Extracorporeal membrane oxygenation in children: A brief review

Ken Sakurai and Nitesh Singhal
1Department of Paediatric Intensive Care, The Children's Hospital at Westmead, Sydney, New South Wales and 2Sydney Medical School, University of Sydney, Sydney, NSW, Australia

With the advancement in technology and increasing familiarity, the use of extracorporeal membrane oxygenation (ECMO) has expanded in the past decade. Although ECMO can be lifesaving for critically ill children, it is an invasive therapy associated with complications that may necessitate rehabilitation and long-term follow-up. Paediatric clinicians play an essential role in managing these children, especially after the acute phase of their illness. This review provides an overview of ECMO and will provide a basic understanding of ECMO and its principles.

Key words: cost–benefit analysis; extracorporeal membrane oxygenation; review.

Extracorporeal membrane oxygenation (ECMO) is an advanced therapy used to manage critically ill patients with severe respiratory or cardiovascular dysfunction that is refractory to conventional management.

Over the last decade, the field of ECMO has expanded, requiring multidisciplinary involvement in the care of these complex patients. ECMO survivors need ongoing monitoring and rehabilitation after leaving the intensive care unit (ICU) setting and often long after discharge from hospital. Follow-up in this context often requires a multidisciplinary team including general paediatricians and physicians; however, as highlighted recently, there is a knowledge gap with regards to ECMO and its long-term effects amongst follow-up care providers.

This review will attempt to fill that gap by providing a basic overview of ECMO, outlining its history, types and basic physiology, its indications, complications and outcomes, with a particular focus on paediatrics, in order to smooth the transition of care of ECMO survivors from ECMO centres to the general paediatrician.

**Key points**
1. Management of children on extracorporeal membrane oxygenation (ECMO) requires a multidisciplinary approach.
2. As ECMO survivors are at risk for developing neurodevelopmental delay, they should have a structured neurodevelopmental follow-up.
3. ECMO is complex and resource-intensive but can be cost-effective.

**History of ECMO**

The successful use of ECMO was first described in 1972 in the management of post-traumatic respiratory failure in an adult patient. In the same year, ECMO was successfully used in a neonate after Mustard operation for transposition of the great arteries. This was soon followed by the management of severe meconium aspiration syndrome. Despite early disappointments in adult critical care, the use of ECMO continued to develop in neonatal and paediatric medicine in the late 20th century. The Extracorporeal Life Support Organization (ELSO) was formed in 1989 to support clinicians with guideline publication and education, ECMO research and registry data collection. An early randomised control trial of ECMO use in neonatal respiratory failure showed promising results, and the Australian experience during the H1N1 influenza pandemic demonstrated the feasibility of widespread ECMO use.

Today, there are 492 ECMO centres registered with ELSO, with a total of 151,683 ECMO runs to date, half of which have been in neonates and paediatric patients.

ECMO technology has developed significantly over the decades. Surface modifications of the circuit tubing have reduced the risk of thrombosis. The oxygenator has evolved from silicone membrane to polypropylene or polymethylpentene cross-flow systems to prevent clot formation and improve gas exchange. Advances in technology have also allowed ECMO systems to become more compact and mobile. With these improvements, the safety, efficiency and longevity of ECMO continue to progress.

**Types of ECMO**

ECMO is broadly categorised into either veno-venous (VV) ECMO or veno-arterial (VA) ECMO. In both VV and VA-ECMO, deoxygenated blood is withdrawn from the venous circulation and passed through a membrane oxygenator for gas exchange. In VV-ECMO, this oxygenated blood is returned to the
systemic venous circulation (Fig. 1), augmenting the lung’s gas exchange functions. In VV-ECMO, the patient’s native cardiac function is required to deliver this oxygenated blood to the body. In VA-ECMO, blood is returned directly to the systemic arterial circulation (Fig. 2) and thus provides circulatory support in addition to respiratory support.

**ECMO Configurations**

Sites of vascular access can be central or peripheral. Central ECMO requires sternotomy with associated surgical risks, whereas peripheral ECMO can be established via percutaneous, surgical or hybrid techniques. Access in peripheral ECMO is established via an internal jugular vein (IJV) or femoral vein (FV).

