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Pediatric Cardiology

Left Ventricle Decompression Strategies in Pediatric Peripheral Extracorporeal Membrane Oxygenation

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Background: Extracorporeal membrane oxygenation (ECMO) is widely used in patients with potentially reversible acute cardiac and/or pulmonary failure who are unresponsive to conventional treatment. Patients with profound left ventricular (LV) dysfunction under venous-arterial (V-A) ECMO may experience LV distention, pulmonary edema, and thrombus formation. It is critical to unload the left ventricle to prevent such complications. The aim of this study was to identify the risks, timing and methods of LV decompression in pediatric peripheral ECMO.

Methods: Between August 2006 and November 2017, 51 patients received peripheral ECMO support in our pediatric intensive care unit. All of them were less than 18 years of age and non-cardiotomy surgery-related. We retrospectively reviewed the patients' clinical presentations, decompression methods and outcomes.

Results: The overall success rate of ECMO removal was 76.5% (39/51), and the survival rate after discharge was 62.7% (32/51). The myocarditis group had the most favorable outcomes among the ECMO patients (100% survival). LV decompression was needed in 12 patients who had profound LV dysfunction under V-A ECMO. Five patients received medical treatment successfully, and the other 7 patients underwent intra-aortic balloon pump (IABP) procedures. In the IABP group, 1 patient still needed further pigtail-decompression. All of our decompression patients survived with good neurological outcomes (Glasgow Outcome Scale 5).

Conclusions: The patients with profound LV dysfunction under peripheral VA ECMO were at risk of thromboembolic events and LV decompress was needed. If medical decompression fails, IABP is a feasible approach for LV decompression in pediatric peripheral ECMO.

Key Words: Decompression • Extracorporeal membrane oxygenation • Intra-aortic balloon pump • Pediatric • Peripheral

INTRODUCTION

Extracorporeal membrane oxygenation (ECMO) is widely used in patients with potentially reversible acute cardiac and/or pulmonary failure who are unresponsive to conventional treatment.[1-6] ECMO can be classified into two 2 modes: veno-venous (V-V) and veno-arterial (V-A) modes. Patients with left ventricular (LV) dysfunction should undergo V-A mode ECMO for circulatory support. However, peripheral V-A mode ECMO will increase LV afterload, and this may worsen cardiac output, especially in patients with profound LV dysfunction. Increased LV afterload increases LV wall stress, closes the aortic valve, and subsequently causes LV distention,

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pulmonary edema, and thrombus formation. Thus, LV decompression is critical for accelerating recovery of the left ventricle, preventing thromboembolic events, and improving outcomes.[7-9]

Several literature reviews have discussed the methods of LV decompression, which can be done either by transcutaneous or surgical interventions. Based on the location of the decompression, left atrium (LA) venting, LV venting, or pulmonary artery (PA) venting can be performed.[8,10-14] Likewise, the use of an intra-aortic balloon pump (IABP) system combined with ECMO has been reported; however, most of these studies were limited to adult patients.[14-16] The purpose of this study was to review our LV decompression strategies in pediatric peripheral ECMO patients. To the best of our knowledge, this is the first report to discuss the effect of adding IABP in pediatric ECMO patients.

METHODS

Patients

Between August 2006 and November 2017, a total of 51 patients received peripheral ECMO support in our pediatric intensive care unit (PICU). All of the patients were less than 18 years of age and presented with sudden and acute onset of cardiac and/or pulmonary failure that was unresponsive to conventional therapy. In addition, they were all non-cardiotomy surgery-related. We retrospectively reviewed the patients' clinical presentations and data to identify the need for LV decompression. In addition, treatment strategies and results of LV decompression were analyzed. This study was approved by the Institutional Review Board of Chang Gung Memorial Hospital.

