Technique

Rapid Pediatric Cardiopulmonary Support System

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ABSTRACT

Emergency cardiopulmonary support (CPS) systems for pediatric patients have not achieved widespread acceptance because they have been limited by extended setup times and large priming volumes requiring blood products. To address these limitations, we developed a miniaturized CPS system which can be rapidly assembled with a small bloodless priming volume. This system was successfully utilized in two infants with congenital heart disease in whom emergent cardiopulmonary support was instituted outside the operating room. The pediatric CPS system proved safe and effective in allowing the salvage of both patients. Further study of this system is warranted to evaluate potential future applications.

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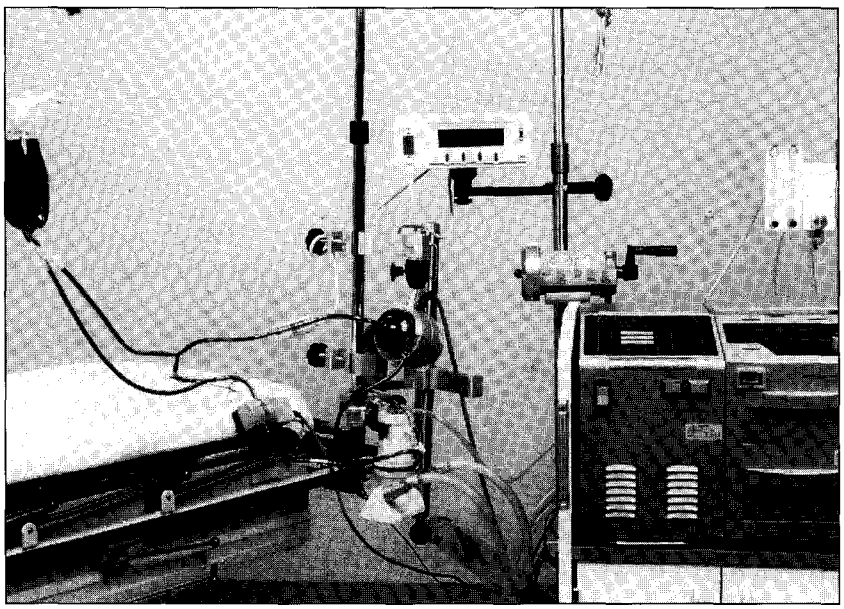
INTRODUCTION

Emergency cardiopulmonary support (CPS) systems for adult patients have been utilized successfully for resuscitation during acute cardiac and pulmonary failure (1,2,3). The priming volume of these systems (approximately 800 ml) has little hemodilutional effect on the average adult (4); therefore, adult CPS can be initiated without the use of blood products. In pediatric patients, even a modest amount of crystalloid priming volume can cause extreme hemodilution resulting in unacceptably low hemoglobin levels and necessitating blood transfusion.

Many pediatric centers currently use extracorporeal membrane oxygenation systems (ECMO) for emergency resuscitation (5,6). ECMO systems generally consist of a silicone membrane oxygenator, a bladder, and a roller pump. ECMO also requires a large priming volume. Furthermore, during acute cardiac or pulmonary failure, speed is critical (4,7). Prolonged ECMO setup times are problematic. ECMO assembly times are often prolonged by several factors: debubbling the silicone membrane oxygenator, using CO_2 flushing, and adding blood to the prime. Blood products also require the addition of bicarbonate and calcium to reverse the effect of citrate phosphate dextrose (CPD); these additives have been implicated in reperfusion injury (8).

The use of conventional cardiopulmonary bypass (CPB) for emergent resuscitation outside the operating room is limited by the cumbersome size and weight of most bypass machines. We developed a mobile miniaturized CPS system to overcome the limitations of adult CPS systems, conventional ECMO systems, and standard CPB circuits. We now report our use of this system in two infants.

Figure 1:



The CPS system consists of a preassembled Carmeda coated circuit, a BP-50 Biomedicus cone, a Minimax plus oxygenator, a Biomedicus flow probe, and a CDI 100 hematocrit/venous oxygen saturation monitor. A Biomedicus external drive unit and a Minimax oxygenator bracket are attached directly to the patient's bedside where the system can be assembled and primed in under five minutes. The centrifugal head and membrane oxygenator are attached both to the patient's bed and the mobile cart by a flexible arm coming off the cart and clamped on the bed.

