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Results of pediatric mechanical assist for postcardiotomy ventricular failure and cardiac arrest

Postkardiyotomi ventriküler yetmezlik ve kardiyak arrest için pediyatrik mekanik destek sonuçları

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Background: This study aims to evaluate the results of pediatric mechanical assist device use for postcardiotomy ventricular failure and cardiac arrest in the intensive care unit.

Methods: Between February 2000 and February 2012, 1800 patients underwent pediatric cardiac operation in our department. Among these patients 10 (5 boys, 5 girls; median age 3 months; range 2.5 month to 4.5 years) needed mechanical assist devices for postcardiotomy cardiac failure and cardiopulmonary failure in the intensive care unit. In four patients, roller pump support with left atrial appendage and ascending aorta cannulation was used for temporary left ventricle support. In six patients, extracorporeal membrane oxygenation (ECMO) was used for temporary cardiac and pulmonary support.

Results: Three patients in the roller pump support group (75%) and three patients in the ECMO support group (50%) were successfully weaned from the mechanical assist. The longest mechanical support with the roller pump for left ventricle dysfunction was 160 hours in a seven-month-old infant after arterial switch operation. Mechanical support was required in two patients in the roller support group including one (4 years old) after arterial switch operation and one (2.5 months old) due to the left ventricular dysfunction after surgery for anomalous left coronary artery from pulmonary artery. Both patients were successfully weaned from the roller pump support after 48 hours. In two patients ECMO support was necessary for cardiac arrest due to pulmonary hypertensive crisis in the intensive care unit following the ventricular septal defect closure and ECMO was successfully weaned off after 12 and 48 hours.

Conclusion: Pediatric mechanical circulatory support is a life-saving procedure for patients who develop cardiopulmonary failure after cardiac surgery and are unresponsive to the conventional resuscitative efforts. Conventional roller pump support is an alternative method for temporary left ventricle dysfunction in selected cases.

Key words: Centrifugal pump; extracorporeal membrane oxygenation; roller pump; ventricular assist device.

Amaç: Bu çalışmada postkardiyotomi ventriküler yetmezlik ve kardiyak arrest için yoğun bakım ünitesinde pediyatrik mekanik destek cihaz kullanımının sonuçları değerlendirildi.

Çalışma planı: Şubat 2000 - Şubat 2012 tarihleri arasında kliniğimizde 1800 pediatrik kalp ameliyatı yapıldı. Bu hastalardan 10'unda (5 erkek, 5 kız; medyan yaş 3 ay; dağılım 2.5 ay ile 4.5 yıl) postkardiyotomi kalp yetmezliği ve kardiyopulmoner yetersizlik için yoğun bakım ünitesinde pediatrik mekanik destek cihazları gerekli oldu. Dört hastada sol atriyal apendiks ve çıkan aort kanülasyonu ile roller pompa desteği geçici sol ventrikül desteği için kullanıldı. Altı hastada ise, ekstrakorporeal membran oksijenasyonu (ECMO) geçici kardiyak ve pulmoner destek için kullanıldı.

Bulgular: Roller pompa destek grubunda üç hasta (%75), ECMO destek grubunda üç hasta (%50) başarılı bir şekilde mekanik destekten ayrılabildi. En uzun mekanik destek, arteriyel switch ameliyatı sonrası yedi aylık bebekte sol ventrikül yetmezliği nedeniyle 160 saat süre ile roller pompa desteği ile yapıldı. Roller pompa desteği grubundaki iki hastadan biri (4 yaş) arteriyel switch ameliyatı sonrası, diğeri (2.5 ay) pulmoner arterden çıkan anormal sol koroner arter anomalisi nedeniyle yapılan ameliyat sonrası, sol ventrikül disfonksiyonu nedeniyle mekanik desteğe gereksinim duydu. Her iki hasta da 48 saat sonra roller pompa desteğinden başarılı şekilde ayrıldı. İki hastada ventriküler septal defekt kapatılması sonrasında yoğun bakım ünitesinde pulmoner hipertansif kriz nedeniyle kardiyak arrest gelişti ve ECMO desteği gerekli oldu ve ECMO desteği 12 ve 48 saat sonra başarılı bir şekilde sonlandırıldı.

