

Case Report

Use of the Abiomed BVS 5000 for Temporary Right Ventricular Assist Following Implantation of the TCI HeartMate for Left Ventricular Assist: A Case Report

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ABSTRACT

Until recently, right ventricular failure following implantation of a left ventricular assist device carried a 100% mortality. Unsuccessful use of centrifugal pumps for right ventricular assist in this patient population has been attributed to bleeding complications. In this patient, an Abiomed BVS 5000 was used for 5 days until the right ventricular function recovered and the patient was successfully weaned. Following transplantation and removal of the TCI HeartMate device, the patient's right ventricular function again deteriorated and required 8 days of right heart assist with the Abiomed BVS 5000. The patient was again weaned and has fully recovered. The benefits of the Abiomed BVS 5000 for ventricular assist include the automatic control of pump flow and the minimal system pressures which reduce blood trauma and bleeding complications.

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INTRODUCTION

The use of a left ventricular assist as a bridge to transplantation is associated with a 52% incidence of right ventricular failure requiring inotropic or mechanical support (1). Review of bridge to transplant patients revealed a 43% incidence of isolated left ventricular failure and a 57% incidence of biventricular failure (2). In another series, 4 of 13 patients (30.7%) developed right heart failure following LVAD implantation (3).

It has been hypothesized that changes in the RV cross-sectional shape may be a contributing factor in the development of RV dysfunction and results from a shift in the septum from right to left (4). Improvement in right ventricular function occurs in some patients due to afterload reduction as measured by end-systolic elastance despite a decrease in systolic performance measured by fractional area change (5). Other clinical studies have confirmed this and attribute the improvement in RV function to reduced afterload and decreased circulating blood volume (6). Until recently, right ventricular failure following implantation of a left ventricular assist device carried a 100% mortality. Unsuccessful use of centrifugal pumps for right ventricular assist in this patient population has been attributed to bleeding complications (7).

TCI HEARTMATE

The TCI HeartMate^a is a pneumatically driven ventricular assist device which utilizes an external drive source (8). The device is implanted intra-abdominally with left ventricular apex and ascending aorta cannulation. Due to the textured surfaces of the device and the use of porcine xenograft valves, no long term anticoagulation is used. The TCI HeartMate has textured surfaces to permit early covering of the blood contact surfaces with a tightly adherent coagulum. These blood contacting surfaces include titanium textured with sintered titanium microspheres, an integrally textured polyurethane diaphragm, and a woven dacron graft. This results in the formation of a pseudoneointimal lining (9). When blood is exposed to the textured surface, fibrin and cellular components are trapped within its interstices. This converts to a dense biologic surface that covers all the surfaces including joints and seams. After the initial process, the blood is exposed to only a blood derived surface. This reduces the requirement for anticoagulation and no thromboembolic events were noted during the entire support period. The TCI HeartMate automatically controls the cardiac output by adjusting the rate to maintain a nearly full pump chamber (95%) out of a maximum volume of 83 ml. This allows for additional stroke volume due to an increased filling volume which then triggers an increase in heart rate. The emptying and filling volumes are monitored by the Hall-effect sensor inside the pump. These volumes are displayed on the console continuously during operation. In this manner, the device automatically adjusts the pump output based on the patient's own right heart output. By maintaining a near constant filling volume, the potential for thromboembolism is reduced by maximal washing action of the blood on the pump surfaces (10).

The TCI HeartMate is an excellent device for isolated left ventricular support and can be used without anticoagulation and constant monitoring. This is a long term device intended to provide total left ventricular output while the patient is recovering from a period of rapid cardiac deterioration. This recovery period is considered to be at least 30 days following the implantation of the assist device, and then the patient is again listed for transplantation. During this period of recovery, the patient can walk around the hospital while pushing the battery operated drive console. The longest successful bridge to transplantation with this device is 324 days (11).

ABIOMED BVS 5000

The Abiomed BVS 5000^b is a pneumatically driven external pulsatile ventricular assist device that can be used for either biventricular or univentricular support (12,13). A microprocessor-based drive console supplies power to the disposable pneumatically driven blood pump. Transthoracic cannulas are used to connect the external pump to the patient. These large bore cannulas (46 Fr) and 1/2" tubing permit asynchronous pulsatile flow while minimizing blood trauma. The blood pump consists of two polyurethane atrioventricular chambers that are separated by a tri-leaflet polyurethane valve. There is a second tri-leaflet polyurethane valve that prevents backflow into the ventricular chamber.

