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# **Introductory Chapter: Evolution of ECMO from Salvage to Mainstream Supportive and Resuscitative Therapy**

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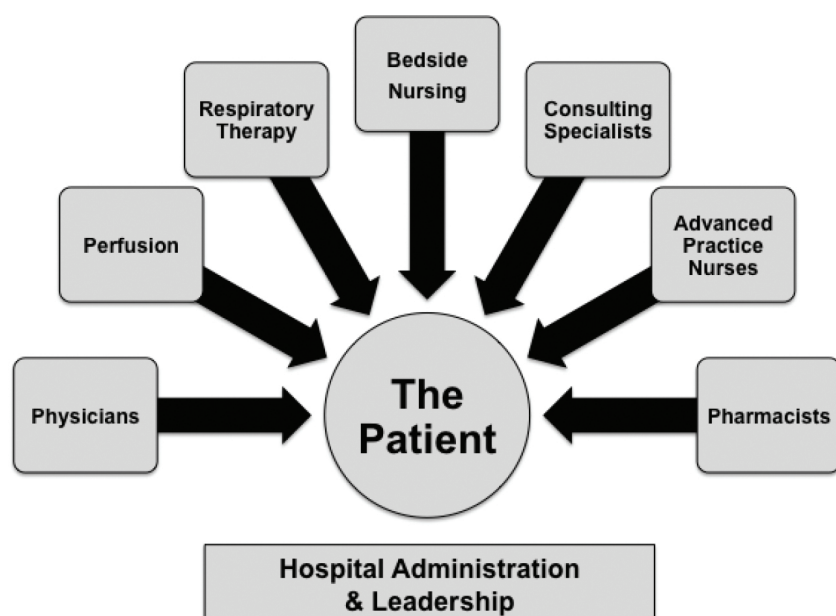
## **1. Introduction**

Extracorporeal membrane oxygenation (ECMO), also known as extracorporeal life support (ECLS), has evolved from a salvage form of life support, used only in cases in which all other therapies have failed, to a mainstream therapy for patients experiencing acute cardiac and/or respiratory failure. Initial experiences were associated with poor outcomes and few survivors [1]. Challenges to success included difficulties in optimal patient selection, crudely designed and implemented technologies, an unclear understanding of the relationship between the patient and the extracorporeal circuit, lack of management guidelines, and difficulties in managing complications and guiding patients. However, over the past 20–30 years, there has been a growing recognition of the potential life-saving benefits of the role of extracorporeal support in allowing the failing heart/lungs to heal, possibly allowing for recovery, or serving as a bridge to more definitive end-organ replacement therapy, such as ventricular assist devices or transplantation [2]. This evolution has reflected a long journey—a journey that continues to evolve in part due to the hard work, dedication, and overall commitment by those who recognize that tremendous potential for ECMO to bring hope and restore life to those who would otherwise die [3].

This text reflects the collective efforts of those, worldwide, who have dedicated countless energy to achieving a better understanding of those details that will ultimately yield better outcomes. The key to clinical success—and not just in a single patient but also for a program and an Institution—is Teamwork.

The first step in success is understanding the theory, technology, and the development of a team. ECMO requires a comprehensive Team—and one that must be prepared to implement the therapy anytime and anywhere. The specifics of the Team may vary from program to program—but they must be organized and developed in advance. Effective Teams must work

and communicate together—they must trust and value the expertise and dedication that each member must bring to the patient. Most importantly, effective Teamwork must rise above traditional professional hierarchies and embrace in the principles of Crew Resource Management in which everyone has a voice and that voice is valued and respected. The Team must comprise of experts in all related disciplines—perfusionists, pharmacists, physicians (of all specialties—surgeons, critical care, pulmonary, infectious disease, etc.), nursing (bedside and advance practices), respiratory therapists—and most importantly, a champion to lead them all. The tremendous need for dedicated resources—often working long hours and under stressful conditions—also mandates the support and encouragement of hospital leadership and administration at all levels (**Figure 1**) [4].



**Figure 1.** ECMO "Team".

Before the first patient is supported in ECMO, the Team must be prepared. The pump and circuit must be available, bedside nursing must be prepared and educated, protocols and guidelines need to be developed, and goals must be set [5]. The chapter by Yiu and colleagues on simulation training helps to outline those steps necessary to build and educate a Team. Clearly, a foundation in education is critical to success.

One of the most important aspects of ECMO is patient selection and choice of therapy. As the chapters in this text illustrated, there are significant differences in the support for failing lungs, failing heart, or both. Understanding the difference between veno-veno (VV) and veno-arterial is an important step even before consideration is given to patient selection. Indications for each type of therapy are critical to understanding the goals, and patient selection is an important first step. Much like understanding the differences between veno-veno (VV) and veno-arterial is important, so are the indications and timely implementation of the therapy. Various chapters in this text provide insight into some of the technical options for cannulation strategies, including some of the key differences between veno-veno and veno-arterial support and

circuit. The chapter describing the techniques and benefits of unusual cannulation algorithms—specifically triple cannulation—by Dr Christian helps to build on the chapter by Dr Ramaiah on the basics of ECMO cannulation.

