

ECMO (extracorporeal membrane oxygenation) retrieval services in NSW

Neonatal and paediatric patients

NOVEMBER 2020

Contents

At a glance	1	References	13
Summary	2	Appendix 1: Search methods	15
Introduction and background	4	Acknowledgements	16
The research evidence	6		
The experiential evidence	12		

Rapid evidence reviews are based on a simplified systematic review methodology. They are generally completed in a 2–4 week timeframe and include a process of peer review. Reviews may not be entirely exhaustive, but aim to provide a balanced assessment of what is already known about a specific problem or issue. They examine the strength of the evidence in a particular area and consider not only the outcomes of studies, but their quality, quantity and design.

The information is not a substitute for healthcare providers' professional judgement.

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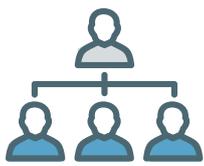
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Neonatal and paediatric ECMO retrieval services

Evidence at a glance

Seven main elements



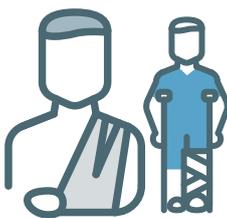
1. Structure

Central ECMO centre with a surrounding network.
Services that perform at least 20–30 annual ECMO runs do significantly better than the low-volume centres.



5. Transport mode

Ambulance, helicopter or fixed-wing aircraft.
Choice of transportation is impacted by availability, weather and distance.



2. Patient selection

Failure of conventional management, and clinical criteria, e.g. unacceptable risk of deterioration during conventional transport, cardio circulatory failure, inability to maintain acceptable oxygenation and ventilation.



6. Equipment

In principle the same as that used in hospital ECMO. Minimum components of a mobile ECMO service exists, including blood pump, membrane oxygenator and others.

For retrieval of neonates, proper sizing of the pump is required.



3. Pre-retrieval management

Once decision to initiate ECMO is made, ECMO team primes the ECMO circuit, cannulates and stabilises the patient.



7. Training and education

Extracorporeal Life Support Organization (ELSO) produce guidelines on training requirements for ECMO.

Basic training and experience required to become part of a transport team varies.



4. Retrieval team

At a minimum, an ECMO physician or specialist, a nurse (transport and ECMO/ICU specialist nurses), a perfusionist, and a cannulating physician.

Outcomes

Patient and technical complications are described, however most studies reported having no transport-related major complications.

Summary

Extracorporeal membrane oxygenation (ECMO) is a means of providing prolonged cardiopulmonary support. In neonatal and paediatric care, ECMO is a low-volume specialist service, generally consolidated into one high-volume centre. This means that retrieval, or transport to the specialist service is an important component of care. Retrieval consists of transporting personnel and equipment to the referring hospital, preparatory procedures at the referring hospital and transport back to the ECMO centre.

This report draws on two types of evidence: research evidence and experiential evidence.

Existing models

ECMO centres are usually affiliated with the international ELSO. ELSO provides training standards and maintains a data registry to track outcomes and assess performance. A well-established model in Sweden makes up a large portion of the published literature on paediatric ECMO. Other services described in grey literature operate in the United States, France, Germany and the United Kingdom. Generally, patients are referred to a specialist ECMO centre from another hospital and the on call ECMO physician decides if the patient fulfils the criteria for ECMO. These criteria typically include gestational age over 34 weeks; and failure of either mechanical ventilator support or other forms of rescue therapy.

Within Australia, the Royal Children's Hospital Melbourne runs a paediatric ECMO retrieval service that covers Victoria, Tasmania and Southern NSW. The team includes a senior paediatric nurse and doctor, a cardiac surgeon and cardiac perfusionist. Queensland Children's Hospital also provides an ECMO retrieval service. Patients are referred directly to the hospital's Paediatric Intensive Care Unit (PICU) or via the Retrieval Services Queensland coordination centre.

ECMO retrieval services

There are seven main elements in the neonatal and paediatric ECMO services.

