Original Article

Impact of Extracorporeal Membrane Oxygenation Support on Clinical Outcome of Pediatric Patients with Acute Cardiopulmonary Failure: A Single-Center Experience

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Background: Conventional therapy against acute pediatric cardiopulmonary failure (APCPF) caused by a variety of disease entities remains unsatisfactory with extremely high morbidity and mortality. For refractory APCPF, extracorporeal membrane oxygenation (ECMO) is one of the last resorts.

Methods: In this study, the in-hospital outcomes of pediatric patients with refractory APCPF receiving ECMO support were reviewed.

Results: Between August 2006 and May 2011, a single-center cohort study was performed in pediatric patients who required ECMO support due to cardiogenic shock or severe hypoxemia. A total of 22 patients with mean age of 7.0 ± 6.3 years received ECMO (male = 11; female = 11). The indications included acute fulminant myocarditis (AFM) ($n = 6$), congenital diaphragmatic hernia (CDH) ($n = 3$), acute respiratory distress syndrome (ARDS) ($n = 6$), enterovirus 71 ($n = 3$), viral sepsis ($n = 2$), refractory ventricular fibrillation due to long QT syndrome ($n = 1$), and pulmonary edema with brain herniation ($n = 1$). Eighteen patients received veno-arterial (VA) mode ECMO, while another four patients undertook the veno-venous (VV) mode. The duration of ECMO use and hospitalization were 6.1 ± 3.1 and 24.4 ± 19.4 days, respectively. The survival rate in patients with AFM was 100% ($n = 6$). Successful ECMO weaning with uneventful discharge from hospital was noted in 14 (63.6%) patients, whereas in-hospital mortality despite successful ECMO weaning occurred in 5 patients (22.7%). Failure in ECMO weaning and in-hospital death was noted in 3 patients (13.6%).

Conclusions: ECMO resuscitation is an effective strategy in the clinical setting of APCPF.
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At a Glance Commentary

Scientific background of the subject

Refractory APCPF, a variety of disease entities, causes extremely high morbidity and mortality. The ECMO support is a effective treatment modality for improving prognostic outcome in this clinical setting.

What this study adds to the field

The results of the present study encourage the use of ECMO in patients with clinical setting of cardiopulmonary failure that is refractory to the conventional therapy.

Key words: acute cardiopulmonary failure, clinical outcome, extracorporeal membrane oxygenation, pediatrics

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Despite advanced pharmacological regimens and the state-of-the-art equipment available, acute pediatric cardiopulmonary failure (APCPF) resulting from various diseases such as acute fulminant myocarditis (AFM), congenital diaphragmatic hernia (CDH), or acute respiratory distress syndrome (ARDS) remains an important cause of morbidity and mortality in the pediatric intensive care units.[1-7] Therefore, a safe and effective therapeutic strategy for patients with APCPF, especially when conservative medical treatment is inadequate, is of utmost importance for pediatricians.

Extracorporeal membrane oxygenation (ECMO) has been utilized for several decades as a rescue therapy for pediatric CDH, acute myocardial failure, or ARDS refractory to conventional medical therapy.[8-13] However, the reported promising outcomes highly rely on appropriate patient selection and appropriate disease setting.[8-14] On the other hand, the clinical outcome of routine use of ECMO support for patients with unselected causes of APCPFs at a single center has been not reported. Since such information is essential in guiding the use of ECMO for APCPF, this study reported the routine application of ECMO support at a single pediatric center in focusing on various disease entities causing APCPF.