Sonuç: Pediyatrik mekanik dolaşım desteği, kardiyak cerrahi sonrası kardiyopulmoner yetmezlik gelişen ve konvansiyonel resüsitatif çabalara yanıt vermeyen hastalar için hayat kurtarıcı bir işlemdir. Geleneksel roller pompa desteği, seçilmiş olgularda geçici sol ventrikül disfonksiyonu için alternatif bir yöntemdir.

Anahtar sözcükler: Centrifugal pump; extracorporeal membrane oxygenator; roller pump; ventriküler destek cihazı.

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Failure to wean a patient from cardiopulmonary bypass (CPB) in the operating room or cardiac arrest in the intensive care unit (ICU) that is unresponsive to conventional resuscitative efforts are the two most common tragic scenarios in pediatric cardiac surgery. The advanced resuscitation methods used in the operating room or ICU are extracorporeal membrane oxygenation (ECMO), left or right ventricular assist device (VAD) support, and conventional CPB support. For countries with limited resources, conventional CPB support and centrifugal pump or roller pump VAD support are readily available. Starting ECMO support is more complicated due to the need for a special oxygenator and a heater-cooler system along with a tubing set, various other special parts, and specially trained doctors, perfusionists, and ICU nurses. Pediatric mechanical cardiopulmonary support is a life saving procedure for patients who develop cardiac and respiratory failure after pediatric cardiac surgery. In this report, we evaluated the results of this type of support for postcardiotomy ventricular failure and cardiopulmonary failure in our ICU.

PATIENTS AND METHODS

Between February 2000 and February 2012, 1,800 patients underwent pediatric cardiac surgery at our department. Among these patients, 10 (5 boys, 5 girls; median age 3 months; range 2.5 months-4.5 years) needed mechanical assist device support for postcardiotomy cardiac failure and cardiopulmonary failure in the ICU. In four of these patients, roller pump support was implemented for temporary left ventricle support while ECMO was used in the other six for temporary cardiac and pulmonary support. The pathologies, operation type, mode of failure, mode of support, and outcomes are outlined in Table 1.

When cardiopulmonary failure occurred in the operating room, ECMO support was initiated with right atrial and aortic cannulae, whereas left VAD support was started with left atrial appendage and aortic cannulation (Medtronic DLP arterial cannulae 8-12F and Medtronic DLP venous metal angled cannulae 14-24F. Medtronic Inc., Minneapolis, MN, USA) for left ventricle failure in the operating room. A left atrial catheter or a pulmonary artery catheter along with atrial and ventricular pacing wires were then inserted. Sternum was not closed, and the mediastinum was covered with a plastic membrane. For cardiopulmonary failure in the ICU, support with a standard CPB system was started, and ECMO system was replaced, or ECMO support was started directly in the ICU with Medtronic ECMO oxygenator system (Medtronic Inc., Minneapolis, MN, USA). In addition, a Terumo Sarns roller pump (Terumo Medical Corporation, Somerset, NJ, USA) was used for left ventricle support. Pump flow was adjusted to full or 75% flow maintaining left atrial pressures of 10-15 mmHg in the first two days. Gradual weaning was planned during this period depending on left atrial pressure, blood gasses, pulmonary indices, and ventricular function [shortening fraction (SF) >28%] with serial echocardiographic examinations.

Anticoagulation was maintained with heparin infusion and activated clotting time (ACT) monitoring. The target ACT for the left VAD was 130-180 seconds while the target ACT for ECMO was 180-220 seconds. Blood products were transfused to maintain hematocrit levels of between 35 and 45% and a platelet count of >50.000/mm^3. Furthermore, albumin and fresh frozen plazma (FFP) were transfused, and low-dose inotropic and vasopressor support, furosemide infusion, peritoneal dialysis, and ultrafiltration were also employed to maintain fluid balance. The circuit pressure was constantly checked, and the patient was continuously monitored by the perfusionists for mechanical device failure, air bubbles, and hemolysis. The patient's lactate dehydrogenase level and urine analysis were used for monitoring the hemolysis. In addition, the raceway tubing was replaced every 72 hours and repositioned every 24 hours to prevent the risk of rupture. ECMO weaning and decannulation was routinely performed in the operating room.