As described above, the first step to a successful program is optimal patient selection. Recognizing that even successful programs have outcomes that range from 60 to 70% survival for ideally selected patients for veno-veno support to sometimes less than 20–30% for veno-arterial- and ECMO/ECLS-supported emergent cardiopulmonary resuscitation (E-CPR) [6, 7]. While it would not be unusual for starting programs to initially have lower success rates, over time, with experience, improvements in Institutional protocols, and better (and more timely) patient selection, the hope that outcomes would improve. Ironically, as programs become more successful and outcomes improve, there are also—as seen in other areas of innovative and novel clinical therapies—attempts at pursuing high-risk cases that might be slightly out of the boundaries of the traditional indications for therapy. Such dynamic attempts to support lower than higher risk patients on ECMO are not uncommon and typically based upon Institutional (and sometimes, personal) outcomes. A series of successful low-risk patients then help justify attempting the salvage a higher-risk patient and, conversely, potentially less than ideal outcomes in higher-risk patients might then limit selection back to lower risk patients. Nevertheless, there must always be Institutional processes established for reviewing outcomes (clinical and financial), and continuous quality improvement with refinements in local guidelines and protocols. Team engagement, including both bedside clinical support staff and hospital administration and leadership, is critical and cannot be emphasized enough. Active membership and participation in ELSO (the Extra-Corporeal Life Support Organization: <https://www.elseo.org>) can provide important international outcome data to benchmark institutional success. In addition, membership in such organizations provide a community to exchange ideas, partner with colleagues, and serve as a resource for important and timely communications and developments in the field.

It is also important to understand that there are significant differences in patient populations that might require either VV or VA support. Inherent with these different populations comes different patient selection criteria, management guidelines, expectations, and goals of therapy. Specific chapters in this text help outline the nuances of selecting patients who are providing support—and hopefully weaning from support—to these very clinically diverse populations.

1. Neonatal applications (Dr Rais-Bahrami).
2. Support for lung transplant patients (Dr Young-Jae).
3. Support for heart transplant patients (Dr Loforte).
4. Applications for high-risk catheterization lab procedures—often in the setting of cardiogenic shock (Dr Ganyukov).
5. Applications in cardiac arrest (Dr Brunner).

One of the most rapidly expanding indications for the ECMO therapy is in unusual patient populations. As it is becoming more recognized that ECMO can be extremely useful in patients experiencing acute cardiopulmonary end-organ dysfunction, there is becoming a greater role

for the ECMO support (even if temporary) for high-risk procedures [8]. Typically, such applications are limited to high-risk procedures in the catheterization laboratory as defined by complex anatomy, baseline impaired cardiopulmonary function, or to reduce the inherent procedural-associated risk of complex interventions such as percutaneous aortic valve procedures, coronary or cardiac structural interventions, or electrophysiologic-guided ablative procedures for malignant or complex arrhythmias. The primary goal of providing support during these procedures is to minimize the inherent risks of end-organ dysfunction or failure during the anticipated cardiopulmonary impairments during the procedures or to mitigate the risk of a physiologic catastrophe in the event of a procedural-associated cardiopulmonary collapse and the inherent time delay (even if anticipated) in resuscitative interventions and reestablishing hemodynamic stability [9]. The chapter by Dr Ganyukov illustrates clearly the growing successes and applications in these areas.

The growing use of ECMO in patients experiencing “trauma” or out-of-hospital accidents, such as a blunt force or penetrating injuries, is also becoming more common [10]. Trauma patients also reflect a unique management challenge because often their injuries are extensive, involve multiple organ systems, are at high risk for bleeding (even if they are not already coagulopathic from the growing use of anticoagulation or antiplatelet agents), and are often susceptible to secondary nosocomial problems. Such nosocomial issues can often be catastrophic, difficult to manage, and be of greater physiologic impairment than the initial injury. Problems, including septic shock from acquired infections, cardiogenic shock from acute coronary syndromes (and potentially superimposed acute or chronic heart failure), pulmonary emboli from poor or limited mobility, and adult respiratory distress syndromes with pulmonary failure (either as a primary or secondary process), all lend themselves to support with ECMO. Furthermore, despite the inherently high risk for bleeding after an injury, there is also a growing experience with using ECMO for support the acutely injured lung or heart (i.e., pulmonary or cardiac contusions or destructive structural injuries that might require intervention) in these patients who often have multiple other injuries. A rapidly expanding area is also the use of ECMO to support higher risk trauma-associated procedures in which the need for early definitive repair, such as orthopedic stabilization, must be balanced against the risk of surgery in a patient with already difficult to manage cardiopulmonary status [11]. Ronson and colleagues, in their chapter on the use of ECMO in Trauma, discuss this evolving area in detail.