1. Structure of ECMO services

Several studies using ELSO data show that the number of annual ECMO runs correlate with survival. For paediatric and neonatal populations, services that perform at least 20 to 30 annual ECMO runs do significantly better than low-volume centres (five or fewer retrievals each year). Some systems use a hub and spoke model. The hub is a high-volume ECMO centre and the spokes are low-volume centres, which have the capability to commence ECMO and support an eligible patient for hours or days, until they can be transferred to the high-volume unit by a mobile ECMO team. Some models also incorporate arrangements for patients in centres without ECMO capability.

2. Patient selection

Criteria for ECMO transport generally reflect the criteria for ECMO support. These include failure of conventional management and clinical criteria such as unacceptable risk of deterioration during conventional transport, cardio-circulatory failure and the inability to maintain acceptable oxygenation and ventilation. Candidates for ECMO transport are considered on a case-by-case basis, generally with input from a paediatric intensivist. A few studies analyse predictors of survival. Secondary transport for congenital diaphragmatic hernia and post-cardiac mobile ECMO renal support are associated with lower survival.

3. Pre-retrieval management

Evidence on the management of patients at the referring hospital while awaiting ECMO retrieval is limited. In most systems, the retrieval team provides the referring hospital with a list of requirements. Generally, the referring hospital provides blood products for circuit priming and allocates local resources to facilitate cannulation before arrival of the mobile ECMO team. If the referring hospital staff are able to cannulate patients and initiate ECMO, this can be performed. However, the ECMO retrieval team usually primes the ECMO circuit, cannulates and stabilises the patient.

4. Retrieval team

Retrieval personnel require proficiency in patient assessment, cannulation, ECMO circuit priming and initiation and management of patients on ECMO. The management of patients on ECMO involves monitoring the ECMO circuit, ventilator, medications and anticoagulation and responding to any problems or complications. Retrieval teams usually include, at a minimum, an ECMO specialist, a nurse (transport and ECMO/ICU specialist nurse), a perfusionist, and a cannulating physician. Some studies describe services with an ECMO coordinator.

5. Transport mode

Paediatric and neonatal ECMO retrieval can be via ambulance, helicopter or fixed-wing aircraft. Choice of transportation is influenced by availability, weather and distance.

6. Equipment

In general, hospital ECMO equipment is used for retrieval. For neonates, appropriate sizing of the pump is required. Minimum components of a mobile ECMO service include a suitable blood pump, a membrane oxygenator, a device for heating and

regulating circuit blood temperature, medical gas tanks and equipment for the provision and adjustment of blended sweep gas to the oxygenator, a venous and arterial pressure monitoring device, point-of-care anticoagulation monitoring equipment, an emergency pump, an uninterruptable power source and a portable ultrasound machine.

7. Training and education

While ELSO produces guidelines for training requirements, basic training and experience required to become part of an ECMO transport team varies between centres and countries. Some retrieval services require a minimum number of years of clinical experience (in addition to training).

Outcomes

Complications described in the literature include loss of tidal volumes, equipment failure, mechanical complications, climate and transport vehicle problems. Survival to discharge following ECMO retrieval has been reported as 60–75% for neonates and 65–83.3% for paediatrics.

Experiential evidence

The findings from the experiential evidence were consistent with the themes found in the research evidence. Additional findings include, current safety concerns for retrieval including the need for a governance framework to manage safety and quality issues, early identification of patients, single point of contact for advice and the coordination of resources, arrangements to ensure 24/7 availability and consideration of work flow impacts.

Introduction and background

Extracorporeal membrane oxygenation (ECMO) is a means of providing prolonged cardiopulmonary support. In paediatric and neonatal care, ECMO is a low-volume, specialist service generally located in one hospital. This means that retrieval, or transport to the specialist service is an important component of care. ECMO retrieval, also described as ECMO transport or transfer, consists of transport to the referring hospital with personnel and equipment, the procedures at the referring hospital and transport back to their own facility or to another ECMO centre.¹

Primary retrieval consists of transporting personnel and equipment to the referring hospital, preparatory procedures at the referring hospital, and transport to the ECMO centre. If the referring hospital has capability for cannulation and initiation of ECMO, this may have already been done by the referring hospital, this is known as a secondary transport.²

