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Successful use of the centrifugal ventricular assist device for postcardiotomy cardiogenic shock.

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Abstract

A centrifugal pump was successfully used as a left ventricular assist device (LVAD) in a 54-year-old female who developed cardiogenic shock following open heart surgery. Cardiac index prior to the LVAD support was 1.4 l/min/m2 and increased to 3.0 l/min/m2 at removal of the device, which assisted for 88h. She resumed her daily activity 10 months after the operation and is in New York Heart Association functional class I.

KEYWORDS: centrifugal pump, left ventricular assist device, cardiogenic shock

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A centrifugal pump was successfully used as a left ventricular assist device (LVAD) in a 54-year-old female who developed cardiogenic shock following open heart surgery. Cardiac index prior to the LVAD support was 1.4 ℓ/min/m^2 and increased to 3.0 ℓ/min/m^2 at removal of the device, which assisted for 88 h. She resumed her daily activity 10 months after the operation and is in New York Heart Association functional class I.

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Profound refractory heart failure remains one of the major cause of death in high risk patients after cardiac surgery. Conventional medical therapy and intra-aortic balloon pump (IABP) provide an adequate circulatory support and survival in approximately 70 % of patients with postcardiotomy cardiogenic shock (1). However, if failed, a more aggressive form of circulatory support like a ventricular assist device (VAD) is necessary to maintain systemic and/or pulmonary circulation. The VADs have most commonly been employed in those patients who could not be weaned from cardiopulmonary bypass (2, 3).

We report herein, a case who developed cardiogenic shock following cardiac surgery and successfully treated with a centrifugal VAD.

Materials and Methods

A 54-year-old female underwent aortic valve replacement for aortic stenosis in April 1990 at the Okayama Red Cross Hospital. Prior to surgery, the trans-valve gradient was at 92 mmHg, although left ventricular ejection fraction was normal (74 %).

For the myocardial protection, crystalloid cardioplegic solution (St. Thomas) of 1000 ml was infused at first into the aortic root and topical cooling with iced slush was added. After aortotomy, the cardioplegic solution was infused to the coronary artery (left: 300 ml, right: 200 ml) every 30 min during the period of aortic clamping. The aortic cross-clamp time was 139 min. However, massive bleeding from the aorta needed another clamp of 62 min. The patient was weaned from cardiopulmonary bypass (CPB) with IABP and maximum inotropic supports 375 min after the initiation of bypass. Since the blood pressure had dropped to 70 mmHg by sternal closure, only the skin was closed. Four hours after the operation, the cardiac index decreased to 0.96 ℓ/min/m^2 despite the blood trasfusion, while blood pressure remained between 70 and 80 mmHg with IABP and a

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right atrial pressure of 16 mmHg. Her hemodynamic state met a predetermined set of shock criteria derived from the study of Norman *et al.*: cardiac index less than 2.0 ℓ /min/m^2 and systolic blood pressure less than 90 mmHg (4). Since urine output of less than 10 ml per hour and severe hypotension continued for 4 h, she was again taken to the operating room 8 h after the first operation, and the left ventricular assist device (LVAD) was implanted.

The left heart bypass circuit consisted of a centrifugal pump (Bio-Pump, Biomedicus, Inc., Minneapolis, MN, USA), outflow and inflow cannulae, and Tygon tube (Morton, Inc., Akron, OH, USA). The centrifugal pump, a vortex pump constructed of valveless rotator cones made from acrylics, was magnetically coupled to an external drive motor to generate nonpulsatile flow in proportion to the motor speed. The outflow cannula (the National Cardiovascular Center, Osaka, Japan) had a highly smooth blood-contacting surface coated with segmented polyurethane and a Dacron graft formed its end which allowed a standard anastomosis to the aorta. The inflow cannula was a standard USCI venous cannula (32F) (William Harvey, Inc., Santa Ana, CA, USA).

A side-biting clamp was placed on the ascending aorta at the site of the aortotomy, and the Dacron graft of the outflow cannula was anastomosed end-to-side. The inflow cannula was then inserted to the left atrium through a Dacron cuff which was sutured to the dome of the left atrium. The centrifugal pump primed with saline solution was connected to each cannula by Tygon tubing and actuated electrically. When connections were completed, the CPB was discontinued with a peak arterial balloon-assisted pressure of 100 mmHg. The set-up of the mechanical circulatory assist in the patient is illustrated in Fig. 1.