The atrial chamber fills by gravity without use of vacuum pressure. The console controls the beat rate and systolic/diastolic ratio based on filling of the ventricular chamber and the displacement of compressed air into the drive console. The pump output is therefore determined by venous return and adjusted by a computer algorithm to maintain a stroke volume of 82 ml. The same console can be used for both left and right heart assist and controls each side independently. This automatic control eliminates the need for continuous monitoring by a perfusionist.

There are three backup systems within the console to insure patient safety. First, a battery backup is provided in case of alternating-current power loss and provides one hour of operation when fully charged. Second, a hardware based backup system provides assist at a fixed beat rate should the microprocessor system fail. And third, a foot pump is incorporated into the console for manual operation of the device in the event of a complete console failure.

Priming of the system is easily accomplished by gravity filling the blood pump with electrolyte solution and recirculating the volume through a cardiomy reservoir to remove any air. The cannulas are then connected to the blood pump which is positioned less than 25 cm below the patient's right atrium. This blood pump location allows adequate venous return and minimizes afterload. The blood pump can then generate up to 5 L/min of blood flow depending on these two factors.

Anticoagulation is maintained with a continuous heparin

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- a Thermo Cardiosystems Inc., Woburn, MA 01888
b Abiomed, Danvers, MA 01923

infusion and is begun within 24 hours postoperatively. The ACT is kept in the range of 180-200 seconds. During weaning, the ACT is increased to 300 seconds when flow is reduced below 2 L/min to prevent thrombus formation within the device or cannulas.

CASE REPORT

The patient was a 57 year old male with ischemic cardiomyopathy and an ejection fraction of 10%. He suffered a myocardial infarction in 1980 and underwent surgery for coronary revascularization in 1981. He was listed for cardiac transplantation in October 1992, but was admitted to another hospital in April 1993 with progressive shortness of breath and unstable angina. He was transferred to Columbia-Presbyterian Medical Center after further cardiac decompensation (Table 1). His blood pressure was 80/60 mmHg with a mean pulmonary capillary wedge pressure of 48 mmHg. Pharmacological support at this time included dopamine, dobutamine, and amrinone. After meeting the inclusion criteria for the TCI HeartMate device, the pneumatic LVAD was implanted. The patient appeared to tolerate the procedure well and was stable after being weaned from CPB until approximately half the protamine was administered. At this point his blood pressure rapidly decreased and he became bradycardic and would not respond to volume administration. Manual compression of the ventricles was instituted. With this and ventricular pacing, an adequate output was once again achieved with the LVAD at a flow rate of 4 L/min.

The patient had a stormy postoperative course with significant bleeding resulting again in a decrease in blood pressure and urine output. At 4 hours post implant, the blood pressure was 58/28 mmHg with a PA pressure of 49/30 mmHg and a CVP of 21 mmHg. Flow from the LVAD device was 2.7 L/min. The cardiac index was 1.46 L/m²/min. At 11 hours after implantation, the patient was brought to the operating room in an emergent fashion. The chest was opened rapidly to remove clot and begin manual compression in order to increase flow across the lungs into the LVAD. Attempts at weaning the patient from manual compression resulted in temporary success, but was followed by eventual decrease in right ventricular function. A decision was made to employ an Abiomed BVS 5000 as a right ventricular assist device (RVAD). Following cannulation of the right atrium and the pulmonary artery, the Abiomed pump was connected and RVAD assist instituted (Figure 1). The Abiomed pump rapidly produced enough right side flow to increase the HeartMate blood flow on the left side to 4.5 L/min. The CVP decreased from 20 mmHg to 12 mmHg. Heparin was not administered during the first three days due to significant chest tube drainage (8103 ml for the first 48 hr). On the third day, the drainage from the chest tube decreased to 202 ml and heparin was begun. The ACT was then maintained between 180-200 seconds. Flow from the HeartMate ranged from 3.3-4.8 L/min. Blood pressure was 135/75 mmHg, with a PAD of 19 mmHg and a CVP of 7 mmHg. On the fifth day of right ventricular assist, the patient was weaned and the Abiomed

Table 1

Major interventions during hospital stay.

