

Ventricular Assist in the Infant

Susan C. Ratty, BS, Mary Winkler, RN, CCP, John Lamberti, MD and Ricardo Moreno-Cabral, MD

Sharp Memorial Hospital
UCSD Medical Center
Cardiovascular Perfusion, Inc.
San Diego, CA

Keywords: Ventricular assist, ECMO, heparin

Abstract

Two cases are described in which the Bio-Medicus centrifugal pump is used to support ventricular failure post CPB in the infant patient. The first patient (5 kg) was diagnosed with anomalous left coronary artery and pre-operative myocardial infarction. This patient required left ventricular assist support for 70 hours following surgical repair and failure to wean from CPB. The second patient (5 kg) presented 12 days status post mustard procedure with post operative ECMO support, for resuscitative CPB following an acute cardiac arrest incident. The patient could not be weaned from CPB with adequate cardiac output and required systemic ventricular support for 24 hours. Both patients were cannulated from left atrium to ascending aorta. The circuit consisted of 1/4" tubing an electromagnetic flow probe, and a pediatric bio-pump head connected to the Bio-Medicus centrifugal pump. High flows and minimal anticoagulation were maintained and both patients were successfully weaned from the left ventricular assist device. The text will describe the details of perfusion management and patient outcomes. We conclude that ventricular assist is a viable adjunct to the care of infants unable to be weaned from CPB.

Introduction

Ventricular assist devices (VAD's) have been used effectively for many years to treat acute post-cardiotomy ventricular failure and reduce postoperative mortality in the adult population (1, 2). Although a variety of devices exist to bypass the failing ventricle, the pediatric patient has been limited by size and technical constraints from the benefit of many of these VADs (3). One system that has been used successfully in children for post-cardiotomy ventricular failure is extracorporeal membrane oxygenation (ECMO) (4, 5). There are also limited reports of centrifugal pumps being used as VADs in pediatrics for postoperative cardiac failure and bridging to transplantation (6, 7). The efficacy and safety of using centrifugal pumps for temporary circulatory assist has been well documented (3, 7, 8). These pumps are readily available, relatively easy to use, and comparatively inexpensive.

Address correspondence to: Susan C. Ratty, Cardiovascular Perfusion, Inc., 7910 Frost St., Suite 204, San Diego, CA 92123

Our experience in treating infants with postoperative cardiac failure had been limited to the use of ECMO. This paper will present our first experience utilizing a centrifugal pump to support the systemic ventricle in two infants who were unable to be weaned from cardiopulmonary bypass (CPB), despite maximal conventional therapy. The VADs performed without technical complications, were able to provide adequate perfusion, and rested the myocardium enough to allow weaning. However, both patients were only short term survivors.

Patients

Patient number one, S.B., was a two and one-half month old, 5 kg. male (BSA. 35m²), with a diagnosis of anomalous left coronary artery and ischemic cardiomyopathy. He was admitted with symptoms of congestive heart failure and irregular cardiac rhythms. The chest x-ray showed cardiomegaly and echocardiography revealed a dilated left ventricle with reduced contractility and global hypokinesis. The patient subsequently underwent cardiac catheterization which verified aberrant origin of the left coronary artery from the main pulmonary artery. S.B. required pharmacologic and ventilatory support pre-operatively for stabilization of his low cardiac output state and ventricular arrhythmias. Primary heart transplantation was presented to the parents as an option of treatment and declined. He then underwent surgical correction by reimplantation of the anomalous coronary artery into the aorta. Following repair and rewarming, the patient could not maintain adequate cardiac output and perfusion pressure to be separated from CPB, despite maximal pharmacologic support. The echocardiogram revealed severe left ventricular dysfunction with mild mitral insufficiency. He was then converted to the VAD system and an intra-aortic balloon pump (IABP) inserted. S.B. was transferred to the intensive care unit (ICU) with VAD flows 600-700 cc/minute, arterial blood pressure 90/60 mmHg, and left atrial pressure 13 mmHg. Initial CPB time was 130 minutes, with 52 minutes of aortic cross clamp time. Prior to VAD insertion there were two additional CPB runs of 12 and 15 minutes, with only brief periods off bypass.

