Techniques Involved in a Ventricular-Assist Program Using a Centrifugal Pump in a Community-Based Practice

Dennis Mills, Thomas Golden, Roxanne Wolfe, Keith Johansen, and Connie Pipp
Cardiac Systems Inc.
Minneapolis, Minnesota

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Abstract

Our community-based perfusion practice provides bypass and other cardiac-related services at six hospitals. While the incidence of ventricular dysfunction of sufficient severity to require ventricular assist (VA) is small (0.55%), it is necessary to provide this service for all of our surgeons at all six hospitals. We describe our VA program and present our experience with seven patients aided during a 22-month period. Four had left ventricular assist, two required bi-ventricular support, and one received right ventricular assist, all by means of Centrimed centrifugal pumps. Three of these patients have survived between 3 and 13.5 months. Three patients were not anticoagulated. Duration of support ranged from 6.5 to 96.5 hours; mean flows ranged from 3 to 6 L/min.

Introduction

In the Minneapolis/St. Paul area, most perfusion groups are affiliated with surgeons rather than with hospitals. This means each perfusion group provides services at several Twin Cities hospitals and therefore participate in community-based, rather than hospital-based, practices. This report chronicles the evolution of a program to provide uniform ventricular assist (VA) services by a perfusion practice that involves six different hospitals.

We opted to utilize a centrifugal pump, rather than a pulsatile ventricle pump, because this type of pump could be put into routine use during cardiopulmonary bypass (CPB) making it always available for VA. The Centrimed® centrifugal pump was selected to accomplish this dual duty because:
1. Its pump head was small in size and low in volume yet high in output capacity;
2. Its motor drive unit is coupled to the console by a power cable, allowing it to be placed very close to the patient to keep the blood circuit short; and
3. Its control console may be mounted on a mast or other convenient bracket for prominent access at the bedside without usurping excessive space.

Materials and Methods

Patients

Seven patients required either left ventricular assist (LVA), right ventricular assist (RVA), or both during the 22 months between May 5, 1985 and February 26, 1987. All were post-surgical patients and represented 0.55% (7 of 1,274) of the patients perfused during this period.

Most of these patients were males (6 of 7); the average age was 65.6 years (range: 57 to 73 years). Table I summarizes the cardiac procedures each patient received and the factors that indicated the need for assist.

Apparatus

One or two Centrimed centrifugal pumps were used in each instance. The ventricular assist system consisted of one or two Centrimed pump consoles, a battery pack with interconnect cables, a console mounting pole, and a VA support bracket. This support bracket has a broad panel that fits under the mattress and an adjustable arm that is used for positioning one or two pumps and motor drives in close proximity to the patient’s chest, allowing...
Table 1

Surgical Procedures and Indications for VA

<table>
<thead>
<tr>
<th>Patient</th>
<th>Procedures</th>
<th>Indications</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Closure VSD.</td>
<td>Unable to wean from CPB</td>
</tr>
<tr>
<td></td>
<td>Resect LVA, CABG</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Closure VSD.</td>
<td>&quot;  &quot;</td>
</tr>
<tr>
<td></td>
<td>CABG, Mitral annuloplasty</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Closure VSD</td>
<td>&quot;  &quot;</td>
</tr>
<tr>
<td>4</td>
<td>CABG, MVR</td>
<td>&quot;  &quot;</td>
</tr>
<tr>
<td>5</td>
<td>PTCA-CABG</td>
<td>Emergency, Failed PTCA</td>
</tr>
<tr>
<td>6</td>
<td>Resect LVA</td>
<td>Unable to wean from CPB</td>
</tr>
<tr>
<td>7</td>
<td>CABG</td>
<td>Emergency, Destabilized 3 hrs postop</td>
</tr>
</tbody>
</table>

CABG = coronary artery bypass grafting; CPB = cardiopulmonary bypass; LVA = left ventricular aneurysm; MVR = mitral valve replacement; PTCA = percutaneous transluminal coronary angioplasty.

A very short patient-pump-patient circuit (Figures 1 and 2).