Day	1	Implant HeartMate LVAD
Day	2	Abiomed RVAD
Day	7	Abiomed RVAD removed
Day	9	Transferred out of ICU
Day	77	Replacement of HeartMate (candida sepsis)
Day	154	Cardiac transplantation followed by Abiomed RVAD
Day	162	Abiomed RVAD removed
Day	240	Hospital discharge

Figure 1

Diagram of right ventricular assist with Abiomed BVS 5000 and left ventricular assist with TCI HeartMate.

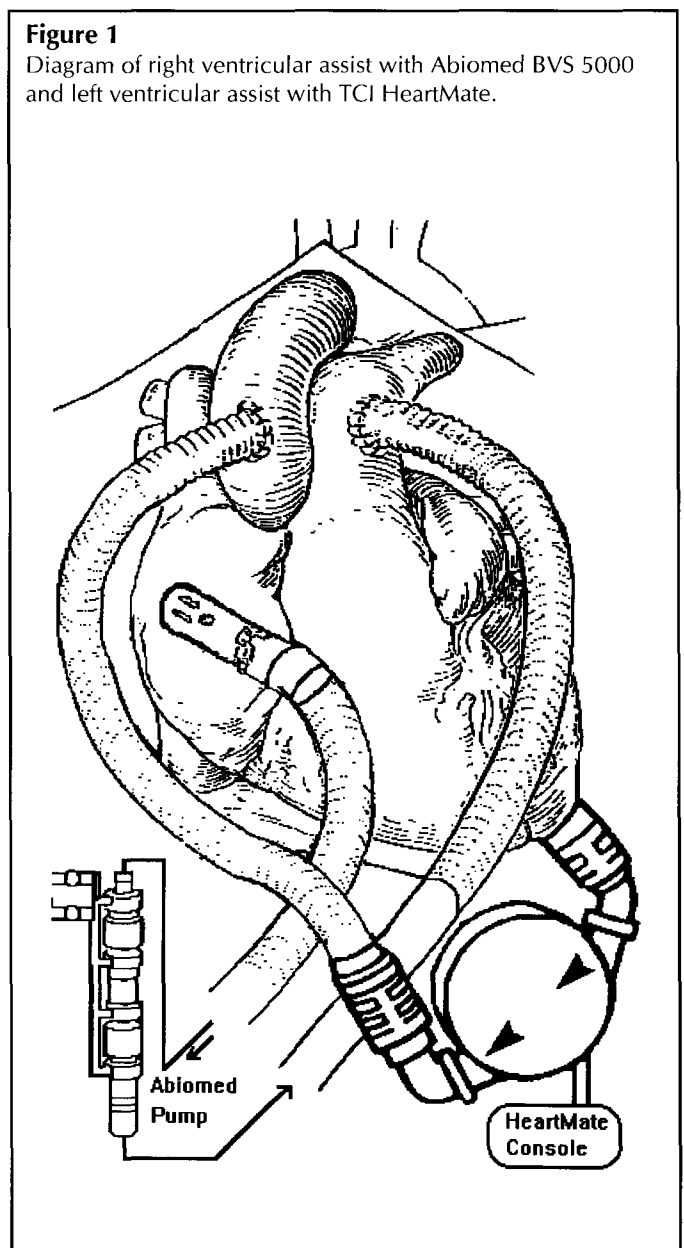
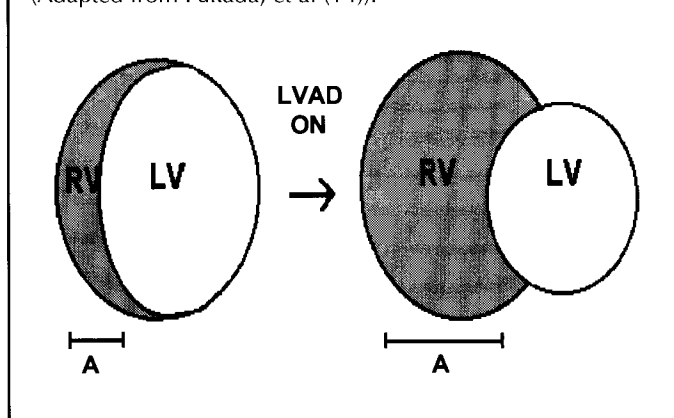


Figure 2

Effect of LVAD pumping on right ventricular shape. Unloading of the LV by the LVAD results in a decrease in LV volume and an increase in RV volume. This causes a septal shift which can be measured by the increased distance from the septum to the RV wall (A) during diastole. (Adapted from Fukada, et al (14)).



cannulas were removed. Thermo dilution cardiac output was 8.2 L/min on day 9. The chest tubes were removed on day 12 and the patient was transferred out of the ICU on day 13.

