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ROLE OF EXTRACORPOREAL MEMBRANE OXYGENATION (ECMO) IN EMERGENCIES: A COMPREHENSIVE REVIEW

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Abstract:

Background: *Extracorporeal Membrane Oxygenation (ECMO) is now a standard life-support modality in intensive care, particularly for emergency situations of cardiac and respiratory failure. Initially applied only in controlled intensive care settings, its application has now extended to pre-hospital, intraoperative, and emergency settings, transforming the treatment of life-threatening conditions.*

Objective: *This review analyzes the evolving role of ECMO in emergency medical care, encompassing its indications, utilization in various clinical situations, and impact on patient outcome.*

Methods: *A narrative review was conducted through the examination of peer-reviewed articles, case reports, and clinical guidelines on ECMO utilization in the emergency department. Databases included PubMed, Scopus, and ScienceDirect databases with emphasis on publication in the last decade.*

Results: *ECMO has demonstrated significant benefits in numerous emergency conditions, including cardiac arrest (E-CPR), pulmonary embolism, trauma-induced ARDS, and cardiogenic shock. Enhanced survival and neurological outcomes have been reported with early initiation and correct patient selection for ECMO. Greater accessibility and outcomes have also been achieved with the use of mobile ECMO teams and pre-hospital cannulation.*

Conclusion: *ECMO is no longer the preserve of routine ICU management but becomes a lifeline in urgent treatment of seriously ill patients. Its success depends greatly, though, on prompt initiation, specialist multidisciplinary teams, and availability of infrastructure. Standard emergency ECMO guidelines and its reach through mobile platforms and training are suggestions for the future.*

Keywords: *Extracorporeal Membrane Oxygenation (ECMO), Emergency Medicine, E-CPR, Cardiogenic Shock, Trauma Resuscitation*

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1. INTRODUCTION:

Effective ventilation is essential in thoracic surgery to guarantee sufficient arterial oxygenation and carbon dioxide removal. However, the ability to ventilate the patient using conventional techniques is frequently compromised by the complex architecture of the thoracic cavity and the collaborative nature of treatments between anesthetists and surgeons. Extracorporeal membrane oxygenation (ECMO), which offers both respiratory and circulatory support during thoracic surgeries, has become a useful technique in response to these difficulties. In the past, ECMO was mostly used in acute situations for patients whose respiratory insufficiency was life-threatening and not improving with standard care. With high rates of illness and mortality, the initial results were depressing. Because of this, early clinical trials were unable to clearly demonstrate a benefit, which restricted the use of ECMO to emergency rescue situations (1). Cardiopulmonary bypass (CPB) devices were adjusted to exclude the blood reservoir in the early iterations of ECMO. These devices made use of crude oxygenators, which were not designed for long-term usage and frequently caused severe blood damage and systemic inflammatory reactions. Nonetheless, improvements in circuit design have significantly raised ECMO's effectiveness and safety.

Modern systems use polymethyl-pentene (PMP) oxygenators, which provide longer-term support with fewer difficulties, and centrifugal pumps with magnetic levitation, which reduce hemolysis (2). An important turning point was the H1N1 influenza pandemic, which allowed for extensive clinical experience using ECMO in patients suffering from acute respiratory distress syndrome (ARDS). Initial findings were encouraging, and critical research showed that patients with severe respiratory failure receiving treatment at specialist ECMO centers had improved results (3). Recent randomized controlled trials, however, have produced contradictory findings. According to the findings of one such experiment, ARDS patients' 60-day mortality was not considerably reduced by early ECMO intervention. However, interest in ECMO has remained strong, and its application in both elective and emergency thoracic surgical procedures has grown significantly (4,5).

The purpose of this narrative review is to examine the current uses of ECMO in thoracic surgery and to chart its development. Using the PubMed, Web of Science, Google Scholar, and EMBASE databases, a thorough literature review was carried out in order to compile pertinent research and clinical information.