Our weaning method from the centrifugal VAD was as follows. When systolic arterial pressure had been stabilized at greater than 100 mmHg for 24 h, the pump flow was decreased to a minimum of 1.0 ℓ /min. The dose of cathecolamine infusion was reduced as much as possible. When pump-on/pump-off data obtained during planned interruption of the VAD perfusion of up to one minute were satisfactory in conjunction with hemodynamic stability at a minimum VAD flow for at least 24 h, the VAD support was terminated.

Results

The postoperative course is depicted in Fig. 2.

The initial cardiac index was only 1.4 ℓ /min/m^2 with the LVAD, IABP and maximum inotropic support. This low output continued for 24 h, then the cardiac index started to increase. On the 3rd postoperative day (POD) peak arterial balloon-assisted pressure increased to 110 mmHg, and right atrial pressure to 11 mmHg with a cardiac index of 3.2 ℓ /min/m^2 and weaning from the LVAD was initiated. Dopamine and dobutamine were also tapered and the IABP was decreased to 1:2 ratio. The arterial pressure and the right atrial pressure remained stable with a cardiac index of 3.0 ℓ /min/m^2 with the LVAD off for 1 min. On the 5th POD the patient was taken back to the operating room and the LVAD was detached by removing the inflow cannula from the left atrium, oversewing the atrial cuff, followed by transection and oversewing of the graft on the ascending aorta. The total duration of the LVAD support was for 88 h. The pump head was changed once 48 h after initiation of ventricular support. Although anticoagulation was not used even during weaning, no thrombi
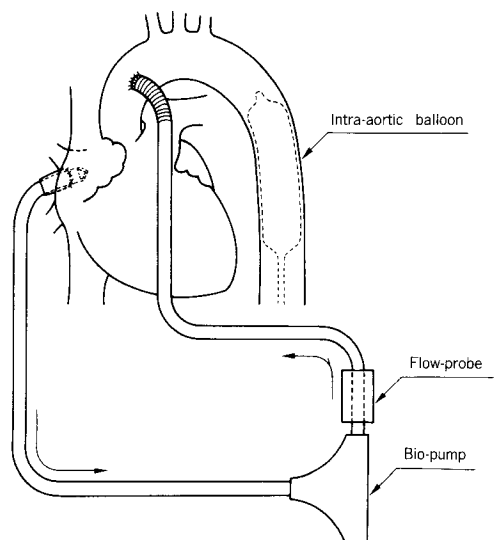

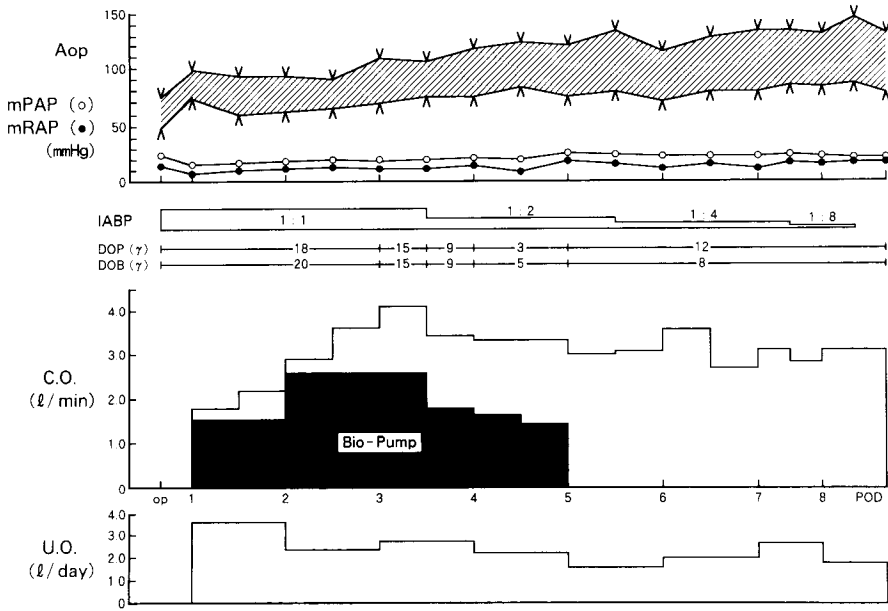Fig. 1 The set-up of the left ventricular support system using the centrifugal pump and intra-aortic balloon.