Overall, ECMO retrieval is considered safe in neonatal, paediatric and adult patients, with the survival of transported patients being comparable to age matched and treatment matched non-transported ECMO patients.³ In a systematic review of patients transported on ECMO, the pooled survival rates for paediatric patients was 68% (95% confidence interval 60–75).⁴ In a Cochrane review, ECMO has been shown to improve survival without increased risk of severe disability in newborn infants.⁵

Review question

What components of organisational models for neonatal and paediatric extracorporeal membrane oxygenation retrieval services, (including patient selection, pre-retrieval management and retrieval) are associated with improved outcomes?

Methods

A rapid evidence review was carried out in grey literature, PubMed and the Cochrane Library. Combinations of related terms representing ECMO including Extracorporeal Life Support (ECLS), paediatric, neonatal, organisational models, care models, retrieval and patient transfer were used to search the databases. The review was not limited by study design or date period. The review was limited to ECMO retrieval only. Studies only evaluating ECMO in hospital settings or those related to patient outcomes without describing the service were excluded. Full details of the search including search string and inclusion criteria can be found in Appendix 1.

The PubMed and Cochrane Library searches retrieved 219 results. After a full text review, 34 studies met the inclusion criteria. An additional four studies were found through other methods such as searching reference lists of included studies, Google searches and searching articles undergoing the peer review process, resulting in a total of 37 included articles.

The experiential evidence described in this document was gathered via an online questionnaire; qualitative content analysis was used to generate key themes from the responses.

A purposive sample was defined, based on an existing contact list held by Intensive Care NSW. The sample consisted of health professionals with knowledge and experience in ECMO, retrieval and/or paediatric or neonatal intensive care.

The questionnaire was administered using the survey function in QARS (quality audit reporting system). Participants received an initial invitation to complete the survey and two reminders through an automated email. The survey was open for completion from 8 November 2019 to 29 November 2019.

A qualitative content analysis was conducted using an inductive approach. This included three main phases: preparation, organisation and reporting of results. NVivo software was used to support data analysis.

Existing models in Australia

Victoria runs an ECMO retrieval service, which also services Tasmania and Southern NSW, known as the Paediatric Infant Perinatal Emergency Retrieval Service (PIPER). It retrieves critically ill children from hospitals throughout these states and transports them to Melbourne's Royal Children's Hospital (RCH) and to Monash Medical Centre in Melbourne. Medical staff include Intensive Care Unit (ICU) specialists from the RCH Paediatric Intensive Care Unit (PICU). The team includes a senior paediatric nurse and doctor, a cardiac surgeon and cardiac perfusionist.

ECMO for children in Queensland is provided by the Queensland Children's Hospital and includes patients in Northern NSW for primary ECMO. Secondary ECMO retrievals are provided Australia wide. The referral process is by phone directly to the Queensland Children's Hospital PICU or via Retrieval Services Queensland's coordination centre. The team includes a PICU ECLS senior medical officer (SMO), a PICU ECLS specialist, a Children's Health Queensland Retrieval Service (CHQRS) clinical nurse, a cardiac perfusionist and a cardiac surgeon (for primary ECMO retrieval only).

Existing models internationally

Many European countries have paediatric and neonatal ECMO services. In France, a survey reported 20 ECMO centres, four of which offered mobile ECMO but no well organised network for the most severe neonates and children.⁶

In Germany, a paediatric and neonatal mobile ECMO service is described. In a review of ECMO in

the United Kingdom (UK), all paediatric cardiac surgical centres in the UK provide cardiac ECMO support but the number offering retrieval services was not described.⁷

There is a well established model in Sweden which provides most of the published literature in this review. In this model, patients are referred by telephone from another ICU or hospital and an ECMO physician decides if the patient fulfils the criteria for ECMO. The transport team is comprised of an ECMO physician, a specialist nurse and a cannulating surgeon. A scrub nurse may also participate. Staff involved in ECMO retrieval require training and accreditation developed by the Extracorporeal Life Support Organization (ELSO).⁸