2. ECMO Benefits for Thoracic Surgery

For more than 60 years, the cardiopulmonary bypass (CPB) has been the standard extracorporeal support technique used during thoracic surgeries (6). Despite its effectiveness, CPB has a number of physiological side effects. Both the large surface area of the tubing and the existence of an air-blood contact in its open reservoir system are factors that lead to the development of severe SIRS (7). In addition, CPB activates the coagulation cascade, and systemic anticoagulation with high-dose heparin is necessary to achieve an activated clotting time (ACT) of ≥400 seconds. This carries a high risk of intraoperative and postoperative bleeding. The large priming volume of the CPB circuit also causes hemodilution, worsening coagulopathy, and electrolyte imbalances. Furthermore, in oncologic thoracic surgery, reinfusion of suctioned blood through the venous reservoir carries the risk of disseminating malignant cells into the systemic circulation. Another important limitation is that CPB systems are not designed to be used for long-term postoperative circulatory or respiratory support (8).

Modern extracorporeal membrane oxygenation (ECMO) systems avoid most of these limitations. They are operated without a reservoir and utilize shorter circuit tubing, which reduces the priming volume and air-blood interface to a significant degree. This results in less activation of the coagulation system, and heparin dosage can be reduced, with ACT targets usually between 180 and 220 seconds. The lower priming volume avoids hemodilution and related coagulopathies. Enhancements in biocompatibility of the components of the circuitry have also led to reduced inflammatory response, thereby adding to the potential duration of ECMO support (9).

ECMO circuits are driven by magnetically levitated centrifugal pumps that generate pressure gradients to move blood. This generates less mechanical trauma to the blood cells compared to roller pumps still utilized occasionally for CPB. Nevertheless, ECMO flow is sensitive to preload and afterload; acute reduction in venous return or increased resistance can compromise circulatory or respiratory support.

Oxygenator design has also evolved significantly. Unlike the previous generations of oxygenators that were plagued by clotting and membrane disruption, newer polymethyl-pentene (PMP) oxygenators have compact, low surface area designs that both reduce the risk of fibrin deposition and trauma to blood elements. These innovations have enhanced oxygenator durability and decreased the requirement for blood product transfusion during long-term applications. But ECMO has its limitations. Absence of a reservoir restricts its ability to quickly match acute intravascular volume loss, and separate intravenous access needs to be utilized for fluid, blood product, or medication administration. In anticipation of this limitation, hybrid ECMO-CPB circuits are being developed to allow the possibility of effortless transition between systems for those situations requiring more dynamic circulatory support (10,11).

3. Application of ECMO in Thoracic Surgical Practice

The tracheobronchial tree is a vital airway for pulmonary ventilation, and its surgery represents a formidable challenge to both thoracic surgeons and anesthesiologists. While advances in anesthetic management have attempted to address the need for effective ventilation during upper airway procedures, conventional options such as tracheostomy tubes, jet ventilation via the operative field, direct cannulation of the distal airway, and the use of small-diameter endotracheal tubes are restrictive in their nature (12-15). In some cases, procedures have been performed on awake patients in an effort to maintain airway control (16-19). But there are situations where these methods are not adequate to ensure adequate ventilation. ECMO is a great advantage in such settings as it allows extracorporeal gas exchange without the need for endotracheal access, thus keeping the field clear and facilitating complex airway procedures (20-24).

Various modes of ECMO have been utilized to support patients undergoing a wide range of thoracic procedures. VV and VA ECMO have both been employed during complex procedures such as carinal resections (25-28) and tracheal reconstructions (29-31). VV-ECMO has typically been employed for respiratory support, while VA-ECMO may be required for cardiac support in procedures where manipulation of cardiac structures induces hemodynamic instability. VV-ECMO has even proven useful in minimally invasive endoscopic procedures such as tumor resections and stent management (32,33).