Table 1: Baseline characteristics of the study patients

Variable	Whole cohort (*n*=22)	Survival (*n*=14)	Mortality (*n*=8)	*p**value
Age (mean±SD) (years)	7.0±6.3	8.0±6.2	5.2±6.4	0.481
Age < 1.0 years	18.2% (4)	21.4% (3)	12.5% (1)	1.0
Male gender	50.0% (11)	50.0% (7)	50.0% (4)	1.0
Body weight (kg)	25.8±18.3	29.3±20.1	19.6±13.7	0.367
Body weight < 15 kg	40.9% (9)	35.7% (5)	50.0% (4)	0.662
Height (cm)	111.5±39.6	119.1±43.5	98.1±29.6	0.272
VT/Vf	36.4% (8)	57.1% (8)	0% (0)	0.018
Complete AVB	18.2% (4)	28.5% (4)	0% (0)	0.254
Cardiac arrest (asystole)	13.6% (3)	14.3% (2)	12.5% (1)	1.0
Pre-ECMO SBP (mmHg)	55.1±42.1	54.3±42.1	56.6±44.8	0.809
Pre-ECMO DBP (mmHg)	33.1±25.4	32.9±26.8	33.6±24.4	0.919
Brain hemorrhage	13.6% (3)	7.1% (1)	25.0% (2)	0.527
APCPF etiologies				
AFM	31.8% (6)	42.8% (6)	0% (0)	0.022
CDH	13.6% (3)	14.3% (2)	12.5% (1)	1.0
ARDS	27.3% (6)	21.4% (3)	37.5% (3)	0.624
Enterovirus 71	13.6% (3)	7.1% (1)	25.0% (2)	0.527
Long QT with Vf	4.6% (1)	7.1% (1)	0% (0)	1.0
Viral sepsis	9.1% (2)	7.1% (1)	12.5% (1)	1.0
Brain herniation	4.6% (1)	0% (0)	12.5% (1)	1.0
Pre-ECMO LEVF	45.7±14.7	45.3±19.6	45.5±16.3	0.946

Data are expressed as mean±SD or % (no.).
Abbreviations: AVB: Atrio-ventricular block; AFM: Acute fulminant myocarditis; ARDS: Acute respiratory distress syndrome; APCPF: Acute pediatric cardiopulmonary failure; CHD: Congenital hernia diaphragm; ECMO: Extracorporeal membrane oxygenation; DBP: Diastolic blood pressure; LVEF: Left ventricular ejection fraction; SBP: Systolic blood pressure; VT/Vf: Ventricular tachycardia/ventricular fibrillation; *: Continuous data were analyzed by Wilcoxon rank sum test and categorical data by Fisher's exact test

METHODS

This was an observational study. The Institutional Review Committee on Human Research at our institution approved the whole study protocol [institutional review board (IRB) number: 100-0407B]. At our hospital, all pediatric patients with APCPF are considered eligible for ECMO support since August 2006. We reviewed our database on all consecutive pediatric patients with a diagnosis of APCPF having received ECMO at Kaohsiung Chang Gung Memorial Hospital Children's Medical Center between August 2006 and May 2011. Totally 22 pediatric patients were prospectively included. The etiologies of APCPF are listed in Table 1. Informed consent was obtained from each study subject.

Indication for ECMO support and the assess route for ECMO implantation

In Kaohsiung Chang Gung Memorial Hospital, the indications for ECMO implantation included: (1) cardiogenic shock of all etiologies for which stable hemodynamics could not be maintained by conventional therapy and maximal dosage of inotropic agent and (2) severe respiratory failure for which arterial oxygen saturation could not be maintained by mechanical ventilatory support (i.e., PaO_2 < 60 mmHg) and conventional medication with or without hypotension/shock.

For patients with body weight (BW) less than 25 kg, the cervical approach (carotid artery and jugular vein) was utilized for ECMO implantation, whereas femoral approach was adopted for those with BW over 25 kg.

ECMO installation and echocardiographic study

Either veno-venous (VV) or veno-arterial (VA) mode of ECMO was used in the current study. ECMO was inserted either in the operating room or in the pediatric intensive care unit. Initially, 100 units/kg of heparin was given to each patient just before ECMO implementation, followed by a continuous maintenance dose to keep the ACT around 160-220 s.

For ECMO operation in patients with shock, inotropic support was kept to a minimum to maintain mean arterial blood pressures of 40 mmHg for newborn, 50 mmHg for child, and 60 mmHg for adolescent. Flow rates were adjusted according to the hemodynamic status to maintain an SVO2 >60% and urine output >1 mL/kg/h. Normothermia was maintained in all patients.