A standardized, sterilized ventricular assist pack, designed for readiness, comprised:
1 Centrimed Motor Drive;
1 Motor Drive bracket;
1 Centrimed disposable pump;
2 Flow probes, one for \( \frac{3}{8} \)" wall tubing and the other for \( \frac{1}{6} \)" wall tubing;

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drug therapy and IABP support. To adequately assess patient status and control VA, such parameters as left and/or right atrial pressure, central venous pressure, arterial pressure, and systemic blood flow are monitored.

The procedure involving the initiation of VA is outlined in Table 2. With post-operative cardiac patients, CPB is maintained if at all possible. Anticoagulation commensurate with an activated clotting time (ACT) of about 480 seconds is desirable during the period of VA initiation. The return cannula is inserted into the aorta (or pulmonary artery for RVA). If CPB is being continued, the existing aortic return cannula may be used.

To prepare the 32 Fr inflow cannula for use, one inch is trimmed from its proximal end (the flared connector) to provide a tighter, more secure connection. After elevating the left atrial pressure to 15 mmHg, the left atrium may be cannulated; preferred site is the left atrial root between the pulmonary artery and the aorta but cannulation may also be accomplished through the left superior pulmonary vein or the atrial appendage. For RVA, the inflow cannula is positioned in the right atrium via the atrial appendage; return flow to the pulmonary artery is via the same 8.0 mm aortic arch cannula used for aortic return.

The Centrimed pump’s outlet fitting is connected directly to the return cannula; there are no tubing segments or connectors used. A minimal circuit is facilitated by the support bracket which holds the pump near the heart. The pump is primed by slow back-filling from the saline-rinsed (CA 510) tubes are useful because they

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**Table 2**

<table>
<thead>
<tr>
<th>Institution of LVA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Insert return cannula (from pump) into aorta, clamp.</td>
</tr>
<tr>
<td>2. a. Raise left atrial pressure to 15 + mmHg;</td>
</tr>
<tr>
<td>b. Trim 1&quot; from flared proximal end of inflow cannula;</td>
</tr>
<tr>
<td>c. Insert cannula into the left atrium, fill, clamp.</td>
</tr>
<tr>
<td>3. a. Connect pump outflow directly to return cannula;</td>
</tr>
<tr>
<td>b. Slowly release aortic clamp to fill pump via retrograde flow then reclamp.</td>
</tr>
<tr>
<td>4. a. Fill inflow (left atrial) cannula with warm saline;</td>
</tr>
<tr>
<td>b. Drip saline, make a bubble-free connection of the cannula directly to the pump inlet.</td>
</tr>
<tr>
<td>5. Place tie bands on pump connections.</td>
</tr>
<tr>
<td>6. Couple sterilized drive motor to pump.</td>
</tr>
<tr>
<td>7. a. Remove the clamp on the inflow cannula, then</td>
</tr>
<tr>
<td>b. Bring pump speed to above 1500 RPM, and</td>
</tr>
<tr>
<td>c. Remove the clamp from the return cannula;</td>
</tr>
<tr>
<td>d. Increase pump RPM to maintain a left atrial pressure of 10 to 15 mmHg.</td>
</tr>
</tbody>
</table>

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d International Technidyne, Edison, NJ 08820

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At this point, the sterile pump drive motor may be coupled to the pump. Temporarily, until it is secured to the support bracket, the pump and drive may be held on a stack of towels by a surgical team member to prevent kinking of the cannulae. The appropriate sterilized flow probe is affixed to the return cannula at the first convenient opportunity.

First, the inlet cannula clamp is released; raising pump RPM prior to removing the inflow clamp may cause suction or cavitation that could bring gases out of solution. Pump speed is now brought up to about 1500 RPM, or the point at which flow just begins, before the clamp on the return cannula is released; this is necessary to prevent backflow through the pump. Pump speed is adjusted to the point at which a left atrial pressure of 10 to 15 mmHg is maintained. For RVA, pump speed is adjusted to hold a right atrial pressure below 20 mmHg.