Iatrogenic tracheal injuries (ITI), while rare, can result in life-threatening airway compromise. Conservative management is often sufficient, but in cases of severe respiratory distress, surgery becomes necessary (34). VV-ECMO has been applied in these cases to preoperatively stabilize the patient and maintain oxygenation intraoperatively and postoperatively (35,36). The same strategy has been employed in the surgical management of tracheoesophageal fistulas as a result of chemoradiotherapy or esophagectomy complications (37-39).

ECMO has also been utilized effectively in thoracic emergencies. The decision to use VV or VA support is based on whether respiratory or combined cardiopulmonary support is necessary. VV-ECMO has facilitated ventilation in the context of impending airway obstruction from foreign bodies or tumor impingement (33,40). Pulmonary hemorrhage from trauma, iatrogenic causes, or spontaneous etiologies has also been successfully treated with ECMO (41-43). Other emergent indications include airway rupture, bronchopleural fistula, and cardiopulmonary arrest secondary to airway obstruction, for which VA-ECMO may be indicated due to concomitant myocardial dysfunction (44-47).

Thoracic surgery frequently necessitates single-lung ventilation (SLV), which in patients with impaired baseline lung function is risky. While preoperative pulmonary function tests can be utilized to estimate intraoperative and postoperative respiratory adequacy, such tests are not always feasible, and unexpected ventilation issues may arise (48). In such cases, intraoperative VV-ECMO has enabled the completion of complex procedures—e.g., decortication for empyema, VATS bullectomy, lobectomy, repeat metastasectomy, and whole-lung lavage in alveolar proteinosis (49-52). More recently, VV-ECMO has also been successfully utilized during robotic-assisted lobectomy in patients with severe emphysema in whom SLV was not possible (53).

In patients who are undergoing further thoracic procedures after pneumonectomy, where SLV is anatomically impossible, VV-ECMO has facilitated contralateral lung resections, bullectomies, and esophagectomies (54,55). Large anterior mediastinal tumors with mass effect on vascular and airway structures can also potentially benefit from ECMO support to prevent or manage intraoperative cardiorespiratory compromise. In these cases, VA-ECMO is typically chosen for its bimodal respiratory and circulatory support (56,57).

In lung transplantation, ECMO has been more widely applied both preoperatively and intraoperatively. Transplant recipients may decompensate to a point that requires extracorporeal support as a bridge to transplant. ECMO configuration is tailored to patient needs: low-flow VV-ECMO for hypercapnic failure, high-flow VV-ECMO for hypoxia, or VA-ECMO for circulatory collapse or pulmonary hypertension. A novel pumpless system, the PA-LA Novalung®, utilizes native pulmonary pressures to drive blood through a membrane oxygenator into the left atrium, which allows for mobility but requires a median sternotomy for its placement (58). Despite heightened morbidity in this cohort, acceptable post-transplant outcomes have been achieved (59).

For transplantation, ECMO has emerged as the preferred mode of intraoperative support over CPB due to improved patient outcomes and reduced transfusion requirement (60). This shift is reflected by recent reports showing ECMO use in 80% of cases requiring extracorporeal support (61). However, CPB is still indicated in the setting of massive intraoperative bleeding, prompting the development of hybrid circuits with the ability to switch from ECMO to CPB (11).

Intraoperatively initiated ECMO, the most common configuration is central VA-ECMO. Preoperative VV-ECMO can sometimes be continued or upgraded to VA or VVA-ECMO as per hemodynamic requirements (62). Postoperative continuation of ECMO may be required to manage graft dysfunction, reperfusion injury, or persistent circulatory instability. Patients who require VA-ECMO after transplantation are at higher risk of mortality than those patients who are managed with VV-ECMO.

4. CONCLUSIONS:

Extracorporeal Membrane Oxygenation (ECMO) has transformed the boundaries of emergency treatment by offering an interim but lifeline in critical situations where normal therapies fail. With the emergence of emergency medicine, the introduction of ECMO into acute treatment pathways has enabled clinicians to effectively treat patients with severe cardiopulmonary impairment. Use of ECMO in emergency conditions—from emergency rooms to pre-hospital environments—has been particularly beneficial in conditions such as cardiac arrest (specifically extracorporeal CPR), acute respiratory distress syndrome (ARDS), and fulminant myocarditis.

