Extracorporeal Membrane Oxygenation Application in Children

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Abstract

Extracorporeal membrane oxygenation (ECMO) is an advanced treatment for patients with failing heart and lung function. Especially in cases of cardiorespiratory failure that do not respond to conventional treatment methods, ECMO can increase patients' chances of survival by supporting the function of vital organs. ECMO therapy is used in a wide range of patients from newborns to adults. In newborns, effective results can be obtained especially in cases such as respiratory distress, congenital heart diseases and meconium aspiration, while in adults, it is successfully applied in diseases such as severe cardiopulmonary failure, viral infections such as COVID-19 and severe pulmonary embolism. Over time, technological advances in ECMO devices and increased clinical experience have increased the effectiveness of the treatment and expanded its area of use. The effectiveness of ECMO depends on factors such as the general health status of the patient, the likelihood of response to treatment and the reversibility of the disease. Therefore, the success of ECMO therapy is directly related to correct patient selection and timely intervention. A multidisciplinary approach and the role of an expert ECMO team are crucial for the successful implementation of this treatment modality.

Keywords: Child, extracorporeal membrane oxygenation, cardiopulmonary support.

Çocuklarda Ekstrakorporeal Membran Oksijenasyon Uygulaması

Öz

Ekstrakorporeal membran oksijenasyonu (ECMO), kalp ve akciğer fonksiyonları yetersiz kalan hastalar için uygulanan, ileri düzey bir tedavi yöntemidir. Özellikle geleneksel tedavi yöntemlerine yanıt vermeyen kardiyorespiratuar yetmezlik durumlarında, ECMO, hayati organların fonksiyonlarını destekleyerek hastaların yaşama şansını artırabilir. ECMO tedavisi, yenidoğanlardan yetişkinlere kadar geniş bir hasta grubunda kullanılmaktadır. Yenidoğanlarda özellikle solunum distressi, konjenital kalp hastalıkları ve mekonyum aspirasyonu gibi durumlarda etkin sonuçlar elde edilebilirken, yetişkinlerde de ciddi kardiyopulmoner yetmezlik, COVID-19 gibi viral enfeksiyonlar ve ağır pulmoner emboli gibi hastalıklarda başarıyla uygulanmaktadır. Zaman içinde ECMO cihazlarındaki teknolojik gelişmeler ve klinik deneyimin artması, tedavinin etkinliğini artırmış ve kullanım alanını genişletmiştir. ECMO'nun etkinliği, hastanın genel sağlık durumu, tedaviye yanıt verme olasılığı ve hastalığın geri döndürülebilirliği gibi faktörlere bağlıdır. Bu nedenle, ECMO tedavisinin başarısı, doğru hasta seçimi ve zamanında müdahale ile doğrudan

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ilişkilidir. Bu tedavi yönteminin başarıyla uygulanabilmesi için multidisipliner bir yaklaşım ve uzman bir ECMO ekibinin rolü oldukça önemlidir.

Anahtar Sözcükler: Çocuk, ekstrakorporeal membran oksijenasyonu, kardiyopulmoner destek.

Introduction

The roots of extracorporeal life support go back to the first blood oxygen generator designed by Dr Gibbon in the 1950s. The use of the blood oxygen generator, which was first produced to provide oxygenation of patients during cardiac surgery, was limited to a few hours due to complications such as haemolysis and bleeding[1]. In 1972, Dr. Hill achieved the first successful use of ECMO in a young adult who had developed severe hypoxic respiratory failure following a motorcycle accident[2]. In that same year, Dr. Bartlett achieved the first successful VA-ECMO in an infant who developed low cardiac output syndrome following a Mustard procedure for transposition of the great arteries. Later, in 1975, Bartlett and Gazzaniga reported the first neonatal survivor a term infant with severe hypoxic respiratory failure due to meconium aspiration supported with VA-ECMO[3]. In 1989, the Extracorporeal Life Support Organization (ELSO) was established with the aim of organising and collecting data on patients receiving ECMO. ELSO publishes guidelines that are accepted and used by the world to support clinicians[4].