In peripheral VV ECMO, both access and return of blood are via the femoral or internal jugular veins (Fig. 3a). Specialised dual-lumen cannulas such as the Avalon cannula (Fig. 3b) can allow single cannulation for both venous access and return, preventing the need for multiple cannulations. However, minor malpositioning can have deleterious effects on ECMO flow rates.

Recent advances have allowed central access for VV ECMO through sternotomy, with blood accessed via the right atrium (RA) or central vein and returned via the pulmonary artery (PA) (Fig. 3c). This helps reduce recirculation to improve the efficiency of ECMO oxygenation and offers support for isolated right heart failure.

Like peripheral VV ECMO, access for peripheral VA ECMO is established via femoral or internal jugular veins. However, blood is returned to the arterial circulation via the carotid, axillary or femoral arteries (Fig. 3d,e).

Access for central VA ECMO through sternotomy is via the RA. Blood is returned to the proximal aorta allowing stable blood supply to the ECMO circuit and reliable flow to the proximal aorta (Fig. 3f).

**Indications and Contraindications**

It is important to emphasise that ECMO is not a destination therapy but a bridge to recovery, decision-making, diagnosis, ventricular assist device (VAD), transplant or rarely, physiological support until organ donation. Over the last decade, indications for ECMO have rapidly expanded (Table 1).

Respiratory support with VV-ECMO can be provided for most respiratory pathologies. Short runs of ECMO can be used for difficult airway surgeries such as tracheal reconstruction and sliding tracheoplasty. ECMO can provide respiratory support in various pathologies such as asthma, bronchopleural fistula, and refractory hypoxaemia, such as in ARDS. Some common
respiratory indications in neonates are persistent pulmonary hypertension of the newborn, congenital pneumonia, meconium aspiration syndrome and congenital diaphragmatic hernia.

VA-ECMO for cardiovascular support is well-established post cardiothoracic surgery in the context of failure to wean from cardiopulmonary bypass, especially in children with congenital heart disease. Other common indications include cardiomyopathy or myocarditis as a bridge to recovery, VAD or transplant.

Favourable outcomes have been demonstrated with the use of ECMO in cardiac arrest, which has led to its uptake as extracorporeal cardiopulmonary resuscitation (ECPR). The International Liaison Committee on Resuscitation recommends considering the use of ECPR in select paediatric patients with in-hospital cardiac arrests refractory to conventional therapy.

The use of ECMO in the management of sepsis is controversial. Outcomes vary with age and clinical presentation, with neonates

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**Fig. 3** Common ECMO Configurations. (a) Peripheral VV ECMO – Blood is accessed and returned via an internal jugular (IJ) or femoral vein. (b) VV ECMO via dual-lumen cannulae – A single cannula placed in the IJ vein provides both access and return. (c) Central VV ECMO – Blood is withdrawn via the right atrium or IJ veins and returned via direct cannulation of the pulmonary artery. (d, e) Peripheral VA ECMO – Blood is accessed via the IJ or femoral veins and returned via the carotid, axillary or femoral arteries. (f) Central VA ECMO – Blood is accessed via the right atrium and returned to the proximal aorta. ECMO, extracorporeal membrane oxygenation; VA, veno-arterial; VV, veno-venous.
and those with septic cardiomyopathy can be catastrophic. The most common neurological complications are the most common and can be either haemorrhagic or thrombotic.

Circuit-related complications are the most common and can be either haemorrhagic or thrombotic.

Haemorrhage is often multifactorial, compounded by a coagulopathy both from anticoagulation and acquired von Willebrand syndrome and platelet dysfunction, circuit-related fibrinogen consumption and ECMO-induced reduction in factor VIII and XII. Coagulopathy from the patient’s critical illness may also contribute. Bleeding can be severe, necessitating massive transfusion, and can occur at the ECMO cannulation sites or can occur de novo, with intracranial haemorrhage (ICH) the most feared. Thrombotic complications are equally problematic and can lead to significant morbidity. ECMO causes a pro-thrombotic state due to blood exposure to non-physiologic surfaces and turbulent flow.