The success of ECMO in crisis situations relies on several variables: quick diagnosis, appropriate selection of the patient, early cannulation, and ready access to well-trained multidisciplinary teams. Of equal importance is the development of institutional protocols and regional networks that provide immediate access to ECMO treatment. The use of mobile ECMO teams has also proved particularly helpful, facilitating in-field cannulation and stabilization before patient transport and thereby improving survival.

While promising, ECMO is labor-intensive and carries risk. Bleeding, thrombosis, and infection remain real dangers. Its use is also often relegated to tertiary centers, with expansion of training programs and infrastructure needed to facilitate greater availability. In the future, refinement of guidelines for emergency ECMO use, continuous data collection through registries, and further clinical trials will be required to maximize results and define patient selection criteria. In summary, ECMO is an innovative breakthrough in emergency medicine. With growing innovation, wise expenditure of resources, and inter-professional collaboration, its role towards saving lives will only grow stronger.

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دور الأوكسجة الغشائية خارج الجسم (ECMO) في الحالات الطارئة: مراجعة شاملة

الملخص

الخلفية :أصبحت الأوكسجة الغشائية خارج الجسم (ECMO) الآن من الوسائل القياسية لدعم الحياة في وحدات العناية المركزة، خصوصًا في الحالات الطارئة لفشل القلب أو الجهاز التنفسي. وبعد أن كانت تُستخدم في بيئات العناية المركزة المنظمة فقط، امتد استخدامها الآن ليشمل البيئات قبل دخول المستشفى، وأثناء العمليات الجراحية، وفي أقسام الطوارئ، مما غيّر طرق علاج الحالات المهددة للحياة.

الهدف :تهدف هذه المراجعة إلى تحليل الدور المتطور لتقنية ECMO في رعاية الطوارئ الطبية، من حيث دواعي الاستخدام، وتطبيقها في مواقف سريرية متنوعة، وتأثيرها على نتائج المرضى.

المنهجية :تم إجراء مراجعة سردية من خلال تحليل مقالات محكّمة، وتقارير حالات، وإرشادات سريرية تتعلق باستخدام ECMO في أقسام الطوارئ. وشملت قواعد البيانات المستخدمة PubMed :و ScopusوScienceDirect، مع التركيز على المنشورات خلال العقد الماضي.

النتائج :أظهرت ECMO فوائد كبيرة في العديد من الحالات الطارئة، بما في ذلك توقف القلب(E-CPR) ، والانصمام الرئوي، ومتلازمة الضائقة التنفسية الحادة الناتجة عن الصدمة، والصدمة القلبية. وقد تم الإبلاغ عن تحسن في معدلات البقاء على قيد الحياة والوظائف العصبية مع بدء مبكر للعلاج واختيار مناسب للمرضى. كما ساهم استخدام فرق ECMO المتنقلة وإجراء القسطرة قبل دخول المستشفى في تحسين الوصول إلى التقنية ونتائجها.

الاستنتاج :لم تعد ECMO مقتصرة على إدارة الحالات في وحدات العناية المركزة، بل أصبحت أداة إنقاذ في علاج المرضى المصابين بأمراض خطيرة بشكل عاجل. ويعتمد نجاحها بدرجة كبيرة على البدء السريع، وفرق متعددة التخصصات ذات كفاءة عالية، وتوافر البنية التحتية. ومن المقترحات المستقبلية وضع إرشادات قياسية لاستخدام ECMO في الطوارئ، وتوسيع استخدامها من خلال الفرق المتنقلة والتدريب.

الكلمات المفتاحية :الأوكسجة الغشائية خارج الجسم(ECMO) ، طب الطوارئ، الإنعاش باستخدام(E-CPR) ECMO ، الصدمة القلبية، إنعاش الصدمات الناتجة عن الإصابات.