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ORIGINAL

Veno-venous two-site cannulation versus veno-venous double lumen ECMO: complications and survival in infants with respiratory failure

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ABSTRACT

Objective. To compare complications and survival between the two-site veno-venous versus the veno-venous double lumen extracorporeal membrane oxygenation (ECMO) in infants with respiratory failure.

Methods. The Extracorporeal Life Support Organization (ELSO, Ann Arbor, Michigan) provided the registry database, collected between 1999-2009 for this research project. During this period, 9086 infants ≤ 7 kg birth weight (BW) were treated with ECMO. From these children, those who were older than 32 days and received veno-venous extracorporeal membrane oxygenation (VV ECMO), were extracted for analysis. From a total of 270 infants who met the inclusion criteria, 236 infants were treated with veno-venous double lumen (VVDL) ECMO and 34 infants received VV two-site ECMO. ELSO records were reviewed for the following information: demographic data, type of ventilation, ventilator days and settings during ECMO, complications during ECMO and survival.

Results. Eighty-seven percent (n=236) of infants were cannulated with VVDL and 13% (n=34) with VV two-site cannulation. Twenty-four hours after ECMO onset, ventilator settings were significantly higher in the VV two-site group. Median ECMO duration was significantly shorter in the VV two-site group (137(90/208) vs. 203(128/336) hours, p=0.01). Total complication rate and survival rates (71% in the VVDL group and 56% in the VV two-site group) were not significantly different.

Conclusion. Both cannulation modes for ECMO are safe for use in infants with respiratory failure. The decision regarding which technique should be used for this group of patients depends mainly on best practice experience of the individual ECMO center and on the technical equipment routinely used by the center.

Key words: ECMO, infants, respiratory failure, complications, survival

Introduction

Extracorporeal membrane oxygenation (ECMO) provides temporary life support for children with severe respiratory or cardiac failure. Since 1990, more than 29,000 children with respiratory failure have received ECMO. The overall survival rate reported by the Extracorporeal Life Support Organization (ELSO) is 75% in neonates and 56% in children. (1) Despite its technical complexity and the need for experienced staff (usually designated as the "ECMO-team"), ECMO support has clearly achieved an important role in pediatric critical care. Although many previous studies describe ECMO treatment in neonatal or pediatric respiratory failure, (2-10) the impact of different veno-venous ECMO methods has remained unconsidered.

ELSO provides a data registry dating back to 1989. All ECMO centers, which are members of ELSO, report their ECMO cases, devices, complications and follow-up status to this registry in an anonymous form. For this purpose, each center uses standardized data capture forms for each patient. Since 1990, more than 30,000 treatments were added to the database containing data from neonatal, pediatric and adult ECMO cases. Currently, data from 116 US and 14 international centers are submitted to ELSO. Submission of cases to the ELSO registry is voluntary. A database of information relating to 10

years of international experience was provided by ELSO for this study.

The objective of this study was to compare complications and survival between veno-venous two-site ECMO (VV ECMO) and veno-venous double lumen ECMO (VVDL ECMO) in infants with respiratory failure.

Methods

This study was designed as a retrospective chart review study. Until recently, most pediatric ECMO studies reported on neonates (body weight 2.5-3.5kg) and/or children (body weight > 10kg) but not specifically on infants (body weight 4-10 kg). The median weight of an infant of 6 months according to international percentile curves is 8 kg body weight for boys and 7,2 kg body weight for girls. (11) We therefore, set the cut-off point for the inclusion criteria at < 7kg body weight and age of > 32 days for infants which were included in this study. This study aims to fill, or at least narrow, this gap. From 1999 until 2009, the registry recorded 9,086 ECMO runs in infants with a body weight ≤ 7kg. Using the 'mode of bypass' data field as a sorting tool, two groups of patients were identified among all infants older than 32 days: the VV two-site ECMO group and the VVDL ECMO group. Two hundred and seventy infants met the inclusion criteria of which 236 infants (87%) were treated with VVDL ECMO and 34 infants (13%) were treated with VV two-site ECMO. Children who had received other modes of ECMO were not included in this study. The decision to use VV ECMO was made at each centre according to their own ECMO criteria. Only data from the first ECMO run were analyzed. Anonymity of the data could be assured as data were related to patient identification (ID) numbers in the ELSO registry. Each institution approved data reported to ELSO through their local institutional review board. The Hospital Research Ethics Committee reviewed the study protocol. And the requirement for ethical approval was waived.