Fig. 2 Postoperative course.
Aop: aortic pressure, mPAP: mean pulmonary artery pressure, mRAP: mean right atrial pressure, IABP: intra-aortic balloon pump, DOP: dopamine, DOB: dobutamine, C.O.: cardiac output, U.O.: urine output.
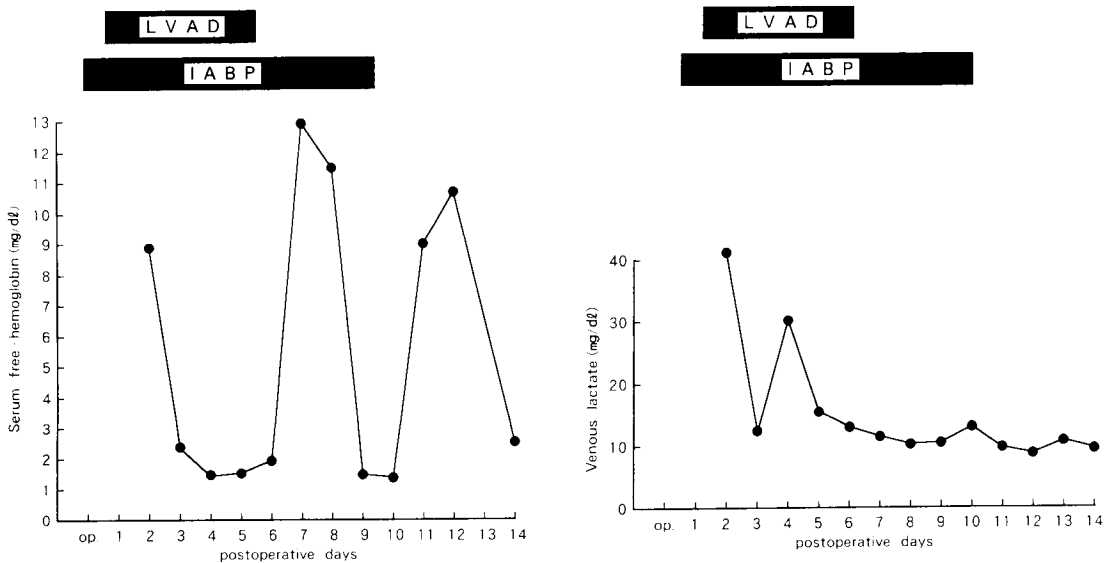

Fig. 3 Changes in serum free hemoglobin and venous lactate.
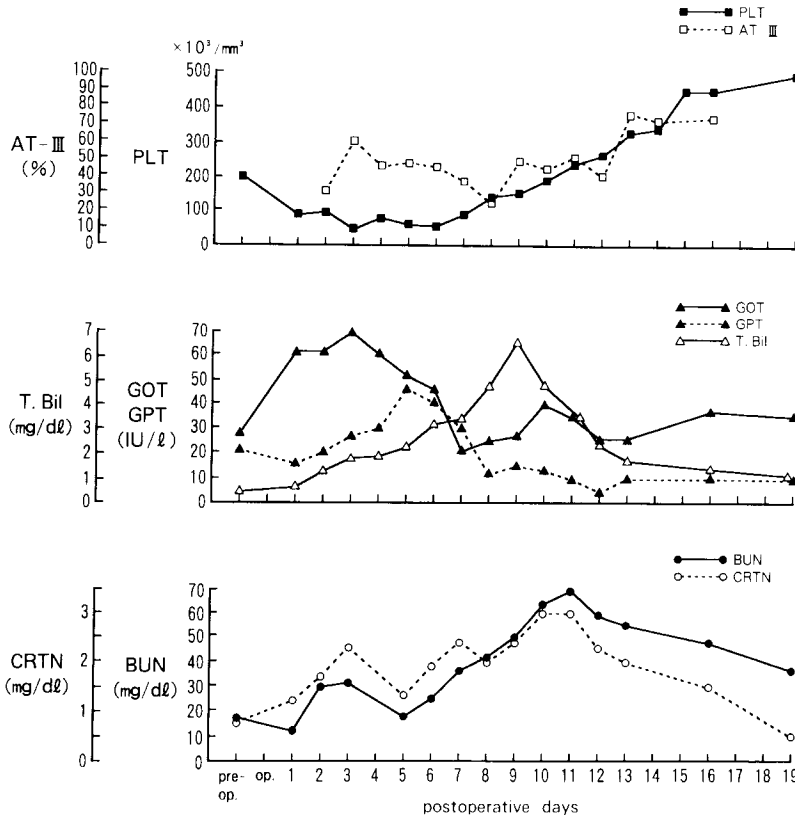LVAD: left ventricular assist device, IABP: intra-aortic balloon pump.