Extracorporeal membrane oxygenation (ECMO) is a life support device targeting cardiac and pulmonary support. While ECMO cleans the venous blood of patients with severe pulmonary insufficiency by extracorporeal gas exchange, it provides circulatory support in addition to blood oxygenation in patients with severe cardiac insufficiency[5]. ECMO device is a mechanical support device that provides haemodynamic support to the patient by bypassing the cardiopulmonary system or works by regulating oxygenation and perfusion in transplantation[6]. ECMO is the only mechanical device that can provide both cardiac and pulmonary support compared to other mechanical support devices, which can be applied in intensive care with cardiopulmonary bypass support. ECMO support therapy can be applied for days or weeks depending on the patient profile. The working principle of the ECMO system is based on the logic of taking blood from the patient's venous vascular bed through a cannula and pump, oxygenating it in the membrane and reintroducing the blood to the system via arterial or venous line[7]. Currently used ECMO applications are divided into two groups as Venoarterial (VA) and Veno-venous (VV) ECMO according to the vessels used. VA- ECMO is the application in which blood taken from a vein is oxygenated and then returned through an artery, while VV-ECMO is the application in which blood taken from a vein is pumped into another vein after being oxygenated[8]. In recent years, the use of extracorporeal membrane oxygenation (ECMO) has increased markedly, particularly during the COVID-19 pandemic. Severe acute respiratory distress syndrome (ARDS) associated with COVID-19 has increased the need for advanced life support modalities such as ECMO in critically ill patients. Recent registry analyses from ELSO have demonstrated improved survival rates and expanded indications for ECMO in both pediatric and adult populations.

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ECMO Circuits and Equipment

The main elements of the ECMO system are similar to the ventilation devices used in the treatment of respiratory failure. ECMO circuit consists of drainage and return cannulas, tubing system, pump system, air and oxygen mixing line, temperature regulated oxygenator, heating and cooling line and control units. The blood taken from the patient with the help of the drainage cannula passes through the pump and is returned to the patient with the help of the return cannula by regulating the temperature in the heat exchanger in the oxygenator by removing CO_2 and oxygenated by providing gas exchange in the oxygenator[9].

Pumps

Pumps are of two types: roller and centrifugal. Roller pumps are more commonly used in standard cardiopulmonary bypass. In ECMO using a roller head, venous return depends on the position of the patient and the force of gravity[10].

Oxygenator

It is the most important part of the ECMO system. It is a gas exchange unit. It is a part of the perfusion apparatus that fulfills the functions of the patient's natural lungs (except endocrine functions) during extracorporeal circulation. Modern oxygenators are produced compactly with a heater unit (heat-exchanger)[11].

Cannulas

In cardiopulmonary bypass, cannulas provide the connection of the patient with the perfusion circuit lines and can be categorised in three main groups as arterial cannulas, venous cannulas and cardioplegia cannulas. In addition to these; left ventricular vent, pulmonary artery vent, aortic root vent can also be used. The size of the cannulae is calculated according to the patient's body surface. The main consideration in the cannulation approach is the flexibility of the lines, which facilitates the use of ECMO[12].

Heat Exchanger

The warming unit is necessary to control the patient's body temperature and blood temperature at certain levels. The warming unit requires an external water reservoir that circulates cooled or heated water as required. In general, the temperature of the water is kept below 40 C (usually 37 C). In the presence of unexplained haemolysis, small amounts of blood and protein are assumed to be in the circulating water, although there is rarely a connection between circulating water and blood. The water in the water reservoir is not sterile and may be contaminated. Therefore, the water reservoir should be cleaned and replaced from time to time with antiseptic solutions[13].