Neurological complications occur in up to 30% of patients on ECMO and can be catastrophic. The most common neurological complications are seizures, ischaemic stroke, and ICH.

### Table 1  Indications for ECMO

| Respiratory failure | Cardiac failure |
|---------------------|-----------------|
| 1 Airway            | 1 Failure to wean from |
| o Management of difficult airway | cardiopulmonary bypass |
| o Airway obstruction | 2 Extracorporeal |
| o Sliding tracheoplasty | cardiopulmonary |
| 2 Lung              | 3 Cardiac failure |
| o Bronchopleural fistula | o Cardiomyopathy |
| o Pneumonia         | o Myocarditis |
| o ARDS              | o Refractory arrhythmia |
| o Acute exacerbation of asthma | o Massive pulmonary |
| o Inhalational injury | o Pulmonary contusion |
| o Pulmonary contusion | o Severe cardiac contusion |
| o Alveolar haemorrhage | Other |
| 3 End-stage respiratory failure awaiting lung transplant | 1 Sepsis |
| 4 Neonatal respiratory failure | 2 Fulminant liver failure |
| o Meconium aspiration syndrome | 3 Toxic ingestion |
| o Congenital diaphragmatic hernia | 4 Organ support for organ donors |
| o Congenital pneumonia | |

ARDS, acute respiratory distress syndrome; ECMO, extracorporeal membrane oxygenation.

### Table 2  Contraindications for ECMO

| Absolute contraindications | Relative contraindications |
|---------------------------|---------------------------|
| 1 Catastrophic brain injury without prospect for recovery | 1 Severe multi-organ failure |
| 2 Untreatable metastatic malignancy | 2 Severe trauma with coagulopathy and haemorrhage |
| 3 End-stage organ failure without prospect for recovery or transplant | 3 Severe immunocompromise |
| 4 Extremes of age | 4 Severe aortic regurgitation |
| 5 Unfavourable vasculature such as aortic dissection | 6 Unfavourable vasculature |

ECMO, extracorporeal membrane oxygenation.

### Respiratory Management

The principle of respiratory management of an ECMO patient is to prevent further iatrogenic lung injury while allowing time for lung recovery. Lung-protective ventilation via ‘Rest Settings’ as suggested by the ELSO guidelines forms the basis of management, minimising ventilator-induced lung injury.

Some degree of venous admixture is expected in VV ECMO, and as such, oxygen saturation of ≥80% should be acceptable for a patient on VV ECMO.

### Cardiovascular and Haematological Management

As with respiratory management, the goal of cardiovascular management of ECMO patients is to provide time to recover, whereas the ECMO circuit provides sufficient blood flow to support end-organ perfusion. Patients on VA ECMO are at risk of left ventricular (LV) distension which can lead to pulmonary oedema, further ischaemic injury, LV thrombosis and thromboembolism. Several LV unloading strategies are available (Table 3) and should be considered as soon as LV distension becomes evident.

ECMO causes various haematological derangements, including both life-threatening bleeding due to circuit-induced coagulopathy and thrombosis and thromboembolism, which generally requires systemic anticoagulation. The circuit can induce haemolysis due to high shear forces, and this requires judicious titration of volume status and pump speed and may even necessitate oxygenator exchange.

### Complications

ECMO is an invasive and complex therapy and is associated with significant complications. These complications can be divided into circuit or patient-related (Table 4). Circuit-related complications include cannula malpositioning and access insufficiency. Negative access pressures can cause air entrainment, leading to circuit failure, and there are reports of device entrainment, such as guidewires. Circuit thrombosis and pump or oxygenator failure can occur.

Patient-related complications are numerous and can be categorised from a system-based approach. Haematological complications are the most common and can be either haemorrhagic or thrombotic.