Patient number two, E.J., was a nine month old, 5.5 kg. male (BSA. 37m²), with a diagnosis of transposition of the great arteries and ventricular septal defect (VSD). He underwent

palliative repair with a Mustard procedure and closure of VSD. Pulmonary artery pressure (PAP) was supra systemic post CPB, necessitating perforation of the VSD patch and placement on ECMO to allow the PAP to normalize. He was weaned from ECMO after seven days and PAP was approximately one-half systemic. Post ECMO, he was gradually improving when his PA catheter, inserted at surgery, was removed. He had continuous bleeding which required emergency sternotomy and open cardiac massage, and was then transported to the operating room for resuscitation with the heart-lung machine. After 104 minutes of bypass, with stabilization of acid-base balance and removal of fluid by hemoconcentration, the patient was weaned with mild to moderate pharmacologic support. However, he required increasing inotropic support to maintain an adequate perfusion pressure and had also become anuric. The decision was made to utilize the VAD system for circulatory support and hemofiltration or hemodialysis as needed. E.J. was transferred to the ICU with VAD flows of 600-700 cc/minute, mean arterial pressure 50-60 mmHg, and central venous pressure 16 mmHg.

Materials and Methods

The Bio-Medicus (a) centrifugal pump was chosen as the ventricular assist device for both patients. Each patient was bypassed from left atrium to the aorta. S.B. was cannulated using a 4 mm Polystan catheter in the left atrium and an 8 FR. DLP (b) catheter in the ascending aorta. E.J. was cannulated using a 7 mm Polystan (c) catheter in the neo-left atrium and a 3.5 mm Sarns (d) catheter in the ascending aorta. The completed VAD circuit consisted of 1/4" polyvinylchloride tubing of the shortest length possible, an electromagnetic flow probe, and the pediatric BP50 Bio-pump head (6). In addition, a Bentley (e) Oxy-Sat connectrode was placed in the pump inflow line to monitor the oxygenating capability of the lungs. (With a RVAD this would be used to monitor venous saturation.) Also, a 1/4"x1/4" luer connector with a three-way stopcock was placed on the positive pressure outflow line for access if hemofiltration or hemodialysis was required. The VAD circuits were pre-primed using blood from the CPB circuit to prevent any further hemodilution. The conversion from CPB to VAD support was easily made without complications in both patients.

Chest wounds were left open and occlusively sealed with either vi-drape dressing or bovine pericardium. Strict asepsis and reverse isolation were carried out in the ICU due to the increased potential for infection. Cultures of blood, urine, and sputum were taken daily and antibiotic therapy instituted for sensitive organisms. The patients were not moved unless absolutely necessary to prevent dislodgement of the VAD cannulae. Continuous vecuronium and fentanyl drips were infused for paralysis and sedation. Precautions for a heparinized patient were followed to avoid stimulation of bleeding, such as, no needle sticks or rectal temperatures, and gentle suctioning.

- a. Model No. 540, Bio-Medicus Inc., Eden Prairie, MN 55344
- b. DLP, Grand Rapids, MI 49504
- c. Polystan A/S, Copenhagen, Denmark
- d. Sarns 3M Health Care, Inc., Ann Arbor, Mi 48106
- e. Bentley Baxter, Irvine, CA 92714

Throughout the duration of ventricular bypass a perfusionist remained at the bedside to assist in patient management and monitor the VAD's function, as well as patient responses to treatment.