Multiple centres in the United States (US) operate ECMO retrieval services. The Children's Hospital of Pittsburgh has a Critical Care Transport Team which offers ECMO. Another service operates out of St. Louis Children's Hospital and has a specially trained ECMO team and mobile ECMO circuit. The Arkansas Children's Hospital run a mobile ECMO service of four trained medical specialists. Their transport service can be divided into three phases: pre-mobile ECMO evaluation, cannulation and mobile ECMO transport.⁹ In Ohio, the Nationwide Children's Hospital in Columbus has a different service in that it only transports already cannulated ECMO patients.¹⁰ Wilford Hall Medical Centre's ECMO transport team is individually tailored for specific missions and has a neonatal configuration for transporting neonates.¹¹ Wilford Hall Medical Centre closed down in 2011, however details on its service are still included throughout this review.

The peer reviewed literature also has case series and reports from the UK, US, Poland, Ireland, France, Italy, Taiwan, Australia and Canada.

The research evidence

ECMO retrieval services

Retrieval consists of transporting personnel and equipment to the referring hospital, the referring hospital's procedures and transport back to the ECMO centre.¹

ECMO retrieval can involve either primary transport where the patient is not already on ECMO, final assessment of the patient, cannulation and initiation of ECMO at the referring hospital and transport or secondary transports, when the patient is already on ECMO at the referring hospital.²

There are seven main elements in the neonatal and paediatric ECMO services.

1. Structure of ECMO services

Several studies using ELSO data show that the number of annual ECMO runs correlate with survival. For paediatric and neonatal populations, services that perform at least 20–30 annual ECMO runs do significantly better than the low-volume centres, which are defined as five or fewer runs each year.¹²

A hub and spoke model is described in the literature. The hub is a high-volume centre and the spokes are low-volume centres, which have the capability to commence ECMO and support an eligible patient for hours or days until they can be transferred to a high-volume unit by a mobile ECMO team. Some models also incorporate arrangements for patients in hospitals without ECMO capability.¹² This has been seen as the most cost and resource effective way to organise ECMO retrieval.¹³ Overall, there is no unifying guidance on how to develop, staff and organise the ECMO retrieval program.¹³

2. Patient selection

ELSO-defined criteria for ECMO transport mirrors the combined criteria for ECMO support (Table 1).

Studies describing patient selection specifically for neonates expand on the ELSO criteria to include:

- Failure of conventional management, one or more arterial post-ductal blood gas studies or no arterial pH defined by standard criteria, no profound hypotension.⁹
- Gestational age of at least 34 weeks, birth weight of greater than 2 kilograms, absence of severe, underlying nonpulmonary disease, no evidence of intracranial haemorrhage on a cranial ultrasound and no uncontrolled bleeding or known bleeding diathesis.¹¹
- Severe, reversible respiratory failure, defined by standard oxygenation index criteria, which is not responsive to pressure amplitude or conventional medical management.¹¹
- Other criteria related to inspiratory pressure and prolonged refractory hypercarbia with acidosis.¹¹

Various criteria are used in different institutions (see data extraction tables in supplementary documentation).

The patient selection criteria are the same as those for in-hospital patients, with the exception that if a patient's condition is rapidly deteriorating, the patient is retrieved earlier to avoid a need for cardiopulmonary resuscitation.⁸

For all cardiac patients, indications are broadly categorised as those related to cardiac surgery and catheterisation and 'other', such as cardio-circulatory failure due to myocardial failure, sepsis and persistent pulmonary hypertension of the newborn.¹⁴ Assessment of the right ventricle is important prior to initiating ECMO to estimate right ventricle pressure and demonstrate the presence and extent of ventricular dysfunction.¹⁵

One team in the US developed a system to identify suitable patients, which included a number of conversations with the referring physicians and the transfer of medical records and relevant images for review. If the risk-benefit assessment was too difficult to make by phone, a transplant pulmonologist from the ECMO specialist centre would travel to the referring hospital to gather additional information. This consultation sometimes led to additional testing.¹⁰