Data management

Data were reviewed for the following:

Demographic data

Primary diagnoses: determined according to the International Classification of Diseases (ICD 9).

Pre-ECMO support: evidenced by the existence of support codes for vasopressor/inotropic drugs, vasodilator drugs, cardiopulmonary bypass, high frequency ventilation/oscillation, nitric oxide, surfactant, narcotics, neuromuscular blockers, bicarbonate, dopamine, dobutamine, milrinone and steroids.

ECMO course data: age in days, cannulation mode (percutaneous/surgical), duration of ECMO in hours, cannula site repair, the year ECMO was performed, pre-ECMO duration of ventilation, ventilation type at ECMO beginning and after 24 hours on ECMO.

Ventilation settings: fractional inspired oxygen (FiO2), respiratory rate, peak inspiratory pressure (PIP), positive end expiratory pressure (PEEP), mean airway pressure (MAP).

Complications

Mechanical: clots in the oxygenator, bladder, bridge, haemofilter, cannula problems, air in the circuit, oxygenator failure, raceway/tubing rupture and pump/heat exchanger malfunction.

Neurologic: seizures, clinically determined/electroencephalography (EEG) determined central nervous system (CNS) infarction/hemorrhage by ultra sound (US) /computed tomography (CT) and brain death clinically determined.

Hemorrhagic: cannulation/surgical site bleeding, gastrointestinal hemorrhage, hemolysis, hemoglobin >50mg/dL, disseminated intravascular coagulation (DIC).

Renal: creatinine 1.5-3.0 mg/dL > 3.0 mg/dL, dialysis/hemofiltration/continuous arterio-venous hemodialysis required.

Cardiovascular: inotropes on extracorporeal life support (ECLS), cardiopulmonary resuscitation (CPR) required, cardiac arrhythmia, myocardial stun by echo, hypertension requiring vasodilators, tamponade (blood/serous/air), Persistent ductus arteriosus (PDA) (L→R, R→L, bidirectional, unknown).

Pulmonary: pneumothorax requiring treatment, pulmonary hemorrhage.

Infectious: culture-proven infection, white blood count (WBC) < 1.500

Metabolic: glucose <40g/dL>240g/dL, ph < 7.20/> 7.60, hyperbilirubinemia (direct > 2mg/dL, indirect > 15mg/dl).

Outcome: discharge from ECLS center (either to home, or to another center), reasons for discontinuation (recovery or reasons for death).

Statistical analysis

Data were received in Excel (Microsoft Inc., Redmond, WA, US) format from the ELSO registry and then transferred for statistical analysis to an SPSS file (SPSS® version 15.0, Chicago IL, US). Data is presented as the median and interquartile range (IQR) (25th and 75th percentile) or as a percentage. For categorical data, Chi-square tests were used, and for continuous data, Mann-Whitney U tests are used. Statistical significance was accepted at $p < 0.05$

Results

Demographic data

Demographic data is shown in table 1. There was no significant difference noted between genders. Infants in the VVDL group had a lower gestational age (30 vs. 39 weeks, p=0.01) but the age at the start of ECMO did not differ significantly. However, the birth weights (1.8 vs. 3.7kg BW, p=0.014) and current weights (3.9 vs. 4.5, p=0.049) observed in the VVDL group were significantly lower.

The primary diagnoses were defined by ICD 9 codes (International Classification of Disease, 9th Revision) and classified into disease groups as listed in table 2.