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ECMO Team

ECMO is performed in institutions under certain standards and by a team competent in ECMO according to the guidelines published by the ELSO[14,15]. ECMO team should consist of system team, surgical team and medical team. These teams consist of physicians, surgeons, nurses, perfusionists and other personnel from various branches[7]. Each member of the team must have received training and certificates for ECMO. The ELSO instruction requires the course to be 24-36 hours theoretical and 8-16 hours practical. If people with ECMO certificates stay away from this application for 3 months or more, their certificates should be renewed[16,17].

Indications and Contraindications for ECMO Support

Indications in Neonates

Respiratory Indications: Respiratory indications for neonatal ECMO involve infants who continue to experience severe respiratory failure despite optimal medical management and ventilatory support. According to the ELSO criteria, ECMO may be considered when: a)The oxygenation index remains above 40 for at least 4 hours,b) The infant cannot be weaned from 100% oxygen for more than 48 hours or the oxygenation index consistently exceeds 20 over the same period, c)Recurrent episodes of clinical deterioration occur despite maximal therapy, d) There is severe hypoxic respiratory failure with acute decline (PaO_2 < 40 mmHg) unresponsive to intervention.Additionally, severe pulmonary hypertension leading to right and/or left ventricular dysfunction that does not improve with inotropic support is also an indication.[18]. In newborns with congenital diaphragmatic hernia, ECMO can be initiated at comparatively higher oxygenation levels to avoid ventilator-induced lung injury (barotrauma)[19].

Cardiac Indications: In neonates, congenital heart disease represents the leading reason for VA-ECMO support, making up roughly 80% of cardiac-related cases. These conditions include hypoplastic left heart syndrome, cyanotic heart defects with reduced pulmonary blood flow, various septal defects, and obstructive lesions affecting either the left or right ventricular outflow[18].

Indications in Children

Respiratory Indications: According to the ELSO guidelines, the most common pulmonary diseases for which there are indications include acute respiratory failure (22%), other causes (22%), bronchiolitis (10%), viral pneumonia (10%), bacterial pneumonia (8%) and non-pulmonary infections (8%)[18].

Cardiac Indications: Indications For Cardiac ECMO in the paediatric population are divided into two groups: those associated with catheterisation or cardiac surgery and those associated with cardiovascular collapse for nonoperative reasons. Indications for venoarterial ECMO include preoperative stabilisation, inability to wean from

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cardiopulmonary bypass, elective support in high-risk surgical procedures and decreased postoperative cardiac output[4].

The management of ECMO in pediatric patients requires consideration of age-specific physiological characteristics and the implementation of individualized treatment approaches. Factors such as body size, blood volume, and organ maturity necessitate careful adjustment of cannula selection, blood flow rates, and anticoagulation strategies. In addition, pediatric ECMO patients require careful monitoring of anticoagulation parameters due to differences in coagulation systems compared with adults. Drug dosing, fluid balance, and hemodynamic targets must also be adjusted according to age-specific physiological characteristics.

Table 1. Indications for ECMO in neonates and children[18]

Patient Group	**Respiratory Indications**	**Cardiac Indications**
Neonates	Meconium aspiration, RDS, pulmonary hypertension	Congenital heart disease
Children	ARDS, pneumonia	Postoperative cardiac failure

Complications of ECMO Support

Bleeding develops between 30% and 50% in patients receiving ECMO support and is the most common complication[20]. Approximately 50% of patients require reexploration due to haemorrhage while ECMO perfusion is ongoing[21]. Mediastinal reexploration is performed in the intensive care unit by providing sterile conditions in order to avoid the risk of cannula dislodgement and tamponade development during transport to the operating theatre. Cerebral haemorrhage is a more common complication in neonates but can also occur in older children. When it occurs, it is a complication with a poor prognosis, which is often the main cause of mortality[22]. In order to prevent this complication, use of heparin-coated sets and selection of a better anticoagulation management regimen (thromboelastography, platelet aggregation tests) may be recommended[23]. Renal failure may be observed as a complication during the ECMO course. It is usually a rare complication[24]. Ultrafiltration or dialysis is rarely necessary. Another complication of prolonged ECMO use is sepsis or mediastinitis. Low cardiac output, development of renal failure, presence of multiple intravascular catheters, direct relationship of ECMO cannulas with the mediastinal cavity, and revisions performed due to bleeding are the main conditions that predispose to infection in these patients[23]. Nurses have a major role in the care of the patient with ECMO and in the management and early recognition of complications[25].