On day 77 of HeartMate support, the patient underwent surgery for replacement of the HeartMate device due to a persistent fungal sepsis with candida parasibsis. Femoral-femoral bypass was used with a 19 Fr arterial cannula in the femoral artery and a 29 Fr venous cannula in the femoral vein, which was advanced to the right atrium. The HeartMate pump and the dacron outflow graft were replaced and the patient was weaned from bypass on low dose dobutamine with a cardiac output of 4 L/min.

On day 154, a suitable donor was found for cardiac transplantation. LVAD flow was 6 L/min with a blood pressure of 169/32 mmHg. Pulmonary artery pressure was 32/12 mmHg and CVP was 12 mmHg. At operation there were dense adhesions throughout the chest and abdomen. The left and right lungs were adherent to the chest wall. The LVAD device in the abdomen was encircled in the abdominal cavity and the outflow graft was dissected free from the underlying right atrium. Cardiopulmonary bypass was then instituted with standard aortic and bicaval cannulation. The heart was dissected free and the donor heart was implanted during which intermittent doses of cold blood cardioplegia were given. A single dose (450 ml) of warm glutamate-aspartate cardioplegia was administered just prior to aortic unclamping. Total ischemic time was 2 hours and 58 minutes. The patient was then weaned from bypass, however, there was significant bleeding. Multiple units of coagulation factors were transfused. CPB needed to be emergently reinstated in order to stabilize the patient. The patient was again weaned from bypass and protamine given, however right heart failure was developing and an Abiomed device was again inserted. Bleeding was still significant and inotropic support included high dose norepineph-

rine and epinephrine. Bypass time was 5 hours and 21 minutes after which transfusion from the autotransfusion machine through the bypass circuit and into a luer lock port on the venous side of the Abiomed continued for 8 more hours. The chest was packed and covered with a clear plastic drape. The patient was then transferred to the recovery room with a poor prognosis due to the copious amounts of chest tube drainage. After 3 days of support the bleeding began to decrease. During this time no heparin anticoagulation was used due to the massive bleeding diathesis that the patient had suffered. After 8 days of Abiomed support, the device was again removed and for the first time in 6 months, the patient was without a ventricular assist device. The patient remained in the hospital for an additional 3 months until he was discharged.

DISCUSSION

The effects of LV assist on right ventricular function as assessed by transesophageal echocardiography (TEE) have been confirmed in several animal models (Figure 2) (14). Tantalum markers were used in the left and right ventricular walls for measurement of biventricular volumes and geometry after the implantation of an LVAD in canines. Significant septal shift occurred impairing RV contractility; however, myocardial efficiency and power output were maintained through the decrease in RV afterload and increase in RV preload (15). In the normal intact porcine heart, the effective contractility of the right ventricle was not altered by significant LV pressure unloading produced with an LVAD (16). Using a canine model of left ventricular failure caused by global ischemia, global ischemia diminished LV and RV function, and this effect was accentuated in the RV after LVAD support. In controls, the RV function was not affected by LVAD support, but after ischemia, LVAD support alone was inadequate (17). Using an artificial heart model (18), these authors simulated a failing right ventricle while maintaining left ventricular output. In the LVAD simulation, cardiac output increased and right atrial pressure decreased, with adaptive changes in pulmonary artery and left atrial pressures. These results indicate that an LVAD can increase right ventricular volume work by decreasing right ventricular pressure work, and that right ventricular failure is not worsened during LVAD assist. A computer model of the heart and circulation was used to evaluate ventricular interactions (19). This model predicts that left ventricular pressure unloading with an LVAD results in impairment of RV systolic function but improved RV function during diastole. The net result is a negligible overall effect due to competition between these two interactions.