Mechanical support equipment

All ECMO pump heads were centrifugal pumps, including the CAPIOX® Disposable Centrifugal Pump (Terumo Cardiovascular Systems Corporation) in 34 patients, BPX-80 Bio Pump® Plus centrifugal blood pump (Medtronic Inc.) in 16 patients, and DELTA*STREAM*® DP3 Pump Head (MEDOS Medizintechnik AG) in 1 patient. A neck approach was used in patients weighing no more than 30 kg, and the femoral approach was used in patients weighing more than 30 kg. The IABP system used was a CS100® with IntelliSync IABP (MAQUET Cardiac Assist). The balloon size was based on the patient's height. A 25 cc Linear IAB was used for patients shorter than 152 cm, and a 34 cc Linear IAB was used for patients taller than 152 cm. Since there are currently no IABPs for pediatric patients, the patient's body weight was limited to 30 kg to prevent the possibility of femoral artery total occlusion. When dialysis was needed, we used continuous arterial-venous hemodialysis (CAVHD), which was connected adjacent to the ECMO arterial and venous catheter. We used ECMO power to drive the dialysis process. If cardiopulmonary resuscitation (CPR) had been performed before and during establishing ECMO, therapeutic hypothermia was performed to protect the brain. The target temperature was maintained at 33 °C by the ECMO heater for 72 hours, and was then gradually increased to 36 °C for 48~72 hours to prevent reperfusion injury.

Echocardiography

Transthoracic echocardiography (TTE) was performed in all patients by 2 pediatric cardiologists before ECMO had been set-up to determine the appropriate mode. The ultrasound machine used was a Philips SONOS 7500 or 5500 system. After setting up ECMO, TTE, and chest X-ray were performed to confirm the catheter tip location. TTE was then performed daily among the patients in the myocarditis group, and they were monitored continuously during cardiac arrest [pulseless electric activity (PEA), ventricular tachycardia (VT), ventricular fibrillation (VF), or asystole]. Aortic valve motion was monitored to confirm the effect of LV decompression.

Timing for LV decompression

For patients receiving V-A mode support caused by profound LV dysfunction, the timing of LV decompression was based on certain clinical warning signs (arterial line waveform, electrocardiography, and echocardiography). A continuously flat arterial line waveform indicated no cardiac output, during which ECG showed VT, VF, PEA, agonal heart rhythm, or asystole. In addition, the echocardiography demonstrated a persistently closed aortic valve, LV dilatation, and even sludge or thrombus formation (Figure 1). These clinical presentations can help to identify and determine the indications and tim-

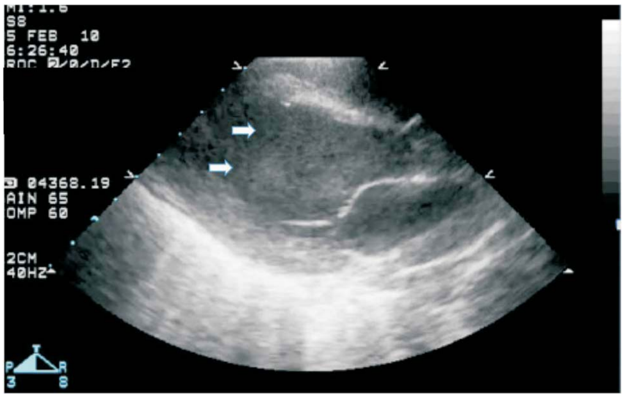

Figure 1. *Echocardiography showed the aortic valve closed persistently and the sludge formed within dilated left ventricle. The white arrows point out the sludge.*

ing of left heart decompression.

Methods of LV decompression

LV decompression can be divided into 2 methods: medical and mechanical decompression. For medical decompression, we used inotropic agents including dopamine, dobutamine, and milrinone to augment contractility; vasodilators such as nitroglycerin to decrease the afterload; and diuretics to control the preload. If decompression was needed, dopamine 10 μg/kg/min and dobutamine 10 μg/kg/min were initially administered, and then dobutamine was gradually titrated to 20 μg/kg/min to open the aortic valve. Milrinone (0.5 μg/kg/min) was added for unresponsive patients. If the aortic valve remained closed for more than 1 hour after medication had been administered, it was defined as medical failure. Thus, mechanical decompression with IABP was performed (Figure 2A). If the IABP still failed to open the aortic valve, a pigtail catheter was inserted retrograde into the left ventricle and connected to the ECMO venous catheter end-by-side for LV decompression (Figure 2B).

Prognosis

The immediate outcome was divided into 3 groups: A, survival until discharge; B, in-hospital mortality despite successful ECMO removal; and C, death while on ECMO. The Glasgow Outcome Scale (GOS) was used to evaluate the midterm results 1 year after ECMO removal (1 – Death; 2 – Vegetative; 3 – Severe disability; 4 – Moderate disability; 5 – Good recovery).

