disappointing preclinical experiments and not particularly encouraging clinical results with extracorporeal circulation (ECC), John Gibbon’s pioneer work marks the start for the development of ECC in the field of heart surgery. Since 1953 the use of the heart-lung machine in cardiac surgery has been steadily increased world-wide and is
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nowadays a standard requisite for modern cardiac surgery. However, during the early years the limiting factor of its use was the massive trauma to the blood components caused by oxygenators and pumps including significant hemolysis often followed by multi organ failure even after a short running time of less than one hour. Since that time ECC has been steadily improved and in 1971 Hill et al. succeeded in bridging a patient with posttraumatic lung failure for 72 hours with extracorporal membrane oxygenation by using a venous/arterial system which was inserted through the femoral artery and femoral vein and this patient could be weaned successfully from ECC (1-4). Already back in 1977 the first series of 28 patients (14 neonates/infants and 14 adults) with ECLS-support was published by Bartlett et al. showing respectable results (5). The further development from bubble- to efficient membrane oxygenators, from roller- to centrifugal- pumps as well as the minimization of the ECLS-systems led to an increased use and an extension of the indications for ECLS therapy. Since 1989 more than 40,000 ECLS and ECMO implantations in over 170 centres have been registered and documented in the Register of the Extra Corporeal Life Support Organization (6). Today ECLS and ECMO therapy is used by numerous centers worldwide and adds to a steadily growing cooperation with other medical departments.

Left ventricular assistance (LVA) and extracorporeal life support (ECLS)

In contrast to left ventricular assistance only supporting the patient’s heart ECLS systems can also if necessary provide additional full lung support and therefore an additional oxygenator is integrated to the tube system. ECLS systems are always deployed in a venoarterial configuration (either peripheral or central cannulation) for the treatment of cardiogenic shock. This is usually seen post-cardiomyotomy, post-heart transplant and in severe cardiac failure due to almost any other cause (e.g. cardiomyopathy, myocarditis, acute coronary syndrome with cardiogenic shock).

ECMO

Veno-venous ECMO is used for respiratory failure and usually involves peripheral cannulation using the femoral veins +/- internal jugular vein if required. The indications for veno-venous ECMO are respiratory failure, most commonly due to adult respiratory distress syndrome (ARDS), pneumonia, trauma or primary graft failure following lung transplantation (8).

Access sites

In general for ECLS as well as for ECMO peripheral access is favorable because target vessels are easy to reach. ECLS devices are used in a veno-arterial fashion (Fig 1 A) whereas ECMO is operated in a veno-venous-fashion (Fig 1B). The venous cannulation in veno-venous ECMO is best carried out via the jugular or the subclavian vein and the femoral vein on the same site of the patient. For arterial cannulation in the ECLS setting, a central cannulation is possible via the aorta or peripherally via the femoral arteries. In general, central cannulation is preferred in case of worse oxygenation combined with heart failure. Technically, after sternotomy
The arterial cannula is placed directly into the ascending aorta or as an alternative in the right-sided subclavian artery by direct cannulation or through an “open approach” by connecting a vascular prosthesis performing an end-to-side anastomosis with the subclavian artery (9). In individual cases, ECLS may also be used as biventricular assist devices, involving cannulation of the left and right ventricle and the aorta and pulmonary artery (Fig. 2). Peripheral arterial cannulation may be either by a direct percutaneous approach using the Seldinger technique or by a surgical cut down and connecting a vascular graft via an end-to-side anastomosis with the femoral artery. The latter technique is used in particular for small vessel diameters, or in patients with peripheral arterial occlusive disease. Percutaneous cannulation is the method of choice under cardiopulmonary resuscitation and the possibility of ultrasound visualization of vessel diameters has increased the safety profile of percutaneous cannulation in Seldinger technique (10).

A study with 176 patients after ECLS/ECMO implantation (31 patients with ECMO/145 patients with ECLS) reported vascular complications in 17 patients (10%) using the veno-arterial approach (dissection, false aneurysm, hematoma, limb ischemia), whereas only 2 patients required surgical revision after false arterial puncture in the ECMO group. However, vascular complications were not associated with a worse outcome (11).
ECLS/ECMO systems

ECLS/ECMO systems include a driver consisting of a controller and a pump. There are different types of pumps available on the market such as roller-, centrifugal and diagonal-pumps. The most frequently used systems are the Rotaflow system (Maquet Cardiopulmonary, Hirrlingen, Germany) (Fig. 3A), available since 1993, a centrifugal-pump based system Biomedicus (Medtronic Perfusion-Systems, Minneapolis, USA) (Fig. 3C) commercially available since 1973, and the CentriMag system (Levitronix, Zürich, Switzerland) (Fig. 3D) which was approved in 2003. In addition, the diagonal pumps Delta-stream DP1–DP3 (Medos Medizintechnik AG, Stolwerk, Germany) (Fig. 3B) received CE-mark in 2003. These modern powerful systems are able to warrant clinically required flow rates of 1–4 l/min at 1000 to approx. 4000 RPM for several weeks and the respective trauma of blood components has been minimized in these systems (12). Table 1 gives an overview of the technical details of each ECMO pump.

