Extracorporeal life support in paediatrics

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Abstract

Extracorporeal membrane oxygenation (ECMO) is a life support technique based on modifications of heart-lung bypass technology. It is used to support severe but potentially reversible pulmonary or cardiopulmonary failure. There is increasing use of the technique for neonates and a return of interest in its use for adults. The number of non-neonatal paediatric patients receiving pulmonary support with ECMO worldwide is, however, small, and survival rates average less than 50%. Initial experience in 15 patients aged 3 months to 5 years with a high survival and low morbidity is reported.

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Extra corporeal membrane oxygenation (ECMO)¹ was introduced as a treatment for respiratory failure in the 1970s. The first successful clinical use was of an adult with acquired respiratory distress syndrome reported by Hill *et al* in 1972.² After this report there was widespread enthusiasm for the technique. A multicentre trial of ECMO for acquired respiratory distress syndrome reported in 1979, however, indicated that ECMO did not improve survival.³ Following this report, the early enthusiasm for ECMO waned as far as adult patients were concerned. Bartlett *et al*, however, and then other groups, were able to show the effectiveness of ECMO for neonatal respiratory failure.^{4 5} By 1985 ECMO had become the standard treatment for severe neonatal respiratory failure in the USA and initial UK experience in neonates is encouraging.⁶

ECMO has been used less often for respiratory failure in older children. We report our early experience of ECMO in this age group. Patients

were referred with refractory respiratory failure due to a variety of underlying pulmonary disorders. All were considered to have potentially reversible problems and to have received maximal conventional treatment.

Patients and methods

Eighteen children aged 3 months to 5 years were referred over a 2.5 year period with severe pulmonary or cardiopulmonary failure. Of these 15 had a primary pulmonary problem, one of whom had concurrent congenital heart disease. They were transferred from up to 350 miles away: 10 by road, three by helicopter, and one by fixed wing aircraft. One further patient was treated in the referring hospital 100 miles away.

Table 1 summarises the clinical features on presentation. Fourteen patients with a variety of underlying diseases were in a progressive decline on high pressure ventilation and high inspired oxygen concentrations (usually $\text{FIO}_2=1$). In each instance there was either severe hypoxia or hypercarbia, or both. In one patient (patient 1) carbon dioxide tension was greater than 30 kPa. Barotrauma was present in many patients, manifested by air leaks and cyst formation within the lung. In a further patient (patient 13), there was severe but relatively stable respiratory failure which required a lung wash for alveolar lipoproteinosis. ECMO was used to provide life support and suitable conditions for this to be performed.

Different techniques of cannulation were used according to the weight of the patient and the degree of cardiac dysfunction (table 2). Bypass circuits all used Scimed spirally wound silicone membrane oxygenations (0.8-2.4 m² of membrane surface area). In the patients weighing less than 8 kg 0.25 inch super Tygon tubing was

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Table 1 Clinical features at presentation

Age (months)	Diagnosis	Ventilation rate	Inspiratory: expiratory ratio	Ventilation pressure	F _{IO} ₂	Minute volume	pH	Carbon dioxide tension (kPa)	Oxygen tension (kPa)	Air leak	Inotropes	Pulmonary vasodilators
34	Viral pneumonia (cystic fibrosis)	90	1:1	40/5 (+ bagging)	1		6.68	31	7.2		+	
59	Croup/ARDS	100	1:1	40/8 (+ bagging)	1		7.35	6.6	5.1		+	
23	Drowned (pig slurry)	40	1:1	45/5	1		7.11	6.6	5.1		+	
6	Respiratory syncytial virus/staphylococcus pneumonia/pneumonitis	40	1:1	48/5 (+ bagging)	1		7.35	10.8	6.0	+	+	
			1:1	40/4	1		7.6	8	7.3		+	
3	Viral pneumonia/pneumonitis										+	
6	Viral pneumonia/pneumonitis	40	1:1	40/5	1		7.48	8.6	7.3		+	+
3	Viral pneumonia/pneumonitis	70	1.5:1	49/5 (+ bagging)	1		6.76	11.8	4.0		+	+
9	Viral pneumonia (vascular ring and Fallot)	40	1:1	45/6 (+ bagging)	1		7.15	8.4	4.6		+	+
65	ARDS (seawater drowning)	20	1:1	60/6 (+ bagging)	1	6.5 l	7.4	5.4	4.5		+	
4	Viral pneumonia/pneumonitis	60	2:1	Bagging PIP 70	1		7.3	4.5	5.2		+	
9	ARDS	20	2.5:1	35/12	0.65		7.69	3.6	7.1		+	
30	ARDS	30	1:1	Bagging 60/10	1		7.36	6.1	10.1	+	+	
40	Alveolar lipoproteinosis	24	1:1	36/-4 (+ bagging)	1	7.2 l	7.42	4.2	9.2		+	
63	Varicella pneumonia/pneumonitis	40	2:1	Bagging PIP >80	1		7.44	6.1	9.1	+	+	
30	Bacterial pneumonia/pneumonitis	35	2:1	35/10	1		7.5	4.2	9.5		+	