RESULTS

A total of 51 patients received peripheral ECMO care in our PICU. Among them, 11 patients received V-V mode ECMO as a result of having only a respiratory problem (acute respiratory distress syndrome), while the other 40 patients received V-A mode ECMO because of pure profound LV failure or respiratory failure combined with a variable severity of cardiac dysfunction. The immediate outcome was 32 patients in group A, 7 patients in group B, and 12 patients in group C. The overall success rate of ECMO removal was 76.5% (39/51), and the survival rate after discharge was 62.7% (32/51). The myocarditis group had the most favorable outcomes among the ECMO patients (100% survival) and comprised the largest group receiving V-A mode ECMO (Figure 3).

Thirteen patients met the criteria for profound LV dysfunction and received V-A mode ECMO, including 11 patients with myocarditis, 1 with malignant arrhythmia, and 1 with Takotsubo syndrome. The survival rate for these 13 patients was 100%. The average age was 11.85 years and 9 of them were female. Twelve patients had a flat arterial line waveform (VT, VF, PEA, and asystole) during ECMO support and required LV decompression. Five patients received medical treatment successfully, and the other 7 patients underwent IABP procedures. In the IABP group, a decompression effect could not be achieved in 1 patient; hence, retrograde pigtail insertion was necessary to decompress the dilated left ventricle. In this case, the IABP catheter was removed and the

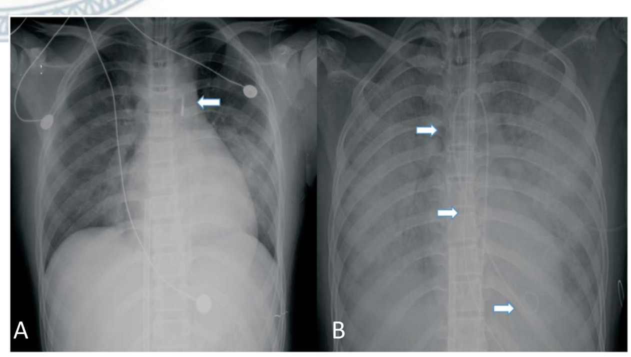

Figure 2. *(A) intra-aortic balloon pump (IABP) was located in thoracic aorta for LV decompression in a patient with pulmonary edema under extracorporeal membrane oxygenation (ECMO). The white arrow points out the tip of IABP catheter. (B) Retrograde pigtail was inserted into LV for decompression in a patient with pulmonary edema under ECMO. The white arrows point out the pigtail.*

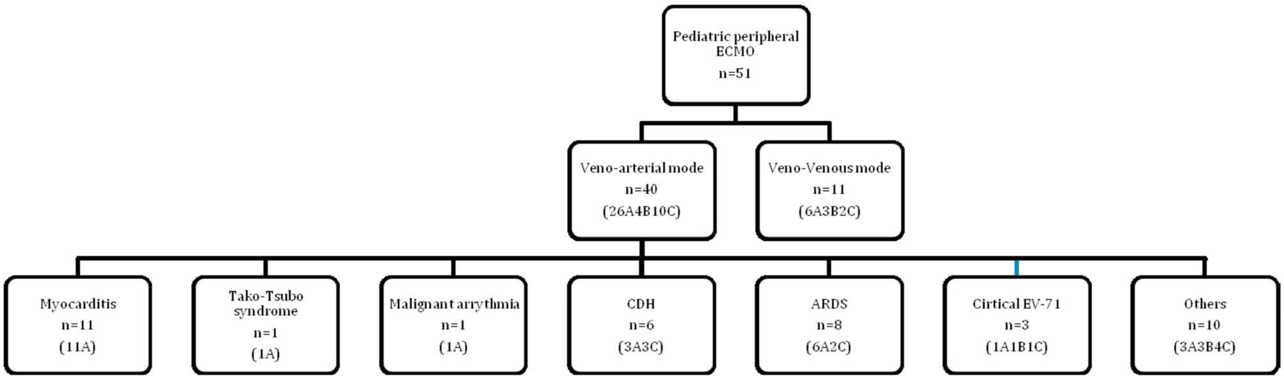

Figure 3. *Results of pediatric peripheral ECMO. Successful rate of ECMO removal: 76.5%, overall survival rate after discharge 62.7%. (A) Survive until discharge; (B) In-hospital mortality despite successful ECMO removal; (C) Death while on ECMO. ARDS, acute respiratory distress syndrome; CDH, congenital diaphragmatic hernia; ECMO, extracorporeal membrane oxygenation; EV-71, enterovirus-71.*