Care in ECMO Support

It is important for the nurse to make a physical assessment from head to toe in the child to be administered ECMO. Monitoring of the patient under ECMO support, vital signs of

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patients (heart rate, arterial blood pressure, oxygen saturation, respiratory rate), capillary refill and peripheral circulation control, skin turgour monitoring, bleeding control, intake-output monitoring, electrocardiography, central venous pressure, pulmonary artery pressure, monitoring of mechanical ventilator settings and patient compliance, monitoring of infusion devices and control of connections, monitoring of the ECMO cycle and all potential risks that this cycle may pose should be monitored[7,26]. The central venous pressure value should be monitored between 5-10 mmHg. High blood pressure should be avoided to prevent blood haemolysis and mean arterial pressure should be lower than 50-70 mmHg in adults[7,27,28]. After VA-ECMO support is established after cardiac arrest, moderate hypothermia (32- 36°C) should be maintained for the first 24-72 hours and normothermia at 37°C afterwards[29]. Respiratory support mode, tidal volume, respiratory rate and Positive End Expiratory Pressure (PEEP) values should be monitored and recorded in patients under mechanical ventilator support. Airway patency and humidification of the supplied air should be ensured in intubated patients on mechanical ventilator. Patients receiving ECMO support for a long period of time are at risk of atelectasis because they are bedridden and frequently immobile[7].

ECMO must be continuously connected to a power source and the nurse must carefully monitor the lights, connection cables and alarms indicating low power. Care should be taken against kinks, tensions and non-contacts that may occur in the connections that provide gas exchange of ECMO. Cannulas in the entire circuit should be checked for possible obstruction, clot formation and air bubbles. The nurse should also check the colour difference between the oxygenated blood sent to the patient and the oxygen-poor blood coming from the patient. The nurse should monitor the rotations per minute (RPM) value, which indicates the number of rotations per minute, as sudden drops in this value may be an indication of hypovolaemia and a kink or break in the cannula[26].

ECMO is a painful procedure because it is an invasive procedure using large cannulae. After cannulation, the patient should be monitored under sedation for the first 12-24 hours. Nurses should monitor the effect of the sedative agent in this process, evaluate the sedation level of the patient and determine the possible side effects of the drug. In case the patient has pain, pain control should be provided with non-pharmacological methods and appropriate pharmacological methods according to the physician's order[7,29].

If appropriate, the child should be fed enteral nutrition and nutritional tolerance should be monitored by residue control. However, if the child cannot tolerate nutrition, the child should be fed parenterally with total parenteral nutrition (TPN) solutions[30]. If oral intake is not contraindicated, the patient should be fed with an appropriate diet. Early Career Faculty The European Society for Clinical Nutrition and Metabolism (ESPEN) recommends that parenteral nutrition should be started within 24-48 hours if enteral nutrition is not tolerated or contraindicated in all patients who are not expected to start oral intake within three days[31].

Complete blood count, C-reactive protein (CRP), electrolytes, calcium, glucose, blood urea nitrogen (BUN), creatinine should be monitored and the relevant physician should

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be informed immediately in case of any complication. In accordance with the physician's order, 2 units of erythrocyte suspension and fresh frozen plasma suspension should be kept ready for the child[30]. Activated Coagulation Time (ACT) value should be checked every 2 hours within the first 12-24 hours after the start of ECMO application in order to detect coagulation-related complications in the early period, and Activated Partial Prothrombin Time (aPTT) value should be checked every 6 hours when ACT value stabilises after 24 hours. In addition, intravenous (IV) therapies other than heparin should be administered from the venous side of the ECMO circulation. During the procedure, the necessary treatments should be prepared and administered according to the physician's order, and appropriate procedures should be prepared for the awakening of the child in the process of leaving the procedure[30-32].