Haemorrhage is often multifactorial, compounded by a coagulopathy both from anticoagulation and acquired von Willebrand syndrome and platelet dysfunction, circuit-related fibrinogen consumption and ECMO-induced reduction in factor VIII and XII. Coagulopathy from the patient’s critical illness may also contribute. Bleeding can be severe, necessitating massive transfusion, and can occur at the ECMO cannulation sites or can occur de novo, with intracranial haemorrhage (ICH) the most feared. Thrombotic complications are equally problematic and can lead to significant morbidity. ECMO causes a pro-thrombotic state due to blood exposure to non-physiologic surfaces and turbulent flow.

Neurological complications occur in up to 30% of patients on ECMO and can be catastrophic. The most common neurological complications are seizures, ischaemic stroke, and ICH.
Ischaemic stroke has been reported in up to 33% and although their neurological status may be increased.

These complications include physical, developmental, and cognitive difficulties. There are reports of poorer physical function and motor and cognitive difficulties in quarter neonatal ECMO survivors with long-lasting effects on their academic performance. Although their neurodevelopment seems favourable in the initial years, some of these children experience difficulties with memory, working speed and spatial ability tasks.

There are complications specific to VA ECMO. In femoral VA ECMO, distal limb ischaemia and compartment syndrome can occur due to the ECMO return cannula impeding blood flow distally, a complication more common in paediatric patients. Appropriate selection of cannulation sites and monitoring of distal perfusion is critical. Augmentation of distal blood flow can be achieved by placing an antegrade distal perfusion catheter in the artery distal to the ECMO cannula.

### Weaning of ECMO Support

De-escalation from ECMO differs between VA-ECMO and VV-ECMO. In VA-ECMO, once recovery of cardiac function is observed, the ECMO flow is gradually reduced with monitoring of haemodynamics, markers of organ perfusion, and serial echocardiographic assessment. If successful, the patient can be weaned off ECMO support.

Weaning of VV-ECMO should be considered once lung recovery is evident. The fresh gas flow to the oxygenator is progressively reduced while ECMO blood flow is maintained. Without fresh gas flow, ECMO ceases to contribute to gas exchange, and the patient is wholly reliant on their own lung function. If this is tolerated, the patient can be decannulated.

### Outcomes

There is significant heterogeneity in neonatal and paediatric ECMO patients, and survival varies with the indication (Table 5). Due to recent improvements in survival, attention should also be directed to long-term morbidity. Neuropsychological issues are present in quarter neonatal ECMO survivors with long-lasting effects on their academic performance. Although their neurodevelopment seems favourable in the initial years, some of these children experience difficulties with memory, working speed and spatial ability tasks.

There are reports of poorer physical function at 36 months, with a significant proportion of patients with learning difficulties. A 5-year follow-up of neonates managed with ECMO revealed a substantial proportion had neurological, motor and cognitive difficulties. In contrast, there was no difference in neurodevelopmental outcomes in a 7-year follow-up study of neonates randomised to ECMO or conventional care. These findings may suggest that the underlying disease condition may be the significant factor determining long-term morbidity, rather than ECMO itself.

Data is also limited with regards to long-term medical outcomes of neonatal ECMO survivors. Although most survivors seem to have normal physical growth, the risk of medical complications such as chronic kidney disease, hearing loss and reduced exercise tolerance may be increased.

### Ongoing Rehabilitation and Long-Term Follow-up

Based on current knowledge of long-term outcomes and the phenomenon that ECMO survivors may grow into their deficits,
clinicians should plan for regular follow-up assessments covering both medical and neurodevelopmental domains.

The current ELSO guidelines suggest that all ECMO survivors should have long-term follow-up in a structured and standardised approach. Long-term follow-up should be individualised depending on the availability of resources, indication for ECMO, nature of underlying disease and presence of other comorbidities. Some of these children will require more active investigation and intervention, and referral to other sub-specialties such as neurology may be warranted.

Neonatal ECMO survivors should have their first follow-up within the first 3 months of discharge, followed by 6 months and 1 year. Further follow-up through school age and adolescence should be individualised. Older paediatric ECMO survivors will also benefit from long-term follow-up.