Oxygenators

Gas exchange is accomplished by pump driven blood flow and a passive oxygen and carbon dioxide gradient through the microporous membranes of the oxygenator tubes. Membrane oxygenators have replaced the formerly used bubble oxygenators as they warrant a more efficient and stable oxygenation of the blood. Membrane oxygenators consist of capillaries with a microporous surface structure and gas exchange occurs by diffusion. However, during long-term usage particle deposition within the oxygenator occurs leading to a creeping “plasma leakage” (Hydrophylisation). This process ultimately results in insufficient gas exchange and oxygenator failure. A recent development is the
so-called diffusion-capillary-membrane-oxygenator. These capillaries are covered with an extra thin layer of silicone or polymethylpentene which ultimately prevents the loss of plasma components. Oxygenators designed in this way are characterised by increased durability and therefore of great importance for long term ECMO support (12).

Coating of the system/anticoagulation

The most important task of current ECLS/ECMO therapy is to avoid device related complications such as thromboembolic events as a consequence of platelet activation by the artificial surface of the tubes of an ECLS/ECMO system and bleeding events as a consequence of a ridged anticoagulation protocol. Therefore, most of the modern ECLS/ECMO-tubing-systems are coated with heparin, e.g. Rheoparin® (Medos Medizintechnik AG, Stol-
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werk, Germany) or Bioline® (Maquet Cardiopulmonary, Hirrlingen, Germany) or use phosphorylcholin-coating (Sorin, Milano, Italy) to minimise the contact between blood components – in particular platelets – and the artificial surface of the tubes. This results in reduced immunological activation of the respective blood components, which in turn enables to reduce the systemic anticoagulation with and also tolerate a PTT of about 50-60s (13,14). In particular during the use of the interventional lung assist a prospective study was able to show that additional application of 1.5 mg/kg bodyweight acetylsalicylic acid (ASS) resulted in improved gas exchange and longevity of the oxygenators (15,16).

Commercially available ECLS/ECMO-systems

Nowadays there are several CE-certified ECLS/ECMO-systems commercially available and approved for in patient use up to 30 days. ECLS/ECMO systems such as the Cardiohelp® (Maquet Cardiopulmonary, Hirrlingen, Germany) (Fig. 4 A,B), the LifeBridge B2T® (Lifebridge Medizintechnik AG, Ampfing, Germany; Fig. 4C) and the CentriMag® Left ventricular assist system (LVAS) (Levitronix GmbH, Zürich, Switzerland; Fig. 4D) and the Medos-Deltastream-System (Medos Medizintechnik AG, Stolwerk, Germany) are very well suitable for the use directly at the patient’s bed. As these systems are rather small and have a compact configuration they are also the device of choice for inter-hospital patient transport by ambulance or helicopter (17-19). ECLS/ECMO therapy is nowadays more and more frequently used for the transport and stabilisation of cardiorespiratory unstable patients giving them a chance to relocate in highly specialized centers and to recover with acceptable results. Transport times of up to 3 h are described so far (20,21). Furthermore, ECLS/ECMO therapy has found its place after inhalation and blast trauma in soldiers from battle zones enabling their rescue by plane or helicopter transportation (23).

Indications

Although there are nowadays recommendations for the implantation and use of ECLS/ECMO (23), in numerous cases an indication for implantation of an ECLS/ECMO system has to be decided on an individual patient base with regard to comorbidities, patient age and the duration of mechanical resuscitation. Nowadays, this is more or less the question to identify a bridge-to-decision patient and our strategy is not the concept that a long term and permanent device should always be placed in an emergent situation. The bridge-to-decision patient has typ-
ically contraindications for permanent ECLS along with an uncertain transplant candidacy due to uncertain neurological status, uncertainty of social support and unknown reversibility of their multi organ failure. A respective algorithm for decision making is shown in Fig. 5. Rapid stabilization of the patient is of primary importance, adequate systemic perfusion must be provided with minimal complications, neurologic functions must be ascertained and end organ function must be allowed to recover.