**Anticoagulation**

The anticoagulation protocol is at the discretion of the surgeon. Our basic protocol is as follows:

1. Full heparinization to an ACT of about 480 seconds is continued during the initiation of VA.
2. When CPB is discontinued, heparin is neutralized with protamine sulfate in the usual manner (1:1); after hemostasis is evident at the surgical sites, usually 3 to 6 hours after protamine administration, heparin anticoagulation, if necessary, to an ACT 1.5 times control is instituted.
3. Maintenance heparinization in these patients is based on pump flow:
   a. No heparin is given if flows are consistently above 3 L/min;
   b. With flows between 2 and 3 L/min, an ACT of 180 to 200 sec is maintained via constant infusion;
   c. Full heparinization, to an ACT of 480 sec, is maintained with flows of 1.5 L/min or less; Presently, all patients with no contraindications to heparin are maintained at an ACT 1.5 times normal.
4. If no heparin is used during VA, heparinization to an ACT of about 480 seconds is accomplished just prior to weaning from VA.

ACT monitoring is achieved using a Hemochron® unit, Ordinarily, the CGA tubes, filled with Celite clay and powdered glass, are used for clot timing but, for more critical determinations at low heparin concentrations, the saline-rinsed (CA 510) tubes are useful because they
initiate clotting more slowly, allowing a broader clotting "window" to be observed. It is useful to make initial or "control" determinations with both kinds of tubes, then either test may be utilized.

Transportation
To move the patient with operational VA, the broad plate of the pump support bracket is placed under the mattress near the head of the bed or cart. The bracket for the pump drive motor is attached to the support bracket. A rack capable of holding one or two consoles (for biventricular assist [BVA]) and the battery pack, is attached to the foot of the bed. These units are then moved to this mounting site.

The pump must be carefully supported while the patient is being moved onto the bed; it is then mounted on its bracket. The ability of the pump to rotate in the motor drive allows the most advantageous positioning to be achieved; one is also able to raise or lower and swing the support bracket to which the pump bracket is mounted.

With the patient comfortably positioned on the bed and all pump, monitoring, and IV lines secured, the console's AC power cable is removed from its outlet; the attached battery pack will now supply the power to operate the pump (3 hours for a single pump, 1 hour for BVA). Once the patient is situated in the Intensive Care Unit, the power cable is again connected to house power and the battery pack is recharged.

Centrifugal pump heads are not changed electively after a prescribed time period. Changing pumps is not to be taken lightly because it is not without risk; the danger of infection and/or embolization are always present. It is our policy to change a pump only when necessary. In this series, only one pump was replaced, at 30 hours, because of a slight intermittent bearing squeal. Our technique for changing pumps is summarized in Table 3.

Table 3
Changing Pumps
1. Clamp outflow cannula, reduce pump speed to "0" and clamp inflow cannula.
2. Remove tie bands and disconnect inflow and return cannulae from pump.
3. a. Connect outflow of new pump to return cannula;
   b. Slowly release aortic clamp to fill pump via retrograde flow then reclamp.
4. a. Fill inflow (left atrial) cannula with warm saline;
   b. Drip saline, make a bubble-free connection of the cannula directly to the pump inlet.
5. Place tie bands on pump connections.
6. Re-institute VA.

Weaning From VA
Patient parameters conducive to weaning from VA are determined by the cardiologist. Ordinarily, flow is decreased by 0.5 L/min increments; weaning continues in stages over a period of 6 to 8 hours so long as the atrial pressures are between 10 and 20 mmHg. When both ventricles have been assisted, the patient is simultaneously weaned from both systems. Table 4 outlines the weaning procedure.

Results
The duration of VA ranged from 6.5 to 96.5 hours. Four patients required LVA, one had RVA and two underwent BVA. Average flows ranged from 3 to 5 L/min during LVA and 3.9 to 6 L/min during RVA. Of the seven patients, five were successfully weaned from VA. Three patients survived more than 30 days; of these, one died at 3 months after BVA. The others are well at 6 and 13.5 months post-assist. Details of VA are summarized in Table 5.