RESULTS

Only 10 patients (0.5%) in the last 12 years needed mechanical circulatory support due to postcardiotomy cardiac failure or cardiopulmonary arrest in the ICU. Three of the four patients (75%) supported by the roller pump for left ventricular failure and three of the six patients (50%) supported by ECMO for cardiopulmonary failure were weaned from mechanical cardiopulmonary assistance. Overall, 50% of the patients were discharged from the hospital without permanent major organ injury (Table 1). The duration of mechanical assistance ranged from 48-160 hours (mean 58±43 hours), with the longest mechanical support for left ventricle dysfunction being 160 hours with a roller pump and ascending aorta-left atrial appendage cannulation in a seven-month-old infant after an arterial switch operation. Two other patients, one after an arterial switch operation (4 years old) and one after surgery for an anomalous left coronary artery from pulmonary artery repair (2.5 months old), were successfully weaned from roller pump support

Table 1. Patient and mechanical support characteristics

No	Age/gender	Pathology	Operation	Mode of failure and support	Duration of support	Outcome
1	4 years/M	TGA, LVOTO, ASD	Arterial switch-AVR	LV failure on postoperative day 1 due to AR in the ICU; initiation of roller pump left VAD (Sarns) in the OR	48	Discharged without permanent injury; normal growth after follow-up; mitral valve repair 10 years later.
2	5 months/F	TA, PA, VSD, restrictive ASD, small PDA	Atrial septectomy, shunt	LV failure in the OR; initiation of Roller pump left VAD (Sarns) in the OR	48	Died of cardiac failure on postoperative day 3
3	4.5 years/M	DORV, VSD, PS	Rastelli	Cardiopulmonary failure postoperative day 1 in the ICU; initiation of ECMO (Medtronic) in the OR	36	Died of multi-organ failure on postoperative day 5
4	3 months/F	VSD	VSD, ASD closure	Cardiac arrest in the ICU 20 hours after operation while weaning from ventilator; initiation of CPB in the OR; creation of atrial fenestration; initiation of ECMO (Medtronic) in the operating room	37	Discharged on postoperative day 24 without permanent injury; extubation 5 days after ECMO weaning; normal growth on follow-up.
5	5 months/M	TGA, VSD	Senning, VSD closure	Cardiopulmonary failure on postoperative day 1 due to PH; initiation of CPB (Terumo Capiox RX5 oxygenator-Sarns roller pump) in the ICU	18	Died of cardiopulmonary failure on postoperative day 2
6	3 months/M	Truncus arteriosus	Truncus repair	Cardiopulmonary failure due to PH 1 day after surgery; initiation of ECMO (Medtronic) in the ICU	51	Died of cardiac and renal failure on postoperative day 7
7	1 year/M	TOF	TOF repair	Postoperative RV failure in the ICU; initiation of ECMO (Medos) in the ICU	72	Died of cardiopulmonary failure on postoperative day 4
8	2.5 months/F	ALCAPA	ALCAPA repair	LV failure; initiation of roller pump left VAD (Sarns) in the OR	96	Discharged without permanent injury; normal growth on follow-up
9	4 months/F	VSD	VSD closure	Cardiac arrest in the ICU due to PH; initiation of CPB (Terumo Capiox RX5 oxygenator-Sarns roller pump) in the ICU	12	Discharged without permanent injury; normal growth on follow-up
10	7 months/F	TGA, VSD	Arterial switch, VSD closure	LV failure; initiation of roller pump left VAD (Sarns) in the OR	160	Discharged without permanent injury; normal growth on follow-up