The engagement of the parents of ECMO survivors is crucial for the success of an ECMO follow-up program. These parents should receive adequate education about potential long-term sequelae to allow timely health-care access, monitoring and intervention.

**Cost Efficacy**

ECMO remains an expensive therapy, but numerous studies have demonstrated cost-efficiency. A US study estimated the average in-hospital costs of paediatric ECMO patients increased from $214 046 to $324 841USD for an average hospital length of stay of approximately 45 days. A longitudinal Canadian study found a median inpatient hospital cost for paediatric ECMO patients of $119 197CAD, with a much shorter average length of stay of 26 days.

For cost-efficiency, a UK-based study of ECMO for respiratory failure demonstrated a favourable cost-efficiency of £16 707 per life-year gained, and £24 775 per disability-free life-year gained. The use of ECMO as rescue therapy post congenital heart surgery costs approximately $156 324USD for the inpatient stay, but with a favourable cost-efficiency of $24 386/Quality of Life-Year.

**Future Directions**

Advances in ECMO have allowed runs up to 20 months with recovery in the patients’ cardiopulmonary function, and this has led to unique and challenging questions about patient selection for the initiation of ECMO. Decisions about ECMO candidacy should be based on patient, family and multidisciplinary team discussion and the ethical distribution of health-care resources.

With continuing improvements in technology, safety and circuit longevity, we are approaching the ‘3rd era’ of ECMO. Soon it may be possible for appropriate ECMO patients to be de-sedated and extubated with a gradual introduction of ambulation, facilitating rehabilitation to prevent deconditioning.

**Conclusion**

As ECMO technology has advanced over the last decade, survival has increased, and the focus has shifted from a reduction in mortality to the prevention of long-term morbidity. Although ECMO remains an expensive therapy, it is a viable rescue therapy for our sickest patients. An understanding of the general principles of ECMO will aid paediatricians in their essential role in the multidisciplinary management and long-term follow-up of these patients.

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**References**

1. Wray J, Kakat S, Brown K, O’Callaghan M, Thiruchelvam T, Hoskote A. Childhood extracorporeal membrane oxygenation survivors: Parents highlight need for structured follow-up and support after hospital discharge. Pediatr. Crit. Care Med. 2020; 21: 461–8.
2. Hill JD, O’Brien TG, Murray JI et al. Prolonged extracorporeal oxygenation for acute post-traumatic respiratory failure (shock-lung syndrome). Use of the Bramson membrane lung. N. Engl. J. Med. 1972; 286: 629–34.
3. Bartlett RH. Extracorporeal life support: History and new directions. ASAIO J. 2005; 51: 487–9.
4. Zapol WM, Snider MT, Hill JD et al. Extracorporeal membrane oxygenation in severe acute respiratory failure. A randomized prospective study. JAMA 1979; 242: 2193–6.
5. UK Collaborative ECMO Trial Group. UK collaborative randomised trial of neonatal extracorporeal membrane oxygenation. Lancet 1996; 348: 75–82.
6. Australia and New Zealand Extracorporeal Membrane Oxygenation (ANZ ECMO) Influenza Investigators, Davies A, Jones D et al. Extracorporeal membrane oxygenation for 2009 influenza a(H1N1) acute respiratory distress syndrome. JAMA 2009; 302: 1888–95.
7. ECMO Registry of the Extracorporeal Life Support Organization (ELSO), Ann Arbor, Michigan, April, 2021.
8. Onatandra A, Annich GM. Novel surfaces in extracorporeal membrane oxygenation circuits. Front. Med. 2018; 20: 321.
9. Yeager T, Roy S. Evolution of gas permeable membranes for extracorporeal membrane oxygenation. Artif. Organs 2017; 41: 700–9.
10. Yeo HI, Kim D, Jeon D, Kim YS, Rycus P, Cho WH. Extracorporeal membrane oxygenation for life-threatening asthma refractory to mechanical ventilation: Analysis of the extracorporeal life support organization registry. Crit. Care 2017; 21: 297.
11. Odish MF, Yang J, Cheng G et al. Treatment of Bronchopleural and Alveolopleural fistulas in acute respiratory distress syndrome with extracorporeal membrane oxygenation, a case series and literature review. Crit. Care Explor. 2021; 3: e0393.
12. Sakamoto T, Morimura N, Nagao K et al. Extracorporeal cardiopulmonary resuscitation versus conventional cardiopulmonary resuscitation in adults with out-of-hospital cardiac arrest: A prospective observational study. Resuscitation 2014; 85: 762–8.
13. Soar J, Macconochie I, Wyckoff MH et al. 2019 International consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Resuscitation 2019; 145: 95–150.
14. Ramanathan K, Yeo N, Alexander P et al. Role of extracorporeal membrane oxygenation in children with sepsis: A systematic review and meta-analysis. Crit. Care 2020; 24: 684.
septic shock: A systematic review and meta-analysis with individual participant data meta-regression analysis. Crit. Care 2021; 25: 246.