Protamine sulfate was administered to reverse the heparin dose used for CPB. After hemostasis was achieved, usually 3-4 hours post protamine in our experiences with adult patients, the activated clotting time (ACT) was maintained between 150-180 seconds. (This parameter is usually for VAD flows in excess of 1.5 liters/minute.) In our first pediatric patient, S.B., with flows averaging 650 cc/minute, it was initially decided to keep the ACT at 200-225 seconds. Heparin was started four hours post protamine and the average dose was 60 units/kg/hour to maintain that ACT. Chest tube drainage was mild to moderate during the first 24 hours. On the second day, with increased bleeding from the chest tubes, the ACT range was lowered to 180-200 seconds. However, bleeding continued throughout the remainder of the VAD period, accepted at 40-50 cc/hour. In E.J.'s case a heparin drip was never used. After initial normalization of the ACT after protamine reversal, the ACT became elevated >220 seconds within three hours, and remained >200 seconds for the entire 24 hour circulatory assist. Bleeding was also a complication in this patient. When VAD support was first initiated the ACT was monitored every 1/2 hour, then every hour after coming within range. Blood products were infused to keep the hematocrit >30%, the fibrinogen level >150 mg/dl, and the platelet count 100,000-150,000/mm³. All chest tube drainage was returned to the patients using a sterile collection system designed for autotransfusion. When possible, only donor specific products were used for transfusions, and single donor pheresis packs for platelet infusions. ACT's were monitored closely when platelets or FFP (fresh frozen plasma) were infused. From our experience, platelet transfusion can shorten the ACT, and FFP can prolong the ACT due to antithrombin III content (13).

Sufficient flow rates were able to be maintained in both patients. S.B.'s flow was 550-750 cc/minute with RPM's of 2000-2200. This flow gave him a cardiac index (CI) of 1.6-2.2 l/min/m² from the VAD, or 110-150cc/kg. The mean arterial pressure (MAP) was kept at 60-70mmHg, and the left atrial (LA) pressure was kept at 10-12 mmHg. E.J. had flows of 600-700 cc/minute with RPM's of 1550-1750. His CI was 1.6-1.9 l/min/m², or flows of 120-140 cc/kg. from the VAD. The MAP averaged 60 mmHg, with an average CVP of 18 mmHg. The difference in RPM's between these two patients, with similar flows and arterial pressures, we felt was due to the different type arterial cannulae used. Frequent volume replacement was required in both patients to maintain adequate VAD preload. Hemodynamic monitoring included arterial and atrial pressures, as well as thermodilution cardiac output assessment in S.B. Inotropic agents were weaned as tolerated to further decrease myocardial oxygen consumption. Indications of right ventricular failure were not apparent in either patient, and metabolic acidosis did not occur. Arterial saturations remained adequate and were monitored by the oxy-sat detectors in the left atrial to pump line.

During VAD support, once every 30 minutes, the pump flow was momentarily decreased to allow an increase in blood flow through the failing ventricle. If the ventricle is contracting, this maneuver may prevent long term stasis of blood in the ventricle and reduce the possibility of thrombus formation. At this time one also has the opportunity to assess left ventricular function and recovery.

Renal function was monitored closely since it is well documented that complications occur in patients with cardiogenic shock requiring circulatory support (9). The combination of large volume requirements and renal dysfunction leads to hypervolemia. A means of removing excess fluid by continuous arteriovenous hemofiltration (CAVH) or dialysis is sometimes necessary. The centrifugal pump VAD circuit has been used effectively to provide access from the high pressure line (from the pump to the aorta) for CAVH (10). Hemofiltered blood is then returned through a central venous line. This set-up was used in E.J.'s case due to his continued renal dysfunction on the VAD. Despite maximal diuretic therapy he remained basically anuric. A hemodialysis pump was primed from the VAD circuit as blood was simultaneously infused to the patient to prevent hypotension. A dialysate bath was not used and CAVH was controlled to remove 500 cc of fluid over a four hour period. This method of CAVH was instituted twice in the 24 hour VAD period with stable hemodynamics. E.J.'s blood urea nitrogen (BUN) was 37-43 mg/dl and his serum creatinine (CR) was 0.8-1.3 mg% S.B. was actively diuresed and maintained good urine output with stable BUN and CR throughout his VAD period. Hemolysis is a known complication of extracorporeal support (11). The types of pumps and cannulae used in the extracorporeal circuit can effect the amount of hemolysis encountered (11, 12). In order to track the amount of hemolysis in our patients, plasma free hemoglobin was monitored daily. S.B. showed a plasma hemoglobin of 33.3 mg% after 68 hours of VAD support. E.J. was only on VAD support for 24 hours, and his plasma hemoglobin level was not drawn.