Prior to ECMO support, echocardiography was used to evaluate ventricular function, i.e., left ventricular ejection

fraction (LVEF), which was regularly followed for each patient after implementation of ECMO to evaluate the recovery of cardiac function. The coma scale was routinely used for estimating the conscious level in all of our patients.

Management of ECMO

A centrifugal pump and a heparin-bound hollow-fiber microporous membrane oxygenator (50% of patients with Terumo, Asitaka, Japan; another 50% of patients with Medtronic Co., Minneapollis, USA) were utilized. The entire ECMO system and all instruments for vascular assess were available and put on a mobile cart to facilitate transportation to the operating room or pediatric intensive care unit.

For femoral VA mode, the tip of the arterial cannula was estimated to reside at the aorto-iliac junction, whereas the tip of the venous cannula was set at the junction of the inferior vena cava and the right atrium junction. The positions of the cannulas were confirmed radiologically. A catheter was placed for antegrade reperfusion if distal limb perfusion was inadequate.

The carotid artery approach was utilized if patient's BW was <25 kg. Additionally, the cannula size to be selected for the carotid artery was (1) 15.5 French (Fr) for BW ≥20 and < 25 kg, (2) 12.0 Fr for BW ≥ 10 and < 20 kg, and (3) 10.0 Fr for BW < 10 kg.

For neck VA mode, the tip of the arterial cannula was advanced to the junction of innominate artery and ascending aorta, whereas the tip of the venous cannula was set at the middle chamber of right atrium. For neck VV mode, the tip of the double-lumen cannula was set at the junction between right atrium and inferior vena cava. The positions of the cannulas were radiologically and echocardiographically confirmed.

The circuit, including pump head and oxygenator, was replaced under certain conditions, including: (1) a marked plasma leak, (2) hemoglobinuria, and/or (3) blood clot formation in the circuit system.

ECMO weaning protocol

The possibility of weaning from ECMO was evaluated in all patients after 72 h of support. Inotropic agent was tapered carefully in patients with shock after stabilization of general and hemodynamic status together with evidence of improvement in left ventricular contractility (>40% of LVEF). Oxygen saturation was continuously monitored until the mixed venous oxygen saturation was ≥70%. In the absence of deterioration in hemodynamic status, pump flow was reduced gradually to 500 mL/min. Finally, ECMO was withdrawn for persistent stability of the patient's hemodynamic status.

For patients with acute respiratory failure without shock, weaning from ECMO was considered if arterial O_2 saturation was >90%. First, the ECMO oxygenator's fraction of oxygenation (%) (FiO_2) was slowly reduced to 21% (i.e., the room air O_2 fraction). If the monitor still showed an arterial O_2 saturation >90%, then the pump blood flow was decreased gradually to 500 mL/min. Finally, ECMO was withdrawn when patient's hemodynamic status and arterial O_2 saturation were found to be stable.

Successful weaning was defined as a survival for more than 72 h after successful cessation of ECMO support. Survival was defined as weaning from ECMO, followed by continued survival till hospital discharge.

Laboratory findings and data collection

For the purpose of this study, all patients undergoing ECMO support were prospectively recruited. Detailed in-hospital data including age, gender, diagnostic criteria, medical treatment prior to ECMO deployment, ECMO-related variables, clinical and hemodynamic condition on admission, laboratory and echocardiographic findings, results of imaging studies, in-hospital adverse events, and in-hospital mortality were obtained. These data were collected prospectively and entered into a digital database.

Statistical analysis

Data were expressed as mean ± SD. Continuous data were analyzed by Wilcoxon rank sum test, while categorical data were analyzed using Fisher's exact test. Statistical analysis was performed using SAS statistical software for Windows version 8.2 (SAS institute, Cary, NC, USA). A p value of < 0.05 was considered statistically significant.