LV: Left ventricle; TGA: Transposition of great arteries; LVOTO: Left ventricular outflow tract obstruction; ASD: Atrial septal defect; AVR: Aortic valve replacement; LV: Left ventricular; AR: Aortic regurgitation; ICU: Intensive care unit; RV: Right ventricle; VAD: Ventricular assist device; OR: Operating room; TA: Tricuspid atresia; PA: Pulmonary atresia; VSD: Ventricular septal defect; PDA: Patent ductus arteriosus; DORV: Double outlet right ventricle; PS: Pulmonary stenosis; ECMO: Extracorporeal membrane oxygenation; CPB: Cardiopulmonary bypass; TOF: Tetralogy of Fallot; PH: Pulmonary hypertension; ALCAPA: Anomalous left coronary artery from pulmonary artery.

for left ventricular dysfunction after 48 hours. In two patients, ECMO support was necessary after ventricular septal defect (VSD) closure because of cardiopulmonary arrest in the ICU due to a pulmonary hypertensive crisis. The patients were weaned off ECMO after 12 and 48 hours, respectively. In addition, after truncus repair, one of the patients in the ECMO group was weaned off cardiopulmonary support after 51 hours but died of multi-organ failure two days later. Furthermore, one patient in the left VAD group and three in the ECMO group died of cardiopulmonary failure.

DISCUSSION

Our first patient was a four-year-old boy with transposition of the great arteries and subpulmonic stenosis who underwent arterial switch operation and subpulmonic resection. Left ventricle failure occurred in the ICU because of aortic regurgitation, and aortic valve was replaced after the aortic annulus enlargement procedure. Due to difficulty in weaning the patient from CPB, left ventricle support was used for 48 hours with a roller pump with ascending aorta and left ventricle apex cannulation. Tracheotomy and ventilatory support were necessary for 20 days postoperatively because of pneumonia. Patient was discharged on postoperative day 35 without permanent organ dysfunction. Mitral valve repair was performed on this patient 10 years later. This case encouraged us to support the left ventricle with a conventional roller pump when sophisticated VADs were not available.[1]

Recoverable cardiopulmonary dysfunction and bridging for transplantation are the two main indications for the need for mechanical assist devices in the pediatric age group. The decision is made according to the patient's clinical condition, technical and logistical sources, and clinical experiences. Conventional CPB systems, ECMO systems, Berlin Heart EXCOR® pediatric VAD (Berlin Heart, GmbH, The Woodlands, TX, USA), Medos VAD (Medos Medizintechnik AG, Stolberg, Germany) and centrifugal pumps are among the currently available support devices. In 1973, Soeter et al.[2] reported the first use of extracorporeal support for a four-year-old child after tetralogy of Fallot (TOF) repair when respiratory failure developed. After 48 hours of support, the child was successfully weaned. Furthermore, Barlett et al.[3] reported the results of the clinical use of ECMO in a case of cardiopulmonary failure in 1976 and 1977. The Extracorporeal Life Support Organization (ELSO) was also established in 1989 and began to collect ECMO data from related centers.

In addition to the conventional CPB and ECMO systems, there are two types of mechanical assist devices: intracorporeal and paracorporeal. Berlin Heart EXCOR® pediatric VAD, Medos VAD, Thoratec VAD, and the AbioMed BVS 5000/AB 5000 (AbioMed, Inc., Danvers, MA, USA) are paracorporeal devices in which the pump, connections, and console are outside of the body. In intracorporeal devices like the DeBakey VAD® Child (MicroMed Technology, Inc., Houston, TX, USA), Jarvik 2000 VAD (Jarvik Heart, Inc., New York, NY, USA), Berlin Heart INCOR® (Berlin Heart, GmbH, The Woodlands, TX, USA), and Thoratec Heartmate II (Thoratec Corporation, Pleasanton, CA, USA), the pump and main connections are inside the body. However, many of these devices are not suitable for children today, and the use of intraaortic balloon pump support is limited in pediatric cardiac surgery because of technical considerations and the elasticity of the aorta.