16 Oberender F, Ganeshalingham A, Fortenberry J D et al. Venoarterial extracorporeal membrane oxygenation versus conventional therapy in severe pediatric septic shock. Pediatr. Crit. Care Med. 2018; 19: 965–72.

17 Maratta C, Potera RM, van Leeuwen G, Castillo Moya A, Raman L, Annich GM. Extracorporeal life support organization (ELSO): 2020 pediatric respiratory ELSO guideline. ASAIO J. 2020; 66: 975–9.

18 ELSO Guidelines for Cardiopulmonary Extracorporeal Life Support Extracorporeal Life Support Organization, Version 1.4, Ann Arbor, MI, USA; August 2017. Available from: www.elsog.org

19 Zampi JD, Alghanem F, Yu S et al. Relationship between time to left atrial decompression and outcomes in patients receiving Venoarterial extracorporeal membrane oxygenation support: A multicenter pediatric interventional cardiology early-career society study. Pediatr. Crit. Care Med. 2019; 20: 728–36.

20 Choudhury TA, Ofori-Amanfo G, Choi J et al. Acquired von Willebrand syndrome and impaired platelet function during veno-arterial extracorporeal membrane oxygenation: Rapid onset and fast recovery. J. Heart Lung Transplant. 2018; 37: 985–91.

21 McVeen RV, Lorch V, Carroll RC et al. Changes in fibroinolytic factors in newborns during extracorporeal membrane oxygenation (ECMO). Am. J. Hematol. 1991; 38: 254–5.

22 Passmore MR, Fung YL, Simonova G et al. Evidence of altered haemostasis in an ovine model of venovenous extracorporeal membrane oxygenation support. Crit. Care 2017; 21: 191.

23 McVeen RV, Lorch V, Carroll RC et al. Changes in fibroinolytic factors in newborns during extracorporeal membrane oxygenation (ECMO). Am. J. Hematol. 1991; 38: 254–5.

24 Murphy DA, Hocking LE, Andrews RK et al. Extracorporeal membrane oxygenation-hemostatic complications. Transfus. Med. Rev. 2015; 29: 90–101.

25 Kozik D. Neurodevelopmental outcomes in pediatric extracorporeal membrane oxygenation. ASAIO J. 2020; 66: 89–90.

26 Said AS, Guilliams KP, Bembea MM. Neurological monitoring and complications of pediatric extracorporeal membrane oxygenation support. Pediatr. Neurol. 2020; 108: 31–9.

27 Fraser CD 3rd, Kovler ML, Guzman W J et al. Pediatric femoral arterial cannulations in extracorporeal membrane oxygenation: A review and strategies for optimization. ASAIO J. 2019; 65: 636–41.

28 Gajkowski EF, Herrera G, Halton L, Vela Antonini M, Vercaemst L, Cooley E. ELSO guidelines for adult and pediatric extracorporeal membrane oxygenation circuits. ASAIO J. 2022; 68: 133–52.

29 Sanaia H, Khoubian JI, Williamson CG et al. Trends in mortality and costs of pediatric extracorporeal life support. Pediatrics 2020 Sep; 146. e20193564.