RESULTS

The baseline characteristics of study patients

Table 1 shows the baseline characteristics and etiologies of APCPF in the 22 study patients. The mean age was 7 years without significant difference between survival group and mortality group. The prevalence of male gender, cardiac arrest, and complete atrio-ventricular block, as well as anthropometric and hemodynamic data including body weight, height, pre-ECMO systolic and diastolic blood pressure were also similar between the two groups. However, the incidence of ventricular tachycardia/ventricular fibrillation was significantly higher in the survival group than that in the mortality group. Three patients experienced intracranial hemorrhage during hospitalization. One was caused by H1N1 infection and another suffered from ARDS associated with hypertension, while the etiology of the third patient was undetermined. Nevertheless, the incidence of this complication did not differ between both groups.

Of all etiologies of APCPF in the study patients [Table 1],

Table 2: Clinical unstable conditions with requirement of different mechanical supports and laboratory findings

Variables	Whole cohort (*n*=22)	Survival (*n*=14)	Mortality (*n*=8)	*p* value
Pre-ECMO with ventilator support	90.0% (20)	85.7% (12)	100% (8)	0.515
Temporary pacemaker implantation	9.1% (2)	14.3% (2)	0% (0)	0.515
Intra-aortic balloon pump support	18.2% (4)	28.5% (4)	0% (0)	0.254
Requirement of distal limb perfusion	18.2% (4)	28.5% (4)	0% (0)	0.254
ARF with emergency hemodialysis	27.3% (6)	21.4% (3)	37.5% (3)	0.624
Nitric oxide (NO) utilization	18.2% (4)	21.4% (3)	12.5% (1)	1.0
HFV utilization	13.6% (3)	7.1% (1)	25.0% (2)	0.527
Pre-ECMO laboratory findings				
White blood cell count (10^3/dL)	18.8±21.3	12.0±5.7	30.7±32.3	0.116
Hemoglobin (mg/dL)	13.1±3.5	13. 0±3.0	13.1±4.2	0.946
Hematocrit (%)	39.8±10.8	39.2±10.0	40.6±12.9	0.638
Sugar (g/dL)	188±87	183.4±80.8	196.9±102.2	0.686
pH value	7.26±0.15	7.31±0.12	7.17±0.15	0.038
CO_2	46.0±30.7	37.1±10.3	61.6±46.8	0.109
BE	7.3±7.5	6.7±5.1	8.4±10.8	0.524
HCO_3	19.9±8.1	19.1±4.5	21.2±12.5	0.814
Lactate level	55.8±33.3	58.9±30.0	50.5±40.6	0.428
SpO_2 (% Sat O_2)	81.1±16.3	85.5±17.8	73.5±10.1	0.043
GOT	762±2378	1136±2952	108±92	0.139
GPT	352±1274	567±1648	36±31	0.316
CPK level (IU/dL)	3314±6291	3590±6894	1933±1737	0.916
Troponin-I level ()	20.8±29.6	27.6±32.1	1.9±1.5	0.156
BUN (mg/dL)	17.4±12.3	16.4±10.5	19.3±15.6	0.919
Creatinine (mg/dL)	1.05±0.76	1.11±0.87	0.93±0.53	1.0
Calcium level (mg/dL)	8.16±1.06	8.21±1.07	8.08±1.01	1.0
C-reactive protein	27.3±55.9	46.5±62.2	19.2±41.6	0.232
On-ECMO laboratory findings				
Peak level of CPK	7994±16900	9076±20316	5562±5511	0.501
Peak level of GOT	2430±4838	3174±5672	537±436	0.662
Peak level of GPT	791±1630	1020±1916	204±227	1.0
Peak level of troponin-I	32.5±35.8	35.4±35.1	26.9±40.8	0.550
Peak level of creatinine	1.85±1.47	1.45±1.30	2.38±1.65	0.090

Data are expressed as mean±SD or % (no.).
Abbreviations: CK: Creatine phosphokinase; GOT: Glutamate oxaloacetate transaminase; GPT: Glutamic pyruvic transaminase; BUN: Blood urea nitrogen; HFV: High-frequency ventilation mode