Results

Both patients were supported on the centrifugal pump VAD without any technical complications relating to the pump or circuitry. The assist devices provided adequate circulatory support while allowing the systemic ventricle to rest and regain enough function to permit separation with stable hemodynamics. Unfortunately, our two patients were only short term survivors.

S.B. was weaned from the VAD after 70 hours of support. Ventricular recovery was evaluated by temporarily decreasing VAD flow and observing filling pressures, arterial perfusion pressure and cardiac output. Within the first 24 hours, his cardiac output was showing improvement, and after 48 hours his cardiac index was 2.0 l/min/m² with minimal VAD flow. He remained on circulatory assist for an additional day to allow optimal time for ventricular recovery. VAD flows were weaned over a four hour period from 600 cc/minute to 150 cc/minute. During this period the ACT was incremental increased to 300

seconds. Echocardiography was employed at this time to further evaluate ventricular function. The ventricle continued to show improvement in contractility and the VAD cannulae were removed after 45 minutes. The echo, although much improved from post-operative data, was not significantly improved from pre-operative data, and still showed areas of hypokinesis and mild mitral insufficiency. After VAD removal the patient remained hemodynamically stable on the IABP. Heparin was stopped at this time and 24 hours later the IABP was removed. The patient initially maintained good cardiac output and perfusion pressure, without arrhythmias, for the first 24 hours after removal of the assist devices. He was maintained on mild to moderate vasopressor and anti-arrhythmic therapy. On the next day he began to have runs of ventricular tachycardia which eventually progressed to ventricular fibrillation and an unsuccessful resuscitation attempt. The autopsy showed that, altogether, 35-40% of the left ventricle was fibrotic or necrotic. The autopsy was otherwise unremarkable.

E.J. was supported on the VAD for 24 hours. The stunned myocardium showed steady recovery when evaluated as above. After his second treatment of hemofiltration, it was decided to remove the VAD due to continued bleeding/coagulopathy. He was transferred to the operating room for device removal and VAD flows were gradually decreased from 650 cc/minute to 300 cc/minute. The ACT was monitored closely during this period and remained between 170 and 200 seconds without heparin. The patient maintained adequate filling pressure and perfusion pressure when separated from the VAD, with continued pharmacologic support. E.J.'s condition remained critical post-VAD and was complicated by continued renal dysfunction requiring peritoneal dialysis, coagulopathy, infection, and unclear neurologic status. Over the next three weeks the patient showed some improvement with return of renal function, stabilization of the coagulopathy, extubation, and was weaned from vasoactive support except for renal dosage dopamine. However, the neurological prognosis remained uncertain after extensive evaluation. The parents elected for comfort care only at this point and the patient died of a cardio-respiratory arrest 24 days after VAD removal. The parents declined to have an autopsy performed.

Post VAD both circuits and cannulae were inspected for any evidence of thrombus formation. All surfaces appeared clean when visually examined.