Similarly, in a service in Sweden, patients are referred by telephone from another ICU or hospital to the on-call ECMO physician, who decides if the patient fulfils the criteria for ECMO.⁹ The final decision, however, for acceptance for ECMO is made at the bedside with the retrieval team. After evaluation by the referring hospital, the ECMO team is consulted to discuss the safety of the patient transfer. Paediatric candidates for ECMO transport are considered on a case-by-case basis, with the patient's status taken into consideration in each individual case.^{8, 11}

Table 1: Patient selection criteria for ECMO retrieval (adult and paediatric)

1. Refractory hypoxemia and hypercapnia (failure of mechanical ventilator support)
I. Unacceptable risk of deterioration during conventional transport in the best clinical judgement of managing physicians
II. Inability to maintain acceptable oxygenation and ventilation without high frequency oscillatory ventilation (HFOV). Although high frequency modes of ventilation during transport are possible in select patient populations, HFOV transport is not currently feasible
III. Dependence upon inhaled nitric oxide (iNO) in the treatment of hypoxemic respiratory failure is not an absolute contraindication to conventional transport, as iNO can be safely administered during transport
IV. Presence of air leak syndrome(s) likely to worsen with continued high levels of positive airway pressure and altitude
2. Refractory septic and cardiogenic shock despite aggressive inotropic and pressor support
I. ECMO support for refractory septic shock may be considered as an indication for ECMO transport, primarily in neonatal and paediatric patients
II. Degree of pre-transport hypoperfusion, hypotension and acidosis coupled with risk of further deterioration during transport. The expected duration of transport must be considered
3. Specific clinical scenarios which may necessitate ECMO transport
I. Worsening acute respiratory distress syndrome (ARDS) or other aetiology of acute refractory respiratory failure at a centre not capable of providing ECMO
II. ECMO support initiated at referring centre for primary cardiac failure and patient needs transport to a transplant centre for evaluation for possible orthotopic heart transplantation (OHT) or other cardiac intervention
III. Patient who is a possible candidate for lung transplantation requires ECMO for safe transfer to a transplant centre
IV. Patient placed emergently and unexpectedly on ECMO support at a centre without resources to maintain the patient on long-term ECMO support

Source: ELSO patient transfer guidelines.²

In cases where referring hospitals do not have adequate equipment for assessment, the ECMO team can be dispatched to evaluate the patient and make a final decision about whether ECMO should be initiated.¹⁷

Among studies that reported survival, only a few looked at predictors of survival. One study showed an association between secondary transport and lower survival to ICU discharge.¹⁸ Another small study showed patients with meconium aspiration syndrome or persistent pulmonary hypertension of newborns had a better survival rate than patients with congenital diaphragmatic hernia. Comparing survivors and non-survivors across all ECMO patients, there was no difference in gestational age, birth body weight, Apgar score and duration of ECMO between the two groups.¹⁹ A further study showed that after adjusting for other covariates, post-cardiac mobile ECMO renal support was the only variable associated with death and the need for cardiac transplant.²⁰

3. Pre-retrieval management

There is limited evidence available on the management of patients at the referring hospital while awaiting ECMO retrieval.

ELSO guidelines for ECMO transport recommends additional supplies, personnel and equipment be allocated if a delay of arrival of the ECMO team is anticipated. The transport team should provide the referring centre with a list of requirements as early as possible. The referring facility usually provides blood products for circuit preparation, cannulation and ECMO initiation.²

Upon arrival at the referring hospital, a final assessment of the patient is performed by the ECMO physician, in conjunction with the cannulating physician, and together they make a final decision regarding whether ECMO is appropriate and the mode of ECMO to be used.⁸

Once the decision to initiate ECMO is made, the ECMO team typically prime the ECMO circuit, cannulate and stabilise the patient and transfer them to the ECMO centre.¹⁷

Guidelines in most jurisdictions stipulate a checklist to guide preparation and to ensure that the emergency equipment rescue kit, console and drive-unit, and blood products are quality controlled. They recommend that equipment such as infusion lines, the ECMO unit, ventilator tubing, cables and oxygen bottles should be checked and secured. A time-out should be performed before removing the patient from the ward to ensure everyone and everything is ready.²¹ Contingency plans should be made and equipment and checklists should be reviewed.¹⁰