Fig. 4   Changes in coagulation factors, hepatic and renal functions.
AT-III: antithrombin-III, PLT: platelet, T.Bil: total bilirubin, GOT: glutamic oxaloacetic transaminase, GPT: glutamic pyruvic transaminase, CRTN: creatinine, BUN: blood urea nitrogen.

were visible on the blood contacting surface in the two pumps. After the weaning from LVAD, a brief assist of the IABP was still necessary, but it was tapered off and removed on the 8th POD.

Fig. 3 shows the postoperative changes in serum free hemoglobin and venous lactate levels. During the left heart bypass serum free hemoglobin decreased to 1.4 mg/dl, suggesting that hemolysis due to the centrifugal pump did not occur. Despite the use of the LVAD, venous lactate level was higher than 12.5 mg/dl. However, it was maintained at around 10 mg/dl thereafter.

The postoperative changes of coagulation factors, hepatic and renal functions are represented in Fig. 4. Marked reduction of antithrombin III and platelet count occurred in the first 7 PODs. Despite the increase of total bilirubin to 6.6 mg/dl, glutamic oxaloacetic transaminase and glutamic pyrubic transaminase were almost within normal range. Serum creatinine and blood urea nitrogen increased after weaning from the LVAD up to 3.0 mg/dl and 68.8 mg/dl, and both values returned to normals on the 19th POD without requiring hemodialysis.

The patient was discharged from the hospital on the 93rd POD, and was in New York Heart Association functional class I at 10 months after

the operation.

Discussion

The main purpose of the temporary ventricular assist is to unload the ventricle and to decrease myocardial oxygen consumption providing opportunity for reversible myocardial injury to recover. The role of VAD has expanded as a bridge to cardiac transplantation (5–7), and as a support device for patients with cardiogenic shock following acute myocardial infarction (8). However, postoperative cardiogenic shock still remains the predominant indication for their use. For the last decade, a variety of designs such as diaphragm type, sac type, pusher-plate type and centrifugal pumps have been developed for ventricular assistance, and there have been an increasing number of reports of the successful use of these devices (9, 10). The nonpulsatile centrifugal pump was used in our patient.

Although the roller pump has been used as a nonpulsatile VAD in patients with postcardiotomy shock by Rose et al., the duration of support was for up to 96 h with maximum flow rate of less than 3000 ml/min (11). The adverse characteristics of the roller pump such as hemolysis and destruction of blood elements have limited their prolonged use. On the other hand, Golding et al. reported nonpulsatile ventricular assist using centrifugal pump in combination with cardiac transplantation for 31 days with low incidence of hemolysis (12).

In this study significant hemolysis did not occur during the VAD support for 88 h. However, transient increases of free hemoglobin were observed after weaning from the VAD. There was a possibility that these hemolysis were caused by massive blood transfusion. Despite an appropriate right atrial pressure, venous lactate level remained high during the VAD support. Therefore shortage of circulatory blood volume and a concomitant right ventricular failure were suspected. The reduction of coagulation factors for the first 7 PODs might be caused by consumption in the CPB or the left heart bypass circuits where blood contacting surfaces were not coated with biomaterials.

In comparison with the pulsatile assist device, the centrifugal nonpulsatile pump is less complicated, less expensive, simple to insert, and easy to manage. On the other hand, one of the most commonly cited disadvantages is the absence of pulsation in flow. In our case, the system provided pulsatility by employing IABP, although the question of the effect of pulsatile flow on renal function has not been resolved (12, 14).