sheath was changed to a 9-French to prevent bleeding. A 6-French pigtail catheter was then inserted for LV decompression. The timing of IABP insertion was within the first 2 days during ECMO support in 6 patients, and the remaining 1 patient with malignant arrhythmia required IABP on the 5th day. No IABP-related complications were noted in this study (Table 1).

Among these 13 patients, 7 had acute kidney injury and 3 underwent CAVHD. Dialysis was not necessary for any of the patients after discharge or during follow-up. Furthermore, all of the patients survived with good neurological outcomes (GOS 5) and were able to resume normal daily activities.

DISCUSSION

Peripheral ECMO is widely used in patients with refractory pulmonary or cardiac failure.[1,3-6,15,17-24] V-V mode ECMO is used in patients with pure respiratory failure, while V-A mode is used in patients with pure cardiogenic shock or respiratory failure with variable cardiac dysfunction. The V-V mode, which draws deoxygenated blood from the venous site and returns oxygenated blood to the venous site, does not influence the preload or afterload of the heart. However, the peripheral V-A mode returns the oxygenated blood to the arterial site which increases LV afterload. In contrast to cardiac by-

Table 1. Data and outcomes of patients with profound left ventricle dysfunction

Case	Age (y/o)	Sex	BW (kg)	BH (cm)	BSA (kg/m^2)	Diagnosis	Decompression method	ECG during decompression	ECMO time (hours)	Result	GOS
1	12	F	60	157	1.62	Myocarditis	None	VT	70.6	Survival	5
2	15	F	50	155	1.47	Malignant arrhythmia	IABP	VT, VF	144.7	Survival	5
3	15	F	43	149	1.33	Myocarditis	IABP	VT, asystole	138.4	Survival	5
4	13	M	34	155	1.19	Myocarditis (DRESS)	IABP	CAVB, PEA	290.5	Survival	5
5	12	F	28	143	1.10	Myocarditis	Medical	CAVB, VT	128	Survival	5
6	12	F	45	152	1.38	Myocarditis	IABP	CAVB, VT	97.1	Survival	5
7	12	M	51	155	1.47	Myocarditis (DRESS)	Medical	ST	136.9	Survival	5
8	12	M	50	167	1.52	Myocarditis	Medical	PEA, CAVB, VT	92.8	Survival	5
9	4	M	16	110	0.86	Myocarditis	Medical	PEA, VT	108	Survival	5
10	10	F	31	145	1.12	Myocarditis	IABP	VT	229.7	Survival	5
11	3	F	13	100	0.72	Myocarditis	Medical	VT, VF, CAVB	187.3	Survival	5
12	16	F	48	156	0.89	Myocarditis	IABP → pigtail	VT, VF, asystole	262.4	Survival	5
13	18	FV	66	165	1.67	Tako-Tsubo syndrome	IABP	VT, PEA	122.1	Survival	5

BH, body height; BSA, body surface area; BW, body weight; CAVB, complete atrioventricular block; DRESS, drug reaction with eosinophilia and systemic symptoms; ECG, electrocardiography; ECMO, extracorporeal membrane oxygenation; GOS, glasgow outcome scale; IABP, Intra-aortic balloon pump; PEA, pulseless electric activity; VF, ventricular fibrillation; VT, ventricular tachycardia.

pass, ECMO cannot completely empty the right atrium chamber; thus, blood can still flow back to the left side of the heart. In patients with profound cardiac dysfunction under peripheral V-A mode ECMO, inflammatory myocardium cells cannot generate enough power to overcome the retrograde ECMO flow-related afterload. Thus, the aortic valve keeps closing, resulting in flattening of the arterial line waveform, LV size progression, sludge formation in the left ventricle, and the development of pulmonary edema. This is why a continuous flat arterial waveform can be a warning sign indicating the need for LV decompression, especially when echocardiography is unavailable. In addition, a distended left ventricle will also increase myocardial energy consumption resulting in ischemia and delayed recovery.