30 Ijsselstijn H, Schiller RM, Holder C, Shappley RKH, Wray J, Hoskote A. Extracorporeal life support organization (ELSO) guidelines for follow-up after neonatal and pediatric extracorporeal membrane oxygenation. ASAIO J. 2021; 67: 955–63.

31 Ijsselstijn H, van Heijst AF. Long-term outcome of children treated with neonatal extracorporeal membrane oxygenation: Increasing problems with increasing age. Semin. Perinatol. 2014; 38: 114–21.

32 O’Brien SG, Carton EG, Fealy GM. Long-term health-related quality of life after Venovenous extracorporeal membrane oxygenation. ASAIO J. 2020; 66: 580–5.

33 Elias MD, Achuff B, Ittenbach RF et al. Long-term outcomes of pediatric cardiac patients supported by extracorporeal membrane oxygenation. Pediatr. Crit. Care Med. 2017; 18: 787–94.

34 Hanekamp MN, Mazer P, van der Cammen-van Zijp MH et al. Follow-up of newborns treated with extracorporeal membrane oxygenation: A nationwide evaluation at 5 years of age. Crit. Care 2006; 10: R127.

35 McNally H, Bennett CC, Elbourne D, Field DJ, UK Collaborative ECMO Trial Group. United Kingdom collaborative randomized trial of neonatal extracorporeal membrane oxygenation: Follow-up to age 7 years. Pediatrics 2006; 117: e845–54.

36 MacLaren G, Butt W, Peek G, Lynch WR, Bartlett RH. Mistaking complications of critical illness for those of critical care. Crit. Care Med. 2014; 42: e173–4.

37 Zwiers AJ, Ijsselstijn H, van Rosmalen J et al. KD and hypertension during long-term follow-up in children and adolescents previously treated with extracorporeal membrane oxygenation. Clin. J. Am. Soc. Nephrol. 2014; 9: 2070–8.

38 Murray M, Nield T, Larson-Tuttle C, Seri I, Friedrich P. Sensorineural hearing loss at 9-13 years of age in children with a history of neonatal extracorporeal membrane oxygenation. Arch. Dis. Child. Fetal Neonatal Ed. 2011; 96: F128–32.

39 van der Cammen-van Zijp MH, Gischler SJ, Hop WC, de Jongste JC, Tibboel D, Ijsselstijn H. Deterioration of exercise capacity after neonatal extracorporeal membrane oxygenation. Eur. Respir. J. 2011; 38: 1098–104.

40 Ijsselstijn H, Hunfeld M, Schiller RM et al. Improving long-term outcomes after extracorporeal membrane oxygenation: From observational follow-up programs toward risk stratification. Front. Pediatr. 2018; 6: 177.

41 Fernando SM, Qureshi D, Tanuseputro P et al. Long-term survival and costs following extracorporeal membrane oxygenation in critically ill children – A population-based cohort study. Crit. Care 2020; 24: 131.

42 Metz A, Edwards L, UK Collaborative ECMO Trial. Cost effectiveness analysis of neonatal extracorporeal membrane oxygenation based on four year results from the UK collaborative ECMO trial. Arch. Dis. Child. Fetal Neonatal Ed. 2004; 89: F263–8.

43 Mahle WT, Forbess JM, Kirshbom PM, Quadrao AR, Simsic JM, Kanter KR. Cost-utility analysis of salvage cardiac extracorporeal membrane oxygenation in children. J. Thorac. Cardiovasc. Surg. 2005; 129: 1084–90.

44 Nelson-McMillan K, Vricella LA, Stewart FD et al. Recovery from total acute lung failure after 20 months of extracorporeal life support. ASAIO J. 2020; 66: e11–4.

45 Bartlett RH. ECMO: The next ten years. Egypt. J. Crit. Care Med. 2016; 4: 7–10.

46 Lehr CJ, Zaas DW, Cheifetz IM, Turner DA. Ambulatory extracorporeal membrane oxygenation as a bridge to lung transplantation: Walking while waiting. Chest 2015; 147: 1213–8.