Post-Cardiotomy-Syndrome: The classic indication for implantation of an ECLS system in cardiac surgery is the so called ‘Post-Cardiotomy-Syndrome’ characterised by a myocardial pump failure and occurring in 1-2% of patients after cardiac surgery. In particular in pediatric cardiac surgery ECLS support after most of the times complex cardiac surgery plays an important role, however, survival in this patient group is only about 35-45% after ECLS therapy (24,25). In a recent study Ras-tan et al. (26) retrospectively analysed ECLS-support as a treatment for post-cardiotomy syndrome in 517 patients with a mean age of 63.5 years. Operative procedures ranged from isolated CABG (37.4%) to thoracic organ transplantation (6.5%). The authors could wean 63.3% of the patients of the postoperative ECLS support. Interestingly 42% of the patients required ECLS support immediately after the procedure and 58% of the patients were treated with ECLS support in a time frame of the first postoperative 63h. After successful weaning, only 24.8% of the patients were discharged from the hospital. The median ECLS supporting time was 3.3±2.8 days and only 13.7% of the patients were alive after five years. Similar results have been published by Wu et al. (27). This group also retrospectively analysed 110 patients on ECLS support with a mean age of 60±14 years. The mean ECLS support time was 143±112 hours. Only 46 patients survived and were discharged from the hospital. Risk factors for death on device were an ECLS

![Exemplary algorithm for decision making in ECLS/ECMO implantation.](image)
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supporting time >110 h, a patient age >60 years and a serum bilirubin concentration above 103 µmol/l (>6 mg/dl) (28).

Temporary right heart failure: A further indication for short term ECLS support is the treatment of temporary right heart failure with respiratory failure after LVAD implantation. The cannules are usually placed in the right femoral vein and the pulmonary artery. If a subcutaneous Dacron conduit connected to the pulmonary artery is used, this system can be weaned and explanted without reopening of the chest (29).

Prolonged resuscitation: Experiences with ECLS support during cardiopulmonary resuscitation are limited to small patient numbers. In particular in children and young adults its use is encouraged in the sense of a last option therapy or also called ‘bridge to decision’ therapy until results of further diagnostics are available and additional therapeutic options can be evaluated (30,31). Examples include drowning accidents, polytrauma, intoxications and myocardial infarctions with subsequent cardiogenic shock. Data about the use of a ECLS during cardiopulmonary resuscitation from the ELSO-Register revealed that only 27% of the treated patients were finally discharged from the hospital. Brain death occurred in 28% of the patients who did not survive and risk factors for death were low oxygen partial pressure (paO2), low blood pressure during resuscitation and the use of hemofiltration during ECLS (28).

Terminal heart failure: During terminal heart failure the following parameters have been suggested to help in decision making which patient to support: a cardiac index (CI) <2.0 l/min/m², a capillary wedge-pressure of >20 mmHg and a systolic blood pressure <90 mmHg. However, as terminal heart failure usually develops over a certain amount of time and therefore permanent support and transplantation play a more important role than short term ECLS. In this context – if at all – the ECLS is mainly used as a Bridge-to-Bridge or rarely as a Bridge-to-Transplantation or permanent support (32,33). In addition, experimental data show that ECLS support does not warrant a completely volume unloaded left ventricle and wall tension can even increase (34). Moreover, there are only very few reports about mid and longer term ECLS with immobilization of the patient being the major problem (35).

Future perspective

During recent years ECLS/ECMO therapy has evolved in smaller and more powerful devices made increasingly user-friendly. The use of ECLS/ECMO systems during recent years expanded into a variety of disciplines including cardiac surgery, anesthesia and cardiology requiring an interdisciplinary treatment approach for these patients aiming for better results. In Germany this led to the formation of a Working Group for extracorporeal circulation in cardiac surgery trying to establish guidelines (36). In addition increasingly bio-compatibilized oxygenators and further miniaturization of ECLS/ECMO systems will play a crucial role for long term ECLS/ECMO support. As a consequence of ever increasing numbers of complex coronary interventions or catheter based valve replacements in peripheral cardiac catheterization laboratories complications can occur and a prolonged use of ECLS/ECMO support or prolonged resuscitation may be a challenge. Especially in this patient cohort outcomes should be thoroughly looked at and analysed.

Conclusion

The ECMO is an established therapy option in severe global respiratory failure to enable lung protective ventilation. Thereby, the survival of these patients has improved by ECMO therapy. The ECLS is used in the context of global cardiopulmonary failure. In particular during resuscitation, a fast access through the
femoral vessels is guaranteed in most of the patients. In addition, further miniaturization of ECLS components and new antithrombotic surface coatings will result in even more flexibility of the systems and a reduction of complication rates.

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Correspondence address
Prof. Stephan Ensminger, M.A. D.Phil.
Klinik für Thorax- und Kardiovaskularchirurgie
Universitätsklinikum der Ruhr-Universität
Bochum
Georgstr. 11
32545 Bad Oeynhausen
Germany
ensienger@hdz-nrw.de