Discussion

Mechanical ventricular assistance for post-cardiotomy cardiogenic shock will continue to be used in patients with potentially reversible ventricular dysfunction. The centrifugal pump has proven to be an efficient device for these procedures and we were pleased with the performance of our pediatric VAD system. The circuits were assembled with ease and speed, which helped decrease the time on CPB and provided immediate full support for the failing ventricle. We now have another safe and effective means of caring for our pediatric patients who fail separation from CPB. Although we will continue to use ECMO in those patients with small hearts, or who have complications

of biventricular or pulmonary failure, there are advantages to the centrifugal VAD. A much smaller surface area for blood to foreign material contact, which can mean less activation of platelets and other pro-coagulant factors, and less hemolysis. Less heparinization is necessary and less transfusions of blood products would be appreciated. Also, there is less set-up time, decreased cost, and fewer technical complications.

In future pediatric VAD's, despite the low flows, we would run our ACT at 150-180 seconds, and continue to utilize a heparin infusion. Continued close monitoring of renal and neurological function, along with bleeding and sepsis, since these parameters can greatly influence patient survival. Continuous or intermittent EEG monitoring will be used, as practiced with these two patients. Use of CAVH as needed, with access through the VAD circuit, is a great benefit in the infant patient. We will begin to follow fibrin degradation products to assess coagulation activation by the circuit, and continue to monitor hemolysis production by plasma hemoglobin determinations.

With the increasing incidence of pediatric heart transplantation and an increasing number of technically successful congenital repairs, there is a need for more alternatives to support pediatric patients in cardiogenic shock. We feel that the centrifugal pump VAD is a viable adjunct in the care of these patients. These circuits will continue to be used for temporary circulatory support and bridging to transplantation.

References

1. Ruzevich S, Kanter K, Pennington DG, et al. Long-term follow-up of survivors of postcardiotomy circulatory support. *ASAIO*. 1988; 11(2): 116-124.
2. Schoen F, Palmer D, Bernhard W, et al. Clinical temporary ventricular assist. *J Thorac Cardiovasc Surg*. 1986; 92: 1071-1081.
3. Pennington DG, Swartz M. Selection of circulatory support devices. Heart Failure: Current Concepts and Management. Weber KT, ed. Cardiology Clinics. W.B.Saunders; 1988: 5-12.
4. Kanter K, Pennington DG, Weber T, et al. Extracorporeal membrane oxygenation for postoperative cardiac support in children. *J Thorac Cardiovasc Surg*. 1987; 93: 27-35.
5. Rogers A, Trento A, Siewers R, et al. Extracorporeal membrane oxygenation for postcardiotomy cardiogenic shock in children. *Ann Thorac Surg*. 1989; 47: 903-906.
6. Roberts C, McCarthy P, Wildman D, et al. Left ventricular assist with a Bio-Medicus Pump on a four-month old infant with anomalous left coronary artery. *JECT*. 1989; 21(2): 73-74.
7. Drinkwater D, Laks H. Clinical experience with centrifugal pump ventricular support at UCLA Medical Center. *Trans Am Soc Artif Organs*. 1988; 34: 505-508.
8. Park S, Liebler G, Burkholder J, et al. Mechanical support of the failing heart. *Ann Thorac Surg*. 1986; 42(6): 627-631.
9. Kanter K, Swartz M, Pennington DG, et al. Renal failure in patients with ventricular assist devices. *ASAIO*. 1987; 10(3): 426-428.
10. Marcis M, Barcenas C, Parnis S, et al. Simplified method of hemofiltration in ventricular assist device patients. *Trans Am Soc Artif Intern Organs*. 1988; 34: 708-711.
11. Wright G. Blood cell trauma. Cardiopulmonary Bypass: Principles and Management. Taylor KM, ed. Baltimore: Williams and Wilkins; 1986: 249-265.
12. Oku T, Harasaki H, Smith W, et al. Hemolysis: a comparative study of four nonpulsatile pumps. *Trans Am Soc Artif Intern Organs*. 1988;

34: 500-504.

13. Gravlee GP, Hopkins MB. Blood plasma products. Effective Hemostasis in Cardiac Surgery. Ellison N, Jobes D, eds. Philadelphia: W.B. Saunders; 1988: 69-81.