With IABP and maximum inotropic support, a need for the VAD in patients on the CPB can be predicted by the change of the CPB flow ratio required. It is more difficult to decide the necessity of VAD support in patients who develop cardiogenic shock after weaning from the CPB, as happened in our patient for whom the VAD support was initiated 6 h after the patient entered a state of shock. Pennington et al. suggested that success of the VAD use depended upon proper patient selection, earlier application of devices, and complete postoperative hemostasis (2). We believe that our success in the use of the centrifugal VAD is attributed to early recognition of a need for the device, rapid insertion techniques, and appropriate timing of weaning and removal.

References

1. McEnany MT, Kay HR, Buckley MJ, Daggett WM, Erdmann AJ, Mundth ED, Rao RS, deToeuf J and Austen WG: Clinical experience with intraaortic balloon pump support in 728 patients. Circulation (1978) 58 (Suppl I), I -124–132.
2. Pennington DG, McBride LR, Swartz MT, Kanter KR, Kaiser GC, Barner HB, Miller LW, Naunheim KS, Fiore AC and Willman VL: Use of the Pierce-Donachy ventricular assist device in patients with cardiogenic shock after cardiac operations. Ann Thorac Surg (1989) 47, 130–135.
3. Joseph LD, Kiser JC, Eales F, King RM, Toninato CJ and Hansen J: Experience with the Sarns centrifugal pump as a ventricular assist device. Trans Am Soc Artif Intern

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Organs (1990) **36**, M619–M623.

4. Norman JC, Cooley DA, Igo SR, Hibbs CW, Johnson MD, Bennett JG, Fuqua JM, Trono R and Edmonds CH: Prognostic indices for survival during postcardiotomy intra-aortic balloon pumping. J Thorac Cardiovasc Surg (1977) **74**, 709–720.

5. Starnes VA, Oyer PE, Portner PM, Ramasamy N, Miller PJ, Stinson EB, Baldwin JC, Ream AK, Wyner J and Shumway NE: Isolated left ventricular assist as bridge to cardiac transplantation. J Thorac Cardiovasc Surg (1988) **96**, 62–71.

6. Farrar DJ, Lawson JH, Litwak P and Cederwall G: Thoratec VAD system as a bridge to heart transplantation. J Heart Transplant (1990) **9**, 415–423.

7. Schiessler A, Warnecke H, Friedel N, Hennig E and Hetzer R: Clinical use of the Berlin biventricular assist device as a bridge to transplantation. Trans Am Soc Artif Intern Organs (1990) **36**, M706–M708.

8. Pae WE Jr and Pierce WS: Temporary left ventricular assistance in acute myocardial infarction and cardiogenic shock. Chest (1981) **79**, 692–695.

9. Takano H, Taenaka Y, Noda H, Kinoshita M, Yagura A, Tatsumi E, Seki J, Sasaki E, Umezu M, Nakatani T, Kyo S, Omoto R, Akutsu T and Manabe H: Multiinstitutional studies of the National Cardiovascular Center ventricular assist system: Use in 92 patients. Trans Am Soc Artif Intern Organs (1989) **35**, 541–544.

10. Sato N, Mohri H, Sezai Y, Koyanagi H, Fujimasa I, Imachi K, Atsumi K, Nitta S and Miura M: Multiinstitutional evaluation of the Tokyo University ventricular assist system. Trans Am Soc Artif Intern Organs (1990) **36**, M708–M711.

11. Rose DM, Connolly M, Cunningham JN and Spencer FC: Technique and results with a roller pump left and right heart assist device. Ann Thorac Surg (1989) **47**, 124–129.

12. Golding LA, Stewart RW, Sinkewich M, Smith W and Cosgrove D: Nonpulsatile ventricular assist bridging to transplantation. Trans Am Soc Artif Intern Organs (1988) **34**, 476–479.

13. Jacobs LA, Klopp EH, Seamone W, Topaz SR and Gott VL: Improved organ function during cardiac bypass with a roller rump modified to deliver pulsatile flow. J Thorac Cardiovasc Surg (1969) **58**, 703–720.

14. Sink JD, Chitwood Jr. WR, Hill RC and Wechsler AS: Comparison of nonpulsatile and pulsatile extracorporeal circulation on renal cortial blood flow. Ann Thorac Surg (1980) **29**, 57–62.