In addition to details of the patient's clinical course, a pre-transport briefing focuses on:

- the patient's ECMO cannulation configuration (venovenous or venoarterial ECMO)
- the presence of ECMO-related complications
- the current anticoagulation regimen
- ECMO machinery and circuit type
- mechanical ventilator mode and settings
- airway devices
- and level of sedation.¹⁰

Early communication with complete and accurate information is essential.²²

4. Retrieval team

The team requires capabilities in patient assessment, cannulation, ECMO circuit priming and initiation and managing the patient on ECMO. Management includes monitoring the ECMO circuit, ventilator, medications, anticoagulation and resolving problems and complications.¹ There are also a range of professional requirements, for example, all perfusionists should be licenced.¹³

The number of staff in the ECMO retrieval service generally ranges from three to six, although one study reported up to 12 and another up to 15.^{9-11, 13, 16, 18, 19, 23-31} Staff, at a minimum, include an ECMO physician or specialist, a nurse (transport and ECMO/ICU specialist nurses), a perfusionist and a cannulating physician. Some also include a scrub nurse or surgical assistant.^{8, 18} An Australian series reported their team included a senior PICU physician, an ECLS nurse specialist, a perfusionist and a cardiac surgeon.²³ If the patient requires cannulation at a referring facility, then a cannulating physician is required.² One series in the US reports three transport nurses in addition to the ECMO nurse and physician.²⁴ Some studies reported having an ECMO coordinator or commander.^{27, 30, 31} In an international survey of 15 centres, all of the centres had staff available for transport 24 hours a day, seven days a week.¹³

5. Transport mode

Transport options for paediatric and neonatal ECMO retrieval reported in the literature are ambulance, helicopter and fixed-wing aircraft.^{1, 9, 17}

A case series reporting on transport modes showed fixed-wing aircraft (5–92%) and ambulance (12.5–80%) are the most common transport modes.^{16, 18, 20, 23, 27, 32, 33} Many case reports in the literature focus on transport via fixed-wing aircraft.^{25, 26, 30, 34, 35} Factors influencing the choice of transport include availability, weather and distance.^{1, 2} Additional regulatory requirements become relevant with medical transports by road and air.

Many guidelines and protocols recommend a staff time-out before leaving any location (including a ward or vehicle). A time-out refers to stopping and discussing information about red flags such as circuit clots; explaining each step of the retrieval; and discussing a back-up plan. There should also be continuous re-evaluation. Where possible, transport time should be kept short.²¹ Continuous monitoring of vital signs and oxygen saturation, as in the ICU, are applied during transfer.¹⁹

6. Equipment

In general, medical equipment used in ECMO retrieval is the same as that used in hospital ECMO treatment.¹ In an international survey, only two services reported the use of dedicated equipment for ECMO retrieval.¹³ Heaters to prevent hypothermia should be used during transport. Appropriate sizing of pumps suitable for neonates should be available.²¹ Equipment needs to be readily accessible and secured.³⁶ Supplies and equipment are transported in several transport packs and with capacity to maintain the patient on ECMO for at least 24 hours.⁹ Equipment should be standardised; integrated into ambulance and air-ambulance configurations; and field and flight-tested in order to ensure compliance with Work, Health and Safety and Civil Aviation Safety Authority regulations.