ARDS=acquired respiratory distress syndrome; PIP=peak inspiratory pressure.

used. In the larger patients 0.375 inch tubing was preferred. A roller pump was used in 13 patients and a centrifugal impeller system (Delfin) in the other two.

Cannulas were placed by surgical cutdown under general anaesthesia after heparinisation of the patient and the blood primed circuit. A heparin infusion was then started to maintain an activated clotting time of 160–200 seconds (usually 30 to 60 units of heparin/kg/hour). Sedation was achieved with a combination of opiates, benzodiazepines, and isoflurane. Intravenous feeding was routinely infused into the circuit. Blood and platelet transfusions were given as necessary to maintain a haemoglobin concentration greater than 120 g/l and a platelet count of greater than $50 \times 10^9/l$. Low dose dopamine was often given to promote diuresis and loop diuretics were used liberally. These steps, in combination with improved oxygenation, were usually successful and haemofiltration was necessary in only one patient. Antibiotics were given according to the underlying condition and the results of serial bacteriology. Ventilation was usually maintained at 'rest settings'; these were chosen to reduce the mean airway pressure and minimise atelectasis. In one patient, with a large lung cyst, continuous positive airways pressure only was used during ECMO and until extubation.

With the emphasis of gas exchange changed from the native to the membrane lung, physiotherapy can be comprehensively applied and was used to promote re-expansion of the atelectatic lung and the drainage of secretions. Bronchoscopy was performed in two patients to assess tracheal obstruction (patient 8) and tracheal damage after a traumatic intubation (patient 12). Echocardiography was usually performed to check the position of the cannulas and in one patient it showed significant right to left shunting through a patent foramen ovale.

Decannulation was performed by re-exploring the incision(s) after a successful trial of ECMO with modest ventilator settings. The cannulated vessels were usually ligated but on three occasions the carotid artery and jugular vein were repaired.

Results

Table 2 give details of the ECMO runs. In all patients effective gas exchange was achieved after the start of ECMO, allowing ventilator settings to be rapidly reduced. The ECMO runs

lasted from 43 to 640 hours (median 132 hours). Patients were often oedematous at presentation due to a combination of fluid overload and capillary leak. Each patient was invariably at or below their weight before illness at the time of decannulation. Technical complications related to the circuit were rare. In over 3000 hours of perfusion three mechanical complications occurred; a bladder box failure, a subacute raceway rupture, and failure of the centrifugal pump heads. In each instance circuit repair or component replacement was quickly achieved and all patients survived. Since the repetitive failure of centrifugal pump heads, roller pump circuits have been used exclusively.

Thirteen patients (87%) survived the acute illness. Of these, one (patient 1) has cystic fibrosis. The patient with alveolar lipoproteinosis had additional irreversible lung disease and had limited benefit from pulmonary lavage. Inadequate pulmonary function persisted and she died after ECMO while awaiting organ replacement.

Two patients died during the acute illness. One (patient 3) died having drowned in pig slurry. The ECMO run was successful with the child regaining full consciousness despite having been severely asphyxiated and hypothermic, and having had a cardiac arrest before transfer for ECMO. After successful weaning from the ECMO, he gradually developed multisystem failure which was shown at necropsy to be due to fungal infection (aspergillus). The other death was in a patient with asphyxia due to viral infection, a vascular ring due to a right ductus ligament, and tetralogy of Fallot (patient 8). The vascular ring was successfully divided through a median sternotomy while receiving ECMO. Having been weaned from ECMO there was a further deterioration in gas exchange, and correction of the tetralogy of Fallot was to no avail. Death was due to inspissated mucus plugs, a consequence of the viral infection, and right heart failure.