AFM and ARDS were the most common. On the other hand, diabetic ketone acidosis complicated by pulmonary edema and brain herniation, and long QT syndrome with ventricular fibrillation and cardiogenic shock refractory to conventional medical treatment had the lowest incidence. Two patients with brain herniation due to intracranial hemorrhage had clear consciousness prior to ECMO implantation. The prevalence of disease entities causing APCPF did not differ between patients who survived and those who did not. Besides, the mean LVEF of the study patients prior to ECMO support was relatively low (45.7%) compared to that of normal controls (≥60.0%), but it showed no difference between both groups of the patients. However, the LVEF was significantly lower in myocardial failure group than in respiratory failure group (33.2 ± 8.4 vs. 57.2 ± 16.3, $p < 0.001$).

Utilization of mechanical assisting devices and laboratory findings

Table 2 shows the incidence of utilizing different assisting mechanical devices in the 22 patients and their important laboratory findings. Up to 90% of the patients experienced acute respiratory failure with requirement of mechanical ventilatory support prior to ECMO implementation. This finding implicated that the majority of our patients were in an extremely unstable condition.

In our series, the indications for intra-aortic balloon pump IABP support included pulseless electrical activity, asystole, or failure of aortic valve opening confirmed by transthoraxic echocardiography after implementation of ECMO. Four patients with AFM fit these criteria and received the IABP support. The incidence of IABP support did not differ between the survival group and the mortality group.

Table 3: Extracorporeal membrane oxygenation procedure, results, and outcomes

Variables	Whole cohort (*n*=22)	Survival (*n*=14)	Mortality (*n*=8)	*p* value
Successful rate of ECMO implantation	100% (22)	100% (14)	100% (8)	1.0
Type of ECMO use				0.602
VV mode	18.2% (4)	14.3% (2)	25.0% (2)	
VA mode	81.8% (18)	85.7% (12)	75.0% (6)	
Access route				
Femoral (V and A)	36.4% (8)	50.0% (7)	12.5% (1)	0.124
Neck (carotid artery and right IJV)	45.5% (10)	42.9% (6)	50.0% (4)	1.0
Open chest (right atrium and aorta)	9.1% (2)	0% (0)	25.0% (2)	0.121
Combined (right IJV and FA)	9.1% (2)	7.1% (1)	12.5% (1)	1.0
Carotid artery ligation	27.3% (6)	28.6% (4)	25.0% (2)	1.0
Right IJV ligation	31.8% (7)	28.6% (4)	37.5% (3)	1.0
Duration of ECMO use (days)	6.1±3.1	5.9±2.6	6.4±4.1	1.0
Inotropic use (dopamine/dobutamine)	95.5% (21)	100% (13)	100% (8)	1.0
ECMO successful weaning	86.4% (19)	100% (14)	62.5% (5)	0.036
ECMO failed weaning and in-hospital death	13.6% (3)	0% (0)	37.5% (3)	0.036
In-hospital mortality	36.4% (8)	-	100% (8)	
Heart transplantation	0% (0)	-	-	-
Duration of hospitalization (days)	24.4±19.4	23.4±14.8	26.1±26.8	0.813

Data are expressed as mean±SD or % (no.).
Abbreviations: ECMO: Extracorporeal membrane oxygenation; IJV: Internal jugular vein; VA: Veno-arterial; VV: Veno-venous

More than 27% of our patients required temporary hemodialysis due to acute renal failure. The incidence of hemodialysis did not differ between survival group and mortality group. Moreover, the incidences of utilizing nitric oxide and high frequency ventilation (HFV) mode as well as the requirement for distal limb perfusion were similar between the two groups. Furthermore, the incidence of temporary pacemaker implantation due to complete heart block was similar between the survival group and the mortality group.