Guidance is consistent across jurisdictions that equipment should be accounted for and secured during transport.¹¹ Incorporating a back-up battery supply, using a low power-consuming heater/cooler device and the availability of an ambulance with a sufficient power output facility were reported as vital elements in one case report.²⁹

ELSO guidelines provide a set of minimum components for a mobile ECMO system (Table 2).²

7. Training and education

ELSO produces guidelines on training requirements for ECMO. These cover physiology of the diseases treated with ECMO, pre-ECMO procedures, criteria and contraindications for ECMO, physiology of coagulation, ECMO equipment, physiology of venoarterial and venovenous ECMO, daily patient and circuit management on EMCO, emergencies and complications, management of complex cases, weaning from ECMO, decannulation procedures, post-ECMO complications, short- and long-term developmental outcomes of ECMO patients and ethical and social issues.³⁷

Table 2. Mobile ECMO minimum components

A mobile ECMO system consists of the following minimum components	
1.	A suitable blood pump, centrifugal or roller.
2.	A membrane oxygenator, appropriate for the patient's size.
3.	Device(s) for heating and regulating circuit blood temperature (less critical for adult transports).
4.	Medical gas tanks, regulators, hoses, connectors, flow meters and blenders for provision and adjustment of blended sweep gas to the oxygenator.
5.	Venous and arterial pressure monitoring device(s), according to centre-specific practices.
6.	Point-of-care anticoagulation monitoring equipment (e.g. Activated Clotting Time).
7.	An emergency pump or manual control mechanism in the event of primary pump failure or power failure.
8.	Uninterruptable power source(s) capable of meeting the electrical power needs of all equipment during transfer between vehicles and in the event of vehicle power source failure.
9.	A portable ultrasound machine, if not provided by the referring facility.

Source: ELSO patient transfer guidelines.²

Reviews in the literature advise regular training, in the form of scenarios, be arranged by senior staff members of the ECMO team.²¹ In an international survey, 13 of 15 centres stipulated that in order to become an ECMO retrieval team member, training and education in critical care transport was mandatory.¹³ Some services require staff complete an ELSO accredited ECMO course.⁸ In some jurisdictions, services require a minimum period of clinical experience in ECMO management, (one, or in more recent studies, four years experience).^{9, 13}

One centre has presented a simulation based training scenario, which includes all stages of ECMO retrieval, including patient selection criteria, the team, therapy configuration, cannulation, perfusion therapy and transport.^{38, 39}

A checklist should be completed before departure. Custom designed circuits have been used for particular transport modes such as aircraft.^{31, 35}

Outcomes

Reported complications include patient and technical complications.^{17, 40} Overall, most studies reported having no transport-related major complications or adverse events.^{1, 9, 11, 36, 42, 43}

Studies that did report complications include:

- One very small series of eight patients had a complication rate of 50%.⁴¹ Another larger study noted complications in 28% of transports.¹⁸
- One study specified minor or major complications, with two minor complications (including equipment failure) and no major complications or deaths during transport.²⁰
- In another series, several mechanical complications occurred, however all were able to be corrected without significant interruption of the ECMO support.³¹

- In a 2019 study, complications were noted in 40% of transports (n=16). The most frequent complication during retrieval was loss of tidal volumes, followed by equipment failure, climate problems and transport vehicle problems.³³

Complications due to ECMO (not specific to retrieval) can include bleeding and thrombosis, which is more likely in patients less than 30 days old and those requiring ECMO for cardiac indications.^{44–46} A 30 day survival rate of 60% was reported in paediatric patients following retrieval in one study.⁴² Across the studies reviewed, survival to discharge ranged between 60–75% for neonates and 65–83% for paediatrics.^{16, 19, 27, 31, 32, 41, 43}

Patient and carer support

All 15 centres in an international survey provide families with information and educational material about ECMO.¹³ The ECMO physician is generally required to obtain consent for ECMO and transport from the next of kin.²

Follow-up and data collection

Some services incorporate a post-transport debrief to allow the involved teams and services to refine processes, equipment lists and checklists, and to further define roles and responsibilities. Action items are generated based on needs identified in the post-transport phase.¹⁰

Three quarters of the centres in an international survey reported regular follow-up and reviews of their retrieval service.¹³ Services report transport-related data to an ELSO registry for transport quality follow-up and research.²¹

The experiential evidence

The survey response rate was 56% (n = 36). Qualitative data analysis identified 18 themes which are described below.

The themes were categorised using a thematic framework informed by the peer reviewed evidence.