All patients had an IABP in place and were simultaneously "pulsed" during VA. Patient 1 expired after the return cannula dislodged after 6 hours of LVA. Right heart failure became apparent in Patient 2 after 64 hours of LVA and RVA was instituted. Twenty-four hours after LVA, IABP was successfully terminated on Patient 5; he expired 12 hours later.

Table 4
Weaning from Ventricular Assist
1. Weaning is not begun until hemodynamic parameters are satisfactory and the patient has been supported by VA for at least 24 hours.
2. Left ventricular ejection is tested with IABP off; the LV waveform is evaluated.
   NOTE: With a high pump flow rate, little blood will be available for LV pumping and the waveform will be weakened accordingly.
3. Weaning is accomplished by reducing pump output 500 ml/min every hour; weaning takes about 6 to 8 hours.
4. Heparinize patient to an ACT of 480 seconds.
5. Critical flow level is reached when peak LV ejection surpasses pump output, usually about 700 to 1,000 ml/min, and causes retrograde flow through the pump; the low flow alarm will sound and the console's flow read-out will fluctuate widely.
6. a. Clamp return and inflow cannulae;
   b. Turn off power to pump.
   c. An observation period of at least 1 to 2 hours precedes the removal of the VA cannulae.

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Table 5

Ventricular Assist Summary

<table>
<thead>
<tr>
<th>Pt.</th>
<th>Sex</th>
<th>Age (yrs)</th>
<th>BSA (m²)</th>
<th>Type of Assist</th>
<th>Duration (hrs)</th>
<th>Flow RPM</th>
<th>L/min</th>
<th>Anti-coagulation</th>
<th>ACT (sec)</th>
<th>MAP (mmHg)</th>
<th>RAP (mmHg)</th>
<th>LAP (mmHg)</th>
<th>Wean</th>
<th>Survive</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>62</td>
<td>1.82</td>
<td>LVA</td>
<td>6.5</td>
<td>1200</td>
<td>6.5</td>
<td>No</td>
<td>95</td>
<td>14</td>
<td>10</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>65</td>
<td>1.98</td>
<td>LVA</td>
<td>96.5</td>
<td>1500</td>
<td>5.0</td>
<td>Yes</td>
<td>177</td>
<td>90</td>
<td>9</td>
<td>13</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>RVA</td>
<td>1800</td>
<td>6.0</td>
<td></td>
<td></td>
<td></td>
<td>(122-296)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>70</td>
<td>1.96</td>
<td>LVA</td>
<td>64</td>
<td>2000</td>
<td>5.0</td>
<td>Yes</td>
<td>202</td>
<td>100</td>
<td>16</td>
<td>11</td>
<td>Yes</td>
<td>No</td>
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<td></td>
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<td></td>
<td>(132-272)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>73</td>
<td>1.78</td>
<td>RVA</td>
<td>30</td>
<td>1600</td>
<td>5.5</td>
<td>No</td>
<td>100</td>
<td>7</td>
<td>15</td>
<td>Yes</td>
<td>Yes</td>
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<td>(132-272)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>5</td>
<td>M</td>
<td>72</td>
<td>1.84</td>
<td>LVA</td>
<td>40</td>
<td>2000</td>
<td>4.5</td>
<td>No</td>
<td>110</td>
<td>13</td>
<td>13</td>
<td>Yes</td>
<td>No</td>
<td>36 hrs</td>
</tr>
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<td></td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>6</td>
<td>F</td>
<td>57</td>
<td>1.92</td>
<td>LVA</td>
<td>39</td>
<td>1300</td>
<td>3.0</td>
<td>Yes</td>
<td>204</td>
<td>130</td>
<td></td>
<td>Yes</td>
<td>Yes</td>
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<td></td>
<td>(160-251)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>60</td>
<td>—</td>
<td>LVA</td>
<td>80.5</td>
<td>1515</td>
<td>3.5</td>
<td>Yes</td>
<td>185</td>
<td>120</td>
<td>13</td>
<td>13</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(139-225)</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

MAP = mean arterial pressure; RAP = right atrial pressure; LAP = left atrial pressure.