The most common primary diagnosis was viral pneumonia: 44% in the VVDL group and 21% in the VV two-site group (e.g. respiratory syncytial virus, adenovirus and parainfluenza virus).

Pre-ECMO data

Groups showed no difference in total amount of pre-ECMO support (96 vs. 91%). Analyses of the pre-ECMO support stage in specific categories, however, showed a significant difference when vasopressors / inotropic drugs were administered (64 vs. 82 %, p=0.03).

ECMO course data

There were no differences between groups in relation to the mode of cannulation (percutaneous or surgical cannulation 170/66 vs. 23/11) used or the in relation to the duration of ventilation observed before ECMO was started (102.5(44.5/191.7) vs. 59(22.2/172) hours). The duration of ECMO was significantly shorter in the VV two-site group (137(90/208) vs. 203(128/336) hours, p=0.01).

There was no significant difference noted between groups with regards to the ventilation mode used pre-ECMO. Twenty-four hours after the onset of ECMO, PIP and MAP were significantly higher in the VV two-site group (22(20/27) vs. 26(20/31), p=0.0174 and 12(10/14) vs. 14(10/18), p=0.049) than in the VVDL group, respectively.

Complications

ECMO-treatment without complications was found in 14% of the VVDL group and in 21% of the VV two-site group. Eighty-six percent of the VVDL group and 79% of the VV two-site group experienced at least one complication during ECMO, with a median of 2 complications per patient in both cohorts. The most frequent complications are classified and listed in table 3. The most frequent mechanical complication was defined as 'cannula problems' (20% of all children). This occurred more frequently in the VVDL group than in the VV two-site group (21% vs. 12%).

Outcome

ECMO survival rates were 82% in the VVDL group and 68% in the VV two-site group. Overall, 217 infants from 270 study patients (80%) survived ECMO of which 71% in the VVDL group and 56% in the VV two-site group were discharged alive from the ICU. This difference was not statistically significant.

Table 1. Demographic data.

	VVDL	VV	p Value
Gender (M / F; %)	57.2/ 41.5	41.2/ 58.8	n.s
Gestational Age (weeks)	30 (27/38)	39 (38/40)	0.01
Birth weight (kg body weight)	1.8 (0.9/2.9)	3.7 (2.9/3.9)	0.014
Age at ECMO start (days)	109 (64/156)	127 (65/176)	0.474
Weight at ECMO start (kg body weight)	3.9 (3/5)	4.5 (3.8/5.7)	0.049

Data are presented as the median and IQR (25th and 75th percentile) for parametric variables or as a percentage (%) for categorical variables. Statistical significance was accepted at $p < 0.05$.

ECMO, extracorporeal membrane oxygenation; IQR, interquartile range; M/F, male/female; n.s, not significant; VV veno-venous two site ECMO group; VVDL, veno-venous double lumen ECMO group.

Table 2. Primary diagnoses.

	VVDL	VV
Viral pneumonia	44	21
Bacterial pneumonia	3	6
Infection (e.g. acute bronchiolitis, pertussis)	13	18
Respiratory disease (e.g. tracheal stenosis, primary pulmonary hypertension)	14	21
Respiratory insufficiency, non-traumatic	9	6
ARDS	5	9
Congenital heart disease	4	6
Other	8	15

Data are presented as a percentage (%) for categorical variables. Statistical significance was accepted at $p < 0.05$.

ARDS, acute respiratory distress syndrome; VV, veno-venous two site ECMO group; VVDL, veno-venous double lumen ECMO group.