Two support modalities are recommended for pediatric cardiac patients: ECMO, which supports both pulmonary and cardiac functions, and left and right VAD systems, which support only cardiac (left and/or right ventricle) functions.[4] The Berlin Heart EXCOR® is currently the most widely used pediatric left/right VAD system.[5] Roller pump support for temporary left ventricular failure was the choice in our patients because of the easy set-up and lack of available pediatric centrifugal pumps or other left VAD systems. Fortunately, new support systems have recently become available in our country, and we aim to use these novel devices for our future patients.

Support systems are most frequently used in pediatric cardiac surgery when there is difficulty in weaning from CPB, low cardiac output, severe left, right ventricular or biventricular failure, respiratory failure, or postoperative cardiopulmonary arrest. However, severe neurological injuries, irreversible sepsis, multi-organ failure, severe coagulation disorders, multiple congenital anomalies, and extreme prematurity are contraindications for mechanical support. The most common complications are bleeding, thromboemboli, hemolysis, infection, and multi-organ failure.[6] Bleeding was decreased in our last two patients via roller pump left VAD support, with for whom we maintained ACT levels of between 120 and 150 seconds, and the use of tubing sets with Terumo Xcoating™ (Terumo Medical Corporation, Somerset, NJ, USA). We did not observe significant hemolysis with negative clinical outcomes in our roller pump-supported patients.

Before starting the weaning process, it is important to evaluate the echocardiographic findings. In our patients, weaning process was started when there was an improved SF contractility of >28%, a mean arterial pressure (MAP) of >50 mmHg, and a left atrial (LA) pressure of <15 mmHg. The support level was decreased by increments of 25% every four-six hours, and once it reached a level of 25%, the patients were transferred to the operating room for safe cannullae removal. Support management for ECMO is more difficult than for VADs and has a higher risk of bleeding, thrombosis, embolization, major organ dysfunction (pulmonary, neurological, renal, and gastrointestinal), and infection. We have

Figure 1. Extracorporeal membrane oxygenation support in the intensive care unit.

Figure 2. Left ventricular assist device support with roller pump in the intensive care unit.

observed that surgeons, anesthetists, intensivists, and perfusionists along with ICU and operating room nurses need advanced training to establish and maintain a successful ECMO program. In our cases that involved cardiopulmonary failure, we used ECMO (Figure 1), and for left ventricle failure, we chose the roller pump (Figure 2). Short-term centrifugal pump support and long-term support with the Berlin Heart EXCOR® might be better alternatives for children, and we plan to use these devices in the future.

Pediatric mechanical cardiopulmonary support is a life saving procedure for patients who develop cardiopulmonary failure after cardiac surgery and do not respond to conventional resuscitative efforts.[7-10] It has always been difficult to manage bleeding problems in these patients, but new ECMO systems need a lower degree of anticoagulation. Centers who deal with these patients should have a blood bank and blood product support and be able to provide the specific laboratory tests that are needed. Certain groups of patients, such as those with anomalous origin of the left coronary artery from the pulmonary artery (ALCAPA) pathology and those for whom an arterial switch operation with left ventricle involution is planned, might be candidates for elective ECMO and left VAD support. Customized support systems for the right and left ventricles, biocompatibility, anticoagulation, control systems, size, price, reliability, and durability are all issues that still need improvement in pediatric cardiopulmonary support systems.[11-14]

One limitation of our study was that, it was made up of a small group of patients; therefore, it was difficult to draw definitive conclusions. In addition, it was not possible to compare our results because there were no available alternative support systems. Nevertheless, we believe that our experiences with these patients could prove to be valuable for centers in countries with limited resources.

Conclusion

Pediatric mechanical cardiopulmonary support is an evolving procedure that might save the lives of children who develop cardiopulmonary failure. Furthermore conventional roller pump support may provide an alternative method for temporary left ventricle dysfunction in selected cases for pediatric cardiac centers with limited resources.

Declaration of conflicting interests

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