The physiologic changes in RV function during LV assist have been simulated in models with normal pulmonary vascular resistance. Without the afterload reduction that is necessary to offset the systolic impairment caused by septal shift, the balance favors RV failure. Patients with ischemic cardiomyopathy and pulmonary hypertension are at highest risk for RV failure based on these studies. The use of a temporary right ventricular assist

device in these patients can salvage this patient population who cannot tolerate the implantation of an isolated left ventricular assist device. Wider application of LVADs to patients with reversible pulmonary hypertension is now possible due to the availability of a safe and reliable device for temporary right heart assist.

REFERENCES

1. Kawai A, Kormos RL, Mandarino WA, et al. Differential regional function of the right ventricle during the use of a left ventricular assist device. *Trans Am Soc Artif Intern Organs*. 1992;38:M676-8.
2. Swartz MT, Pennington DG, Ruzevich SA, et al. The incidence of isolated left ventricular failure in bridge-to-transplant candidates. *Trans Am Soc Artif Intern Organs*. 1989;35:730-3
3. Sato N, Mohri H, Miura M, et al. Right ventricular failure during clinical use of left ventricular assist device. *Trans Am Soc Artif Intern Organs*. 1989;35:550-2.
4. Mandarino WA, Morita S, Kormos RL, et al. Quantitation of right ventricular shape changes after left ventricular assist device implantation. *Trans Am Soc Artif Intern Organs*. 1992;38:M228-31.
5. Morita S, Kormos RL, Mandarino WA, et al. Right ventricular/arterial coupling in the patient with left ventricular assistance. *Circulation*. 1992;86:II316-25.
6. Bennink GB, Noda H, Duncan JM, et al. Clinical evaluation of right ventricular function in patients with left ventricular assist device (LVAD). *Int J Artif Organs* 1992;15:109-13.
7. Frasier OH, Rose EA, MacManus Q, et al. Multicenter clinical evaluation of the HeartMate 1000IP left ventricular assist device. *Ann Thorac Surg*. 1992;53:1080-90.
8. Poirier VL, Sherman CW, Clay WC, et al. An ambulatory, intermediate term left ventricular assist device. *Trans Am Soc Artif Intern Organs*. 1989;35:452-455.
9. Dasse KA, Chipman SD, Sherman CN, et al: Clinical experience with textured blood contacting surfaces in ventricular assist devices. *Trans Am Soc Artif Intern Organs*. 1987;38:418-424.
10. McGee MG, Parnis SM, Nakatani T, et al. Extended clinical support with an implantable left ventricular assist device. *Trans Am Soc Artif Intern Organs*. 1989;35:614-616.
11. Sistino J, Mongero L, Jeevanandam V, et al. Case Report: Left ventricular assist for 324 days followed by cardiac transplantation. *Proc Am Acad Cardiovasc Perf*. 1992;13:180-183.
12. Dixon J, Farris C. The Abiomed BVS 5000 System. *AACN Clin Issues Crit Care Nurs*. 1991;2:552-561.
13. Kaan G, Noyez L, Vincent J et. al. Management of the postcardiotomy cardiogenic shock with a new pulsatile ventricular assist device. *Trans Am Soc Artif Intern Organs*. 1991;37:559-563.
14. Fukuda S, Takano H, Taenaka Y, et al. Chronic effect of left ventricular assist pumping on right ventricular function. *Trans Am Soc Artif Intern Organs*. 1988; 34:712-715.
15. Moon MR, Castro LJ, DeAnda A, et al. Right ventricular dynamics during left ventricular assistance in closed-chest dogs. *Ann Thorac Surg*. 1993;56:54-66.
16. Chow E, Brown CD, Farrar DJ. Effects of left ventricular pressure unloading during LVAD support on right ventricular contractility. *Trans Am Soc Artif Intern Organs*. 1992;38:M473-6.
17. Shuman TA, Palazzo RS, Jaquiss RB, et al. A model of right ventricular failure after global myocardial ischemia and mechanical left ventricular support. *Trans Am Soc Artif Intern Organs*. 1991;37:M212-3.
18. Kinoshita M, Long JW Jr, Pantalos G, et al. Hemodynamic influence of LVAD on right ventricular failure. *Trans Am Soc Artif Intern Organs*. 1990;36:M538-41.
19. Woodard JC, Farrar DJ, Chow E, Santamore WP, Burkhoff D, Hill JD. Computer model of ventricular interaction during left ventricular circulatory support. *Trans Am Soc Artif Intern Organs*. 1989;35:439-41.