MATERIALS AND METHODS

The CPS system (Figure 1) consists of a preassembled heparin-coated circuit with 1/4 inch arterial and venous tubing[a], a BP-50 Biomedicus cone[b], a Minimax plus oxygenator[a], a Biomedicus flow probe[b], and a CDI 100 hematocrit/oxygen saturation monitor[c]. A Biomedicus external drive unit and a Minimax oxygenator bracket are attached directly to the patient's bedside where the system can be assembled and primed in under five minutes. The centrifugal head and membrane oxygenator are attached both to the patient's bed and the mobile cart by a flexible arm coming off the cart and clamped on the bed. After assembly, the circuit is primed with a total volume of 250 ml of Plasmalyte A solution[d] and quickly debubbled. Both the arterial and venous lines include tubing spikes for rapid connection to the crystalloid bag. The flow probe transducer and venous saturation monitor are attached and calibrated. The gas line and temperature probe are then attached to the oxygenator. The arterial and venous lines are clamped and transferred to the sterile field. A cut down is performed in the neck to isolate the common carotid artery and internal jugular vein. Prior to cannulation, the patient is heparinized using 100 IU/kg. The arterial and venous lines are then connected to the appropriate cannulae. The bypass bridge is clamped, bypass is initiated, and the flow rate is slowly increased to 120 ml/kg/min. The activated clotting time (ACT) is measured as soon as possible and maintained between 180-220 seconds. Boluses of 5% albumin are administered to maintain the CVP above 5 mm Hg in order to prevent venous line cavitation. Pre-oxygenator pressures are continuously monitored with the pressure monitor built into the Biomedicus pump console.

a Medtronic Cardiopulmonary, Anaheim, CA
b Medtronic Biomedicus, Eden Prairie, MN
c CDI 3M Health Care, Tustin, CA
d Baxter Healthcare Corporation, Deerfield, IL

CASE REPORTS

CASE 1:

A 7 week old, 4 kg male infant presented emergently with respiratory distress and profound cyanosis (oxygen saturation 40-50%). Echocardiography revealed pulmonary atresia, ventricular septal defect, and double outlet right ventricle. In the intensive care unit, the infant became profoundly cyanotic with evidence of poor systemic cardiac output. Cardiopulmonary resuscitation was initiated. Resuscitation was ineffective and emergent CPS was initiated. The CPS system setup time was 5 minutes, and cannulation was completed in 6 minutes. The patient's oxygen saturation improved immediately to 100%, and the hemodynamics stabilized on CPS.

The patient was then transported to the operating room and converted to conventional CPB via median sternotomy. The right pulmonary artery stenosis was repaired with a pericardial patch and a right modified Blalock-Taussig shunt was created using 3.5 mm graft. Following this procedure, the infant was successfully weaned from CPB (75 minutes on CPS, 110 minutes on CPB at 28°C) and returned to the intensive care unit. The postoperative course was uneventful. The infant maintained a saturation of 80% on room air, had a normal neurologic exam, and was discharged from the hospital 11 days postoperatively.

CASE 2:

A 4 week old, 4 kg male neonate with critical aortic stenosis and left ventricular dysfunction underwent attempted aortic balloon valvotomy in the catheterization laboratory. During the procedure, a guide wire perforated the aortic arch at the level of the ductus arteriosus resulting in cardiac arrest. Despite vigorous resuscitation and inotropic support, the child remained hypotensive. Emergent CPS was initiated. The equipment setup time was 5 minutes, and cannulation was accomplished in 12 minutes.

The infant was transported to the operating room, where he was converted to conventional CPB. Open aortic valvotomy and suture repair of the aortic arch perforation were performed. The total CPS time was 80 minutes and the CPB time for the open repair was 108 minutes. The patient separated from CPB uneventfully and returned to the cardiac intensive care unit. He was discharged home on the twelfth postoperative day with a normal neurologic examination and no evidence of myocardial dysfunction by echocardiography.