The ability of ECMO to allow barotrauma to resolve was best seen in a child with staphylococcal pneumonia. At presentation there were five chest drains in situ (two in each pleural cavity and one draining a pneumoperitoneum) and an expanding bulla in one lung. On ECMO she was not ventilated further. She self ventilated on ECMO and then proceeded from ECMO to continuous positive airways pressure, and then to extubation. The air leaks resolved rapidly and the bulla did not expand in size or rupture. Over a year later her chest radiograph is nearly normal and there is no clinically detectable functional impairment.

Another situation in which ECMO was particularly impressive was when there was a right to left shunt across a patent foramen ovale (patient 2). In such situations increasing ventilation, which may be necessary from the pulmonary point of view, increases the intracardiac right to left shunt. ECMO avoids this particular problem. As a patent foramen ovale is present in up to 27% of the population,⁷ this may be an under-diagnosed phenomenon.

Neurological damage was apparent in one child (patient 7) but had been suspected before

Table 2 Details of ECMO perfusion

Patient No	Cannulation	Time of ECMO (hours)	Outcome
1	Venovenous	110	Survived
2	Venovenous	120	Survived
3	Venoarterial	132	Died
4	Venovenous	235	Survived
5	Venoarterial	277	Survived
6	Venoarterial	140	Survived
7	Venoarterial	640	Survived
8	Venoarterial	77	Died
9	Venovenous	112	Survived
10	Venoarterial	168	Survived
11	Venovenous	32	Survived
12	Venovenous	333	Survived
13	Venoarterial	85	Survived
14	Venovenous	369	Survived
15	Venovenous	184	Survived

ECMO. She died three months later from a separate respiratory illness. None of the other patients have overt neurological damage and have normal developmental assessments. Five of the children did show abnormal movements for a few days after decannulation and this gave rise to concern. In one instance they were severe enough to constitute a non-respiratory cause for reintubation. Extensive investigation did not elucidate a cause and in each instance these abnormalities have resolved spontaneously. The aetiology probably relates to the prolonged administration of multiple sedatives and muscle relaxants in a changing metabolic environment.^{8 9}

Discussion

From the early days of ECMO research and clinical application, it has been shown that this technique can support pulmonary function for prolonged periods of up to days or weeks. With increasing experience and refinements in circuit design and management, serious technical complications have become uncommon. Similarly, patient complications, usually haemorrhage, have become less common and less severe with modern circuit designs and the resultant low requirement for heparinisation.¹⁰ It is also clear that the risks of carotid cannulation, when used, are not as high as feared. Furthermore venovenous perfusion, which obviates this particular risk, is adequate in many instances.

The problem of case selection for ECMO remains and is controversial. ECMO has been applied to neonatal respiratory failure in over 5863 cases in 79 centres worldwide reporting to the central registry (Extracorporeal Life Support Organisation (ELSO)) with a survival rate of 82%. It has also been subjected to two modified design, randomised controlled trials in this age group in an attempt to establish whether it is a viable alternative to conventional ventilation.^{11 12} These trials have raised considerable controversy and criticism.¹³⁻¹⁵ In the UK a trial is currently being organised to try and resolve this issue. There have been no trials of ECMO for paediatric patients with respiratory disorders, and comparatively few patients (309 from 53 centres) have been reported to the ELSO registry. There was a National Institutes of Health study of respiratory failure in adults conducted in the 1970s.³ In this the ECMO and controlled groups had poor outcomes, with survivals of less than 10% in the two groups.