Once the decision to put a patient on support is made and the therapy is initiated, it must be made clear that the real work in patient management begins. Patient management on ECMO can be divided into several key areas—with each focusing on standard of care based upon evidence-based practice management of topics independent of the need for ECMO as a cornerstone to clinical success. However, any and all management decisions must be made in the context of the complex and often practical limitations of caring for patients on ECMO. For example, the management of acute neurologic problems (as discussed by Dr Bowling in her chapter) might be grounded in the extensive experiences and guidelines for dealing with non-ECMO patients who sustain an acute neurologic injury. Decisions must be made in the context of the challenges in anticoagulation/antiplatelet therapies. Even the ability to transport to or obtain routine imaging studies can be difficult in patients on ECMO [12]. While there are many



concepts in how to manage patients on ECMO, as mentioned, there are some key concepts that are outlined in various chapters of this text:

1. Routine care of the critically ill patient—including ECMO-specific guidelines for the management of sedation, analgesia, and delirium (Dr Satypriya's and Dr Maldonado's chapters). Ventilator management and lung-protective strategies that allow for lung healing while on support is an extremely important topic as discussed in Dr Stahl's chapter.
2. Also of importance is understanding the complex biologic (human) to machine (ECMO circuit) interactions—both from a theoretical standpoint in the context of understanding the nuances of pump design, flow characteristics, and blood contact with nonbiologic surfaces (pumps, tubing, and oxygenators). Understanding these interactions and the role of anticoagulation testing and management is necessary to help maintain the delicate balance, as Dr Maul discusses in his chapter, between the inherent risks of bleeding and clotting while on ECMO.
3. While the need for ECMO support is often obvious and therapies once on support must be focused on “fixing” those problems, it must be remembered that often these patients have difficult problems that require a focused and integrated multidisciplinary Team. Involvement of expert consultants, such as infectious disease specialists, should be obvious in the setting on infectious problems. However, when patients are supported for primarily cardiovascular problems, the diagnosis and management of these problems often require aggressive testing and interventions in a catheterization laboratory. As illustrated by Dr Duke, even the transport of these patients can be difficult and risky and the ability to evaluate and treat problems often requires a Team approached with consideration for staged interventions.
4. It is well established that complications while on ECMO are, unfortunately, common. Such complications can have a significant impact on patient management and outcomes. An awareness of preventive strategies, role for early intervention, when they occur, and ECMO-specific treatment options are vital. Two of the most important complications—both in terms of frequency of occurrence while on support and in terms of impact on morbidity and/or mortality—are renal failure and neurologic complications. While prevention is key—and it is known that early implementation of ECMO can reduce the risk (and impact) of both of these complications, they nevertheless occur quite frequently. The chapters by Dr Bowling (neurologic) and Dr Thajudeen (renal) discuss the ECMO-specific issues that help in the diagnosis and management of noncardiopulmonary organ system dysfunction.
5. As the chapters that focus on specific patient populations discuss, once a patient is placed on support for whatever reason, the longer they are on support, the less likely they are for coming off and ultimately surviving. Therefore, a primary focus needs to be a continuous evaluation of those factors that either limit or need to be “fixed” or recovered before a patient can be weaned from support. Often recovery is based upon treating the primary problem and allowing the injured organ to recover. In addition to conventional

medical therapies, such as appropriate antibiotics for overwhelming pneumonias and sepsis, some patients might require invasive procedures, including catheter-based or surgical solutions. Regardless, the concept of weaning, as discussed by Dr Aissaoui and others in their chapters, must always be considered.

As with any intervention on a sick or high-risk patient, open, transparent, and honest on-going communications with families are paramount to help manage expectations. The emphasis of all communications should be on the reality that even in the best of circumstances and with the best of Teams, morbidity and mortality rates in patients supported on ECMO remain high. Even those who do survive will often have prolonged hospital stays, potentially prolonged and difficult recoveries, but many who do survive are able to return to productive lives [6].

## 2. Conclusions

As this book will hopefully illustrate, ECMO is very quickly becoming a mainstream therapy for patients experiencing acute, severe, and often medically refractory cardiopulmonary failure. Over the years, the technology has improved, the guidelines, protocols, and indications for therapy have been refined, and as experiences grow, the knowledge that comes from those experiences, hopefully, contributes to better outcomes [13]. Clearly, there is still much to be learned. Similar to other “resource intensive” technologies in which success or failure is often seen and experienced in the setting of a brief hospitalization, there is often much excitement, interest, and often intrigue when a patient is supported on ECMO. Success requires a Team effort and a tremendous amount of hard work and effective communication. Considering how many people, despite such enormous efforts and dedication, die on ECMO—even in the best of circumstances—it becomes so important that the victories are cherished and shared by all. Such victories can inspire and give hope even in times of when clinical success appears to be futile. Futility—a word that can often rally a Team or help accept the reality that life does not go on forever. Even though this text might not be the final word on this topic, as clearly there is still much to learn; the hope is that this will serve as a cornerstone for program growth and development—and as an inspiration for those intrigued by the potential benefits of ECMO [14].

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Technology discussed might not be approved by the CE/FDA, but is included due to its relevance to the research being presented.

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