One patient required hemodialysis; this was accomplished by splicing a connector with 2 luer-lok ports into the circuit at the pump outlet. Dialysis was performed with extreme caution for two reasons:

1. Fibrin Deposition: It was necessary to carefully aspirate blood from the luer ports to adequately clear any fibrin deposits at these sites, preventing their dislodgement and embolization.

2. Air Embolism: Luer ports should be positioned on the outflow, or pressure, side of the pump. Added to a left-heart support circuit, luer ports carry a more serious risk of air embolism. To dialyze patients receiving biventricular support, the RVA circuit is used because air emboli are better tolerated on the right side.

**Discussion**

Dembitsky supported six patients with right ventricular assistance (RVA). A constant heparin infusion kept the ACT at 170 to 200 seconds; infusion rates ranged from 100 to 1,000 U/hr. Four patients were successfully weaned; three of them expired between 2 and 28 days post-assist. The one long-term survivor had passed 2 years. Two patients required concomitant dialysis. Though the centrifugal pump has not been designed for long-term use, Dembitsky noted it served well in that capacity; he changed the pump head every 24 to 48 hours.

In the discussion following this paper, Hill noted:

1. RVA is useful in cases of high pulmonary resistance because the RV is a volume- rather than a pressure-dependent chamber.

2. "Unlike the left ventricle, the right ventricle can invariably recover." Death in these cases is usually due to secondary problems.

Experience with ventricular assist in 41 patients, with and without anticoagulation, was reported by Park. A centrifugal pump was used without a reservoir in all cases. Thirty-two received LVA only, two had RVA only, and seven were given BVA. Support without anticoagulation was effective if flow was maintained at 2 L/min/m² or more; with lower flows, minimal heparinization with ACTs near 150 seconds were adequate. More recent patients received 10,000 to 20,000 U heparin every 24 hours, and the pump was changed every 24 to 48 hours. Maximum duration of assist was 186 hours. Thirteen patients survived more than 30 days (31.7%); there were four late deaths.

Another cohort of 41 temporary VA recipients, distributed among four centers, was described by Schoen. Pierce-Donachy (14) or Thermedics (24) pumps were used for assisting most patients; 33 were given LVA only, five had RVA, and three required BVA. Mean duration of assist was 62 hours. There were 11 survivors (27%), 6 of whom were long-term. Nonsurvivors (35) died of myocardial necrosis (14), bleeding (9), cerebrovascular accident (3), infection (3), and other causes (6).

Hill and associates also reported using a Pierce-Donachy® and Novacor®.
achy prosthetic left ventricle as an apico-aortic bridge to heart transplantation. The only major complication directly attributable to the pump was paralysis of the left diaphragm which resolved and was thought to be due to irritation from the apical cannula. Advantages of using ventricular assist over a total artificial heart as a bridge were these:

1. Their implantation is a reversible step that buys extra time for diagnostic workup and consultation with the family;
2. Univentricular or biventricular support is possible without removing the heart; and
3. If the ventricle recovers, VA can be removed.

Pennock reported on their experience with circulatory support as a bridge to cardiac transplantation in 6 cases. They relied on such available assist measures as intra-aortic balloon pumps (IABP), ventricular assist devices (VAD), and pneumatic artificial hearts. Two patients had LVA for 11 and 21 days; both were well at 3 weeks and 8 months. Pennock noted that ventricular assist "forms a third line of support for patients whose left ventricular failure is not responsive to drugs or to the intra-aortic balloon." They use low molecular weight dextran to inhibit platelet function and had not as yet observed thromboembolic phenomena.

Conclusion

In conclusion, we believe our methodology and 43% survival rate with VA are comparable to those reported by others. We did not electively change pumps after 24 to 48 hours; one of our early cases involved 96.5 hours of VA with the same pump and with no sign of thrombogenesis.

To provide uniform VA capability at all hospitals we service:

1. The Centrimed pump is used as the arterial return pump for every CPB procedure; this insures that it is always available and everyone is familiar with its operation.
2. All components necessary for establishing VA, both sterile and unsterile, are a part of our basic "kit" that we can carry to every case, to every hospital.
3. The pump circuit has been reduced to a minimum length for simplicity, limited flow resistance, and low thrombogenicity.

References