Parameters for laboratory studies prior to ECMO support included white blood cell count, blood sugar, arterial blood gas (i.e. pH value, BE, CO_2, HCO_3, lactic acid, and % O_2 saturation), liver enzymes, and creatine phosphokinase. Except for pH value and % of arterial O_2 saturation which were found to be significantly lower in the mortality group than in survival group, all of the other parameters [Table 2] did not differ between the two groups.

Extremely elevated serum levels of creatine phosphokinase, glutamate oxaloacetate transaminase (GOT) and glutamic pyruvic transaminase (GPT) were observed in the period of ECMO support. In addition, creatinine level was also notably increased during ECMO. Nevertheless, the fluctuations in these biochemical parameters did not differ between the two groups. However, the peak level of creatinine was significantly higher than initial creatinine level (i.e., prior to ECMO implantation) ($p < 0.001$).

ECMO procedure, results, and outcomes [Table 3]

The successful rate of ECMO implantation was 100%. The VA mode was most frequently used in the current study. Moreover, the incidences of utilizing VA mode and VV mode did not differ between the survival group and the mortality group. Femoral (VA) and neck (carotid artery and internal jugular vein) approaches were the two most common access routes in our series. Post ECMO ligation of carotid artery was performed in 27.3% patients who exhibited no neurological complication during clinical follow-up. The duration of ECMO use and hospitalization were similar between both groups of the patients.

The rate of successful weaning from ECMO was significantly higher in the survival group compared to that in the mortality group, whereas mortality associated with failure in weaning was significantly lower in the former.

Univariate and multiple stepwise logistic regression analyses of predictors for in-hospital mortality [Table 4]

To determine the predictors for in-hospital mortality, univariate analysis followed by multiple stepwise logistic regression analysis was performed in the current study. The results identified AFM as the only independent predictor of freedom from in-hospital mortality.

DISCUSSION

The clinical implications of this study, which reported a single-center experience of the routine used of ECMO support for APCPF, are multiple. First, despite divergent etiologies of APCPF in our series, AFM and ARDS pre-

Table 4: Univariate analysis of predictors of in-hospital mortality

Variables	OR	95% CI	*p* value
Age (years)	0.99	0.98-1.01	0.318
Male gender	1.0	0.18-5.68	1.0
Body weight (kg)	0.97	0.92-1.02	0.234
Height (cm)	0.99	0.96-1.01	0.232
Pre-ECMO SBP (mmHg)	1.00	0.98-1.02	0.898
Pre-ECMO DBP (mmHg)	1.00	0.97-1.04	0.944
Pre-ECMO ventilator support	2.67	0.11-67.10	0.551
AFM	0.017	0.002-0.119	<0.001
CDH	0.86	0.07-11.26	0.907
ARD	2.20	0.32-14.98	0.420
Enterovirus 71	4.33	0.33-57.65	0.267
Long QT with Vf and shock	0.81	0.02-27.03	0.908
Viral sepsis	1.86	0.10-34.44	0.678
Brain herniation	1.23	0.04-50.0	0.879
Pre-ECMO left ventricular ejection fraction	1.00	0.95-1.05	0.984
ARF with emergency hemodialysis	2.20	0.32-14.98	0.420
White blood cell count (10^3/dL)	1.00	1.00-1.00	0.087
pH value	1000	1.15-1000	0.046
Sat O_2	0.95	0.89-1.01	0.108
Lactate	0.94	0.84-1.06	0.118
BE	0.97	0.86-1.09	0.613
Peak level of GOT	1.00	1.00-1.00	0.384
Peak level of GPT	0.999	0.997-1.001	0.382
Peak level of creatinine	1.58	0.83-3.00	0.165
Multiple stepwise logistic analysis of independent predictors for in-hospital mortality			
Variables	OR	95% CI	*p* value
AFM	0.028	0.004-0.197	<0.001

Abbreviations: ARF: Acute renal failure; OR: Odds ratio; CI: Confidence interval

dominated. Second, the results of our series demonstrated that the in-hospital prognostic outcome was best for AFM patients. Third, survival rate of the whole cohort was 63.6%, which is comparable to that from recent reports.[8,12,13,15] The routine application of EMCO for APCPF at our Children's Center, therefore, achieved a patient outcome comparable to that from other major centers in the world.[8,12,13,15]