Discussion

In this chart review study of infants with respiratory failure, no difference in the total complication and overall survival rate was observed between the VV two-site and the VVDL ECMO group. Among a number of potential complications associated with ECMO, intracranial hemorrhage or infarction, during bypass, is perhaps the most devastating. This analysis showed a neurological complication rate of approximately 0.5-6% in both groups, with a marginally lower rate in the VV two-site group. The etiology of these neurological injuries is multifactorial: abrupt changes in local and systemic blood pressure, ischemia/reperfusion, anticoagulation and venous hypertension caused by distal internal vein ligation are reported to play a contributory role. (4)

The duration of pre-ECMO mechanical

ventilation did not differ significantly between groups. Swaniker et al. (5) reported that the only pre-ECMO variable that correlated with survival was pH and they were surprised that the pre-ECMO period of mechanical ventilation was not predictive of outcome, as shown previously for adults. (12,13) With regard to ECMO, they also observed that survival was strongly associated with the presence of renal failure and the need of inotropes.

In both study groups, some of the venous cannulae were placed percutaneously (VVDL 72%, VV two-site 67%). This simplifies access and avoids ligation of the veins. The VVDL cannulation technique is more feasible in neonates and small infants, where cannulation of the femoral vein is difficult, usually because of the risk of vascular compromise to the leg. Furthermore, it is quite difficult to place a venous cannula in a femoral vein, which is large enough to achieve adequate drainage or allow adequate return, in an infant with less than 7 kg body weight. Therefore, in children who cannot yet walk, VVDL bypass is often used as the preferred ECMO mode of VV-ECMO, otherwise VA-ECMO must be used. (14) The VVDL cannula can also eliminate other risks of VA ECMO, such as increased pulmonary vascular resistance, (15) compromised regional blood flow to vital organs, (16) decreased coronary artery oxygen transport, (17,18) impaired cardiac performance (19,20) and altered cerebral perfusion or autoregulation. (21,22) Nevertheless, the size of the double lumen cannula required for older children is considerable and therefore a different mode of VV ECMO may be more suitable. The use of cannulae with smaller diameters, as used in VV two-site ECMO, may be beneficial for the blood vessels in such cases. (23) Since, in this study, infants in the VVDL group had significantly lower birth weight and body weight when ECMO was initiated, this may explain why most ECMO centers preferred this technique of cannulation for their patients. This might also explain, the unbalanced number of patients between study groups (VVDL n=236 vs. VV two-site n=34).

To identify possible differences in the clinical status between groups and explain our findings, we looked at the primary diagnoses and total pre-ECMO support provided to each patient before starting ECMO. We found that primary diagnoses (table 2), ventilation time before ECMO and total pre-ECMO support (96% in VVDL versus 91% in the VV two-site) did not differ between groups. All these findings suggest that groups did not differ in their clinical status when ECMO support was initiated. Although analysis of all the single, specific criteria of pre-ECMO support showed a significantly higher need of inotropic support and also significantly higher MAP and PIP values after 24 hours of ECMO in the VV two-site group (table 3), it cannot be concluded that these infants were more unwell or sicker than those in the VVDL group. This is supported by the results of Roberts et al. (3) who showed that the level of inotropic support provided to ECMO patients during an ECMO run did not provide a good tool for distinguishing between survivors and non-survivors. Diagnosis was much more relevant for this purpose.

Duration of ECMO was significantly shorter in the VV two-site group, but it is not possible to judge whether VV two-site cannulation improves outcomes compared with VVDL techniques, since this finding may also be influenced by the lower survival in the VV two-site group (56% vs. 71%, p=0.071), leading to earlier discontinuation of ECMO at death. Pettignano et al. (2) reported a median ECMO duration of 218 hours in 68 VV patients, with a survival rate at discharge of 77%. In this analysis, ECMO duration in both groups was shorter and the overall survival at discharge was 69%.

Although many authors recommend VV cannulation for acute respiratory failure, VA cannulation remains more common. (24,25) Zahraa et al. compared VA versus VV modes in pediatric patients with respiratory failure. The VV mode yielded survival rates (60%) equal to VA ECMO (56%) in children. (26) A recently published study by Zabrocki et al. (27) demonstrated that among pediatric patients cannulated for respiratory failure, hospital survival rate was 70% for children supported by a VVDL-ECMO, 66%for those supported by VV two-site ECMO , and a significantly lower 51% in children supported by VA ECMO.