Hence, it is critical to unload the left ventricle to prevent thrombus formation, pulmonary edema, and LV wall stress in this situation. Truby et al. reported their ECMO experience on LV dilatation requiring immediate decompression in 7% (9/121) of their patients.[25] Kotani et al. used LA decompression in 12.9% (23/178) of their V-A ECMO patients to help improve LV function and prevent pulmonary edema.[8] Jung et al. analyzed fulminant myocarditis under ECMO support, and showed that 46.2% (6/13) of their patients required LV decompression.[24] In our pediatric non-cardiotomy surgery-related peripheral ECMO experience, LV decompression was necessary in 23.5% (12/51) of the overall cases and 92.3% (12/13) of the profound LV dysfunction cases. However, mechanical decompression was needed in 13.7% (7/51) of the overall cases and 53.8% (7/13) of the profound LV dysfunction cases.

LV decompression can be performed with medical or mechanical methods. Medical decompression includes the administration of vasodilators to decrease afterload, inotropic agents to augment contractility, and diuretics to control preload. If medical treatment is ineffective, mechanical decompression is needed. Many mechanical decompression methods have been reported in the literature including LA, LV, and PA venting, which can either be done surgically or with percutaneous interventions.[7-13,25-34] The most common method for LV decompression is LA venting, which is performed to create atrioseptostomy to drain blood from the LA. Baruteau et al., Paul et al., and Alhussein used percutaneous balloon atrioseptostomy, and Kotani et al. used both surgical and percutaneous interventions to create atrioseptostomy in their study. All of these studies showed that LA venting was a safe and efficient method for LV decompression. However, some complications were observed in their studies, including pericardial effusion, arrhythmia, vessel damage, and even death. Transaortically, Eugene et al. used in-line LV venting,[35] Vlasselaers et al. used a miniature axial flow pump,[27] and Barbone et al. used a percutaneous pigtail catheter for LV decompression successfully.[11] In contrast, Rao et al. performed transapical LV venting,[34] and Leonello et al. reported a case using successful PA venting.[10] However, the patients under ECMO support underwent systemic heparinization, so a less invasive procedure was favored to prevent fatal bleeding. An open chest method will cause increased bleeding and cosmetic problems. In addition, transporting patients under ECMO to a catheterization laboratory or operation room for atrioseptostomy increases the risk both during the transport process and also during the intervention.

In our LV decompression strategy, medical decompression was performed if a continuous flat arterial waveform was observed. However, IABP was considered prior to the retrograde pigtail catheter insertion to minimize the transport risk and also because it is less invasive. In the IABP system, the balloon deflated in the systolic phase and created a vacuum effect that increased the cardiac output and enabled opening of the aortic valve. In the diastolic phase, the balloon inflated and increased coronary perfusion, thereby accelerating myocardium recovery. IABP is not widely used in pediatric patients because of the limited balloon size and higher risk of artery occlusion.[36-38] The effect of using IABP with ECMO has been reported in adult studies with varying results.[14-16,39] Gass et al. and Pengyu et al. reported that the combination of ECMO and IABP had a synergistic result and improved the outcomes. However, this was in contrast to the results reported by Cheng et al. and Lin et al. In our pediatric peripheral ECMO experience, medical decompression was useful in children, especially those with a smaller body size. Combining IABP with ECMO in children allowed for decompression of the left ventricle and improved the outcomes. We assume that the difference in LV decompression ability with an IABP is caused by better aortic compliance and flexible aortic valve in children than in adults.

Study limitations

This is a retrospective study. In addition, this study has a small sample size and there was no control group.

CONCLUSIONS

Patients with profound LV dysfunction under peripheral V-A mode ECMO are at risk of LV distension, intracardiac thrombosis formation, and pulmonary edema. LV decompression is needed if there is no cardiac output. Younger children are more responsive to medical decompression. IABP is a feasible approach for LV decompression in cases of pediatric peripheral ECMO.

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DECLARATION OF CONFLICT OF INTEREST

All the authors declare no conflict of interest.

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None.

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