Although ECMO support in individual disease setting has been well investigated in previous studies,[8-14] the clinical outcome of ECMO support for a variety of life-threatening situations has not been reported. To the best of our knowledge, this is the first report on the safety, efficacy, and outcome of ECMO support for APCPF of different etiologies based on single-center experience. Of particular importance is that our study not only demonstrated the feasibility of routine ECMO support for patients with APCPF, but also showed a favorable patient survival.

The management of patients with AFM, especially those requiring mechanical circulatory support, remains a formidable challenge for pediatricians. Despite initial successful resuscitation, some survivors eventually required heart transplantation due to refractory pump failure.[11] Previous studies have reported promising outcomes from neonatal ECMO service for AFM with an overall survival and discharge rate reaching 62.5-71%.[11,16-19] In our series, AFM was the prevalent etiology of APCPF. The results of our study demonstrated a 100% success rate of cure and discharge for this patient population. Of particular importance is that multivariate analysis demonstrated that AFM was independently predictive of freedom from in-hospital mortality. Accordingly, our result, in addition to reinforcing those from previous studies,[11,16-19] supports the use of ECMO for pediatric patients with AFM to improve their prognostic outcome.

In this cohort study, ARDS was the second prevalent etiology of APCPF. In contrast to a 100% in-hospital survival rate in patients with AFM, only 50% of in-hospital survival rate was achieved in patients with ARDS in our study. By contrast, previous studies[12,15,20] have reported up to 70% of in-hospital survival rate in patients with ARDS. The relatively low in-hospital survival rate in our patients could probably be explained by the distinctive difference in patient population between the previous studies[12,15,20] and our series. While previous studies[12,15,20] mainly enrolled neonatal (<1 year) patients or children after open heart surgery with cardiac failure, the majority of our patients (n = 5) were children (>1 year) with etiology of ARDS not related to cardiac disease/cardiac surgery. We also propose that delayed ECMO support may be another reason for the lower in-hospital survival rate in our patients with ARDS as the consultation for ECMO support from non-cardiologists usually took more than 3 days after the diagnosis of ARDS. Hence, the results of our study reinforce the importance of timely referral for ECMO in the clinical setting of ARDS.

Technical challenge and ECMO-related neurological sequelae

In the current study, up to 45.5% of our patients required a cervical approach (carotid artery and internal jugular vein) for ECMO implantation due to small size of femoral artery. Majority of the carotid arteries in these patients, therefore, were subsequently ligated after weaning from ECMO. No carotid artery ligation-related neurological sequelae were observed in our series. Additionally, patients with body weight <15 kg (40.9% of our patients) or age <1 year (18.2% of our patients), who were not recommended for ECMO support, successfully underwent the procedure without complication. Our findings suggest that ECMO support in neonates and infants of small body size could be a safe and feasible life-saving measure.

Relevant clinical implication of current study and study limitation

Nowadays, the ECMO support, an advanced treatment modality for acute severe cardiopulmonary failure to be permitted in Taiwan, is also widely acceptable in most Asian and Western countries. Additionally, it is suitable not only for the adult but also for pediatric patients. In the present study, the divergent setting of disease entities and the different modes of ECMO to be used as well as small number of sample size, as expected, would preclude the interpretation of statistical significance. Thus, the conclusions are tentative and need to be further verified by large-scale randomized clinical trials.

Although ECMO support in pediatric patients in this clinical setting is particularly important for their survival, the clinical adjustments, including how to select the femoral, carotid cannula, and type of the pump, how to estimate and control the ECMO flow, how to give the fluid and nutrient support, and how to provide mental support for both patients and families are of particular importance for the pediatric physicians and paramedical members.

Conclusions

The results of our study demonstrated that ECMO support is a feasible first-line life-saving tool for patients with APCPF due to its simplicity and effectiveness.

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