The benefits of VV ECMO are manifold: avoidance of carotid artery ligation, preservation of coronary arteries and lung perfusion with oxygenated blood, and maintenance of normal cerebral blood flow velocities. (18, 23) The risk of complications is lower in VV ECMO. In particular, the consequences of circuit emboli are worse when VA ECMO is used.

No prospective randomized studies have so far compared the benefit of ECMO in pediatric respiratory failure to conventional strategies. In a retrospective multi-centre study reported by Green et al. outcomes with ECMO were 47% compared to 26% survival in the control group treated with conventional therapy. (28) ECMO will remain as a rescue therapy in most centers for patients in whom the likelihood of survival with the continuation of conventional therapy appears inaccessible. In that respect, the overall survival of patients in this study (69%, in both groups) appears encouraging.

Brogan et al. recently completed a multi-center case review study in adults with severe respiratory failure treated with ECMO. (29) Most of their alluded primary design limitations are also suitable for this study in infants. They arise from its retrospective and uncontrolled nature, including the absence of standardized criteria for using ECMO. Important variables such as patient selection or indication for ECMO are neither included in the ELSO database nor standardized in the ELSO database forms, since these are rather center specific decisions. Data coding and data entry into the data capture forms are performed by each center and many fields remain empty at the time of data submission to the ELSO registry. Further, diagnoses are recorded using the ICD-9 coding system, which has well-described shortcomings. (30) These disadvantages are confounded

Table 3. Complications during ECMO.

	VVDL	VV	% of all patients
Mechanical			
Cannula problems	21	12	20
Clots: other	14	24	15
Clots: oxygenator	12	12	12
Clots: bladder	13	6	12
Clots: bridge	9	9	9
Oxygenator failure	5	3	5
Air in the circuit	3	9	3
Hemorrhagic			
Cannulation site bleeding	17	15	17
Surgical site bleeding	3	9	4
Hemolysis*	4	15	5
Disseminated intravascular coagulation (DIC)	5	0	4
Neurologic			
Brain death clinically determined	1	0	0.4
Seizures: clinically determined	5	6	5
CNS infarction by US / CT	1.7	2.9	1.9
CNS hemorrhage by US / CT	3.8	0	3.3
Renal			
Hemofiltration required	24	12	23
CAVHD required	4	3	4
Cardiovascular			
Inotropes on ECLS	44	47	44
Hypertension requiring vasodilators	18	15	18
CPR required	6	0	5
Cardiac arrhythmia	4	3	4
Pulmonary			
Pneumothorax requiring treatment	9	6	9
Pulmonary hemorrhage	7	3	6
Infectious			
Culture proven infection	19	18	19
Metabolic			
Hyperbilirubinemia (> 2 direct or > 15 total)	6	3	6
pH < 7.20	5	9	5
pH > 7.60	4	9	4

* p=0.007

Data are presented as a percentage (%) for categorical variables. Statistical significance was accepted at $p < 0.05$.
CAVHD, continuous arteriovenous hemodialysis; CNS, central nervous system; CPR, c-reactive protein; CT, computed tomography; ECLS, extra corporeal life support; US, ultra sound; VV, veno-venous two site ECMO group; VVDL, veno venous double lumen ECMO group.

by the fact that the ELSO registry does not release information on ECMO centers, and therefore no conclusions can be made about the influence of center trends.

It is therefore advised that prospective clinical trials should be performed in infants to determine validated criteria for pediatric patient selection for VV ECMO. Investigations regarding different ECMO modes should be continued in infants and may further improve pediatric survival after ECMO in infants with severe respiratory failure.

Conclusions

The total complication rate was found to be similar in both groups. No difference was found in survival rates between the two groups. Neither of the two-cannulation methods – veno-venous two-site or veno-venous double lumen ECMO

– showed any significant superiority. The decision about which technique to use for infants depends mainly on best practice experiences of each individual ECMO centre and their routinely used technical equipment.

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