With trial data in short supply, case selection must remain empirical. We have selected patients whom we believe to have potentially reversible pulmonary disease, but in whom conventional treatment is becoming increasingly ineffective and dangerous as manifested by deteriorating gas exchange and increasing barotrauma. Information from the ELSO registry has also been helpful in assessing patients with uncommon pathology. We believe our case selection has been justified by the results obtained. Although some of the children might have survived without ECMO, it is unlikely that a group of such sick children would have fared better than we have reported. Our results compare favourably, in terms of survival rates, with

Table 3 ELSO: paediatric respiratory support in January 1992

Primary diagnosis	No of survivors	Survival (%)
Bacterial pneumonia (n=27)	12	44
Viral pneumonia (n=97)	46	47
Intrapulmonary haemorrhage (n=4)	4	100
Aspiration (includes drowning) (n=33)	20	61
Pneumocystis (n=6)	2	33
ARDS (n=82)	34	41
Others (n=60)	29	48
Total (n=309)	147	47

ARDS=acquired respiratory distress syndrome.

those in the ELSO registry (table 3). This is not least because we have made use of information from it in our case selection. Although the two series differ in terms of diagnostic distribution similar indications for ECMO are used in both. In our series, patients with viral pneumonia fare well and form the largest group. There was an interesting subgroup of children with respiratory syncytial virus infection in the presence of mild bronchopulmonary dysplasia, following prematurity. It is known that this disorder tends to have a protracted course and also that further barotrauma is best avoided.¹⁶

Although the place of ECMO in the treatment of respiratory failure in children is uncertain and merits more formal evaluation in clinical trials, we have shown that it can be an effective support treatment in selected patients.

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- 1 Bartlett RH. Extracorporeal life support for cardiopulmonary failure. *Curr Probl Surg* 1990;27:621-705.
- 2 Hill JD, O'Brien TG, Murray JJ, 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 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.
- 4 Bartlett RH, Andrews AF, Toomasian JM. Extracorporeal membrane oxygenation (ECMO) for newborn respiratory failure: 45 cases. *Surgery* 1982;92:425-33.
- 5 Bartlett RH, Gazzaniga AB, Jefferies R. Extracorporeal membrane oxygenation (ECMO) cardiopulmonary support in infancy. *ASAIO Trans* 1976;22:80-8.
- 6 Pearson GA, Field DJ, Firmin RK, Sosnowski A. UK experience in neonatal extracorporeal membrane oxygenation. *Arch Dis Child* 1992;67:822-5.
- 7 Hagen PT, Scholz DG, Edwards WD. Incidence and size of patent foramen ovale during the first ten decades of life: an autopsy study of 965 normal hearts. *Mayo Clin Proc* 1984;59:17-20.
- 8 Rupprecht J, Dworacek B. Central anticholinergic syndrome during postoperative period. *Ann Fr Anesth Reanim* 1990;9:295-304.
- 9 Schneck HJ, Rupprecht J. Central anticholinergic syndrome (CAS) in anesthesia and intensive care. *Acta Anaesthesiol Belg* 1989;40:219-28.
- 10 Pearson GA, Firmin RK, Sosnowski A, Reeves R. Support when gas exchange fails [letter]. *Clin Intensive Care* 1992;3:41-2.
- 11 Bartlett RH, Roloff DW, Cornell RG, Andrews AF, Dillon PW, Zwischenberger JB. Extracorporeal circulation in neonatal respiratory failure: a prospective randomized study. *Pediatrics* 1985;76:479-87.
- 12 O'Rourke PP, Crone RK, Vacanti JP, et al. Extracorporeal membrane oxygenation and conventional medical therapy in neonates with persistent pulmonary hypertension of the newborn: a prospective randomized study. *Pediatrics* 1989;84:957-63.
- 13 Elliott SJ. Neonatal extracorporeal membrane oxygenation: how not to assess novel technologies. *Lancet* 1991;337:476-8.
- 14 Lantos JD, Frader J. Extracorporeal membrane oxygenation and the ethics of clinical research in pediatrics. *N Engl J Med* 1990;323:409-13.
- 15 Sosnowski AW, Bonser SJ, Field DJ, Graham TR, Firmin RK. Extracorporeal membrane oxygenation. *BMJ* 1990;301:303-4.
- 16 Steinhorn RH, Green TP. Use of extracorporeal membrane oxygenation in the treatment of respiratory syncytial virus bronchiolitis: the national experience, 1983 to 1988. *J Pediatr* 1990;116:338-42.