DISCUSSION

ECMO has been the standard technique for resuscitating pediatric patients when conventional cardiopulmonary resuscitation is ineffective. This technique is limited by prolonged setup times (45 to 60 minutes) and the need for blood products to minimize hemodilution. CPS systems for adult patients allow rapid resuscitation, but large priming volumes and excessive hemodilution limit their application in the pediatric patient (1,2,4,7,9). A miniaturized version of the adult CPS system has previously been described, but this system still requires the addition of blood to the system (10). We have further modified this system to reduce the priming volume, eliminate the need for blood priming (neither patient required blood for priming the CPS circuit), reduce transfusion related risk (8), and prevent the inherent delay required to obtain blood products. Neither case required additional blood products, in amounts greater than normal, during conversion from CPS to CPB. Furthermore, transporting patients from remote sites, such as the catheterization laboratory and intensive care unit, to the operating room, is facilitated by the streamlined circuit.

Our rapid CPS system presents two potential disadvantages when compared to conventional bypass or ECMO. The first disadvantage is the increased potential for air embolism secondary to possible venous line cavitation. Although the Biomedicus cone and the Minimax oxygenator will trap small amounts of air, they are not 100% effective. Extreme caution must be undertaken at all times to prevent air entry into the circuit. The second shortcoming is limited durability. The hollow fiber oxygenators are not intended for long term use (>6 hours) due to plasma breakthrough and a loss of gas exchange efficiency; nevertheless, we have used this system for support times of 48 to 72 hours without plasma breakthrough. Because of these two potential disadvantages, close continuous circuit monitoring by a perfusionist is employed.

The most striking advantage of this CPS technique is speed. As described in this report, the CPS system can be assembled at the bedside in five minutes. The infants described in this report were successfully resuscitated within minutes of their hemodynamic collapse. This speed will minimize end organ injury and preserve ventricular function. Moreover, by compressing the CPS system, remote transport of patients requiring cardiopulmonary support may be possible. This might allow patients to be stabilized on site at outlying centers and transported to tertiary facilities.

A rapid and safe technique for emergent pediatric cardiopulmonary support has been developed and successfully utilized in two infants. Further study of this system is warranted to evaluate potential future applications.

REFERENCES

1. Hill JG, Bruhn PS; Cohen SE, et al. Emergent applications of cardiopulmonary support: a multiinstitutional experience. Ann Thorac Surg 1993;55:1281-1282.
2. Pavlides GS, Cieszkowski J, Timmis GC, O'Neill W. Successful resuscitation of a patient with critical aortic stenosis and cardiac arrest by peripheral cardiopulmonary support system. Cathet Cardiovasc Diagn 1990;20:120-122.
3. Phillips SJ, Zeff RH, Kongtahworn C, et al. Percutaneous cardiopulmonary bypass: application and indication for use.

Ann Thorac Surg 1989;47:121-3.
4. Mooney MR, Arom KV, Joyce LD, et al. Emergency cardiopulmonary bypass support in patients with cardiac arrest. J Thorac Cardiovasc Surg 1991;101:450-4.
5. Galantowicz ME, Stolar CJH. Extracorporeal membrane oxygenation for perioperative support in pediatric heart transplantation. J Thorac Cardiovasc Surg 1991;102:148-52.
6. Redmond CR, Graves ED, Falterman KW, Ochsner JL, Arensman RM. Extracorporeal membrane oxygenation for respiratory and cardiac failure in infants and children. J Thorac Cardiovasc Surg 1987;93:199-204.
7. Teirstein PS. Cardiopulmonary support. Am J Cardiol 1992;69:19F-21F.
8 Yano Y, Riggs TR, Milam DF, Alexander Jr JC. Calcium-accentuated ischemic damage during reperfusion. J Surg Res 1987; 42: 51-5.
9. Perchinsky MJ, Long WB, Hill JB, Parson JA, Bennett JB. Extracorporeal cardiopulmonary life support with heparin-bonded circuitry in the resuscitation of the massively injured trauma patients. Am J Surg 1995;169:488-91.
10. McCoach RM, Myers JL, Wise RK, Baer LD, Williams SA, Williams DR. Use of emergency cardiopulmonary support in neonates and infants. Proceed Am Acad Cardiovasc Perf 1994;15:177-180.