Continuous contact of the cannulas with the skin and patients staying in the same position for a long time due to the cannulas increase the risk of pressure injury. In a study, the rate of pressure injury in these patients was reported as 41-65%[33]. A sufficient number of experienced nurses and personnel must be available in the positioning process[28]. Since frequent position changes cannot be performed, it is more appropriate to use an air mattress. Infection and heparin infusion may accelerate skin erosion or facilitate haematoma formation. Oedema, especially in children with heart failure, is also a condition that should be monitored in terms of pressure sores. Oedema and the pressure created by the cannulas can easily lead to pressure sores. In addition, cannulas should be fixed with hydrocolloid-structured tools that can adhere to the skin, as cannulas may cause device-related pressure injury[26]. Care should be taken about desaturation, hypertension, tachycardia, changes in ECMO flow during skin care procedures[33].

Patient and family education is an essential component of ECMO care. During the ECMO treatment process, families often experience significant emotional stress and uncertainty. Providing clear and understandable information about the treatment process, expected outcomes, and possible complications can help reduce families' anxiety levels and strengthen collaboration with the healthcare team. The education process should also include information about post-discharge care, rehabilitation, and long-term follow-up requirements. In addition, psychological support and family-centered care approaches play an important role in helping patients and their families adapt to the treatment process during and after ECMO therapy.

Withdrawal from ECMO

Recovery of arterial pulse pressure, decrease in the need for catecholamine infusion and improvement in myocardial function on echocardiography are necessary indicators for weaning from ECMO[34]. Weaning should be performed at 48-72 hours and ECMO blood flow should be decreased slowly. During the weaning phase, the ECMO flow rate is usually reduced from 60-250 ml/kg/min to 25-40 ml/kg/min within hours[35]. Arterial and venous lines are closed with a clamp and anticoagulant is given every 15-20 minutes until the child is stabilised[36]. In order to ensure compliance with the weaning procedure, the child is usually kept awake and expected to perform his/her own respiration. This

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approach has recently become the standard protocol of many centres. Although sedation policies may vary from centre to centre, the use of muscle relaxants is rarely needed in ECMO patients[37,38]. During the weaning process, cardiac inotropic support such as dopamine is increased to the appropriate dose and ventilatory support is optimised[36]. The amount of oxygen in the blood travelling to the coronary arteries can be increased with moderate ventilator support. For ventilator support, the fractional oxygen amount is adjusted as 40%, respiratory rate 16/min, PEEP 3-5 cm H2O and tidal volume 10 cc/kg[12]. After six hours of haemodynamic stabilisation, the child is weaned from ECMO cannulation. However, chest closure is performed later[36].

After successful weaning from ECMO, patients should be closely monitored due to the risk of long-term complications. These complications may include neurological deficits, impaired pulmonary function, and reduced functional capacity. Early rehabilitation, respiratory physiotherapy, and multidisciplinary follow-up programs are recommended to support the recovery process and improve quality of life. Because ECMO support may affect neurodevelopmental outcomes, long-term follow-up is particularly important in pediatric patients[39,40].

Conclusion

In Türkiye, ECMO services have been increasingly implemented in tertiary care centers, particularly in pediatric and cardiovascular intensive care units. The implementation of ECMO requires coordinated multidisciplinary teamwork. Nurses play a central role in managing patient care both in intensive care units and in clinical settings, as well as in the post-discharge follow-up period at home. High-quality nursing care for patients on ECMO is crucial for preventing, recognizing, and managing potential complications early, and for enhancing patient outcomes and quality of life after discharge.

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