Structure	<ul style="list-style-type: none"> • Safety issues to be aware of include variation in timing of referral, limited ECMO retrieval expertise and a lack of transportable equipment. • Centralised approach is required for timely coordination and deployment of ECMO resources and personnel. • Governance framework is needed to oversee safety and quality issues. • Data must be collected and outcomes benchmarked to build an evidence base. • Single point of contact is required for advice and the coordination and deployment of ECMO resources.
Patient selection	<ul style="list-style-type: none"> • Selection criteria are required to determine suitability, early identification and thresholds for referral including how to weigh the potential risks and benefits of transfer. • Timing of transfers needs to be discussed with clinical experts and the 'optimal window' is to transfer pre-emptively.
Pre-retrieval management	<ul style="list-style-type: none"> • Clear expectations between the retrieval team and referring facility are needed around pre-treatment, staffing and theatre availability. • Families are in crisis and need information about ECMO and assistance with transport.
Retrieval personnel	<ul style="list-style-type: none"> • Team composition must be represented by the smallest (and safest) group of skilled and experienced personnel. At a minimum this includes an intensivist, surgeon (thoracic or cardiothoracic), ECMO retrieval nurse, perfusionist and biomedical engineer or support. • Team availability needs to be coordinated to ensure a 24/7 roster. • Work flow impacts through the reallocation of staff include fatigue, cost and impact on care.
Transport mode	<ul style="list-style-type: none"> • Air and ground transport are required with timely access to ambulance, rotary and fixed-wing aircraft.
Training	<ul style="list-style-type: none"> • Building and maintaining expertise is difficult with high-risk and low-volume activities like ECMO. • Expertise needs to be developed and maintained through education, training and simulated practice.
Equipment	<ul style="list-style-type: none"> • Compact and compatible equipment is required as there are space restrictions in vehicles and aircraft. • Certification of equipment to fly, aligning with jurisdictional regulatory bodies, is essential to mitigate risk and cost. • Protocols are required to improve availability, accessibility and management of ECMO equipment. This includes standardisation of retrieval equipment.

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Appendix 1: Search methods

PubMed

((Extracorporeal Membrane Oxygenation[Mesh]
OR Extracorporeal Membrane Oxygenation[ti]
OR ECMO[ti]
OR Extracorporeal Life Support[ti]
OR ECLS[ti]))

AND (paediatrics[Mesh]
OR paediatric*[tiab] OR pediatric*[tiab]
OR Infant, Newborn[Mesh] OR neonatal[tiab]
OR children*[tiab]))

AND (Models, Organizational[mh]
OR organizational innovation[mh]
OR "model* of care"[tiab]
OR care model*[tiab]
OR "care delivery model" [tiab]
OR "organi* of care" [tiab]
OR "organi* model" [tiab]
OR "healthcare delivery model" [tiab]
OR "Delivery of Health Care/ organization
and administration"[Mesh]
OR interhospital[tiab]
OR inter-hospital[tiab]
OR retrieval[tiab]
OR patient transfer[mh]
OR transport*[tiab]
OR transfer*[tiab]))

AND English[la]

= 209 hits on 6 November 2019.

Cochrane Library

ECMO retrieval: four reviews and four trials excluded because they described adults, were not ECMO and not retrieval.

Paediatric and pediatric ECMO was searched for reviews only, two were found but one was an adult study and one did not describe retrieval.

Grey literature

Searching for national and international models of care, guidelines, government reports and other relevant documents. Google and Google scholar were searched, as well as organisational websites (such as ELSO and NICE). Terms such as 'paediatric ECMO retrieval' 'ECMO retrieval models' 'pediatric ECMO service' and 'ECMO care models' were used.

Inclusion criteria

ECMO retrieval/transfer/transport (study must describe at least one of the below):

- patient selection for ECMO retrieval
- management of patients while waiting for retrieval
- components of retrieval: systems, equipment, notifications, safety, medical credentials and training, and model for retrieval
- any study design including non-systematic reviews
- any date period
- studies describing services that include paediatrics or neonates individually, in combination with each other, or in combination with adult services.

Exclusion criteria

- Language other than English
- ECMO provided in hospital only
- Studies describing adult services only
- Non-ECMO transport.

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