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Abstract

Over the last three years, we have used ventricular assist devices (VAD) in 7 patients. Of these 7, four patients with combined aortic and mitral valvular disease underwent double valve replacement; one patient with annuloaortic ectasia underwent a Cabrol's operation; another had aortic valve replacement; the last patient had triple coronary artery bypass grafts. The only patient who could be weaned from CPB developed cardiogenic shock after the operation. LVADs supported 6 patients for 4 to 8 days and a BVAD supported one patient for 9 days. All patients survived the weaning procedure. Three were discharged from the hospital and survived 7 to 21 months. The 4 other patients died of multiple organ failure. Three of these four suffered from both renal failure and infection, while one patient had arrhythmia and died of ileus. These data suggest that renal failure and major infection can be serious detrimental complications to VAD support.

KEYWORDS: ventricular assist device, postcardiotomy shock, multiorgan failure

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Use of Ventricular Assist Devices in Patients with Postcardiotomy Shock

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Over the last three years, we have used ventricular assist devices (VAD) in 7 patients. Of these 7, four patients with combined aortic and mitral valvular disease underwent double valve replacement; one patient with annuloaortic ectasia underwent a Cabrol's operation; another had aortic valve replacement; the last patient had triple coronary artery bypass grafts. The only patient who could be weaned from CPB developed cardiogenic shock after the operation. LVADs supported 6 patients for 4 to 8 days and a BVAD supported one patient for 9 days. All patients survived the weaning procedure. Three were discharged from the hospital and survived 7 to 21 months. The 4 other patients died of multiple organ failure. Three of these four suffered from both renal failure and infection, while one patient had arrhythmia and died of ileus. These data suggest that renal failure and major infection can be serious detrimental complications to VAD support.

Key words : ventricular assist device, postcardiotomy shock, multiorgan failure

Certain classes of heart disease patients are candidates for ventricular assist devices (VADs). Usually, they have extremely bad ventricles and are unable to be weaned from cardiopulmonary bypass or likely to develop cardiogenic shock after cardiac operations despite optimal preload levels, maximum inotropic support and the use of an intraaortic balloon pump (IABP). In 1965, Spencer first reported a successful application of left heart bypass using a roller pump to a patient with postcardiotomy shock (1). DeBakey successfully used a left ventricular assist device to support a patient after cardiac surgery (2). Since then, there have been a number of reports of

increasing success with the use of these VADs (3-6). Recently, the concept of temporary mechanical circulatory support as a bridge to cardiac transplantation was introduced and there has been increasing experience with both LVADs and the total artificial heart (7). A variety of devices for ventricular assistance have been employed for this, including the roller pump, centrifugal pump, sac-type or diaphragm-type pneumatic pumps, and pusher-plate type electrical powered devices.

This report summarizes our experience with the use of ventricular assist devices in patients with cardiogenic shock following cardiac operations over the last three years.

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Materials and Methods

Three types of blood pumps were used in this clinical study. The first was an air-driven, diaphragm-type pump with an effective stroke volume of 70 ml and a maximum output of 7.0 l/min (8). The second was also air-driven, but had a pusher-plate instead of diaphragm, a stroke volume of 60 ml, a hall effect position sensor which detects the displacement of the pusher plate and estimates pump flow (9). The third was a Bio-pump (Biomedicus Inc, Eden Prairie, Minn, USA), a commercially available centrifugal blood pump which provides nonpulsatile flow (10).

The VAD was inserted during cardiopulmonary bypass. All patients underwent left atrial cannulation by placement of the cannulas through cuffs sutured to the appendage, the dome of the left atrium or through the atrial septum. The right-sided VAD inflow cannule was placed into the right atrium. In all cases, the outflow cannulas were sutured to the main pulmonary artery or ascending aorta. The pneumatic pump was operated in the non-synchronous fixed rate mode to achieve complete filling and ejection. In all cases, anticoagulant was not used even when the weaning process began. When a Bio-pump was used, the pump head was changed every day.

Seven patients, aged 22 to 59 years (mean 47 years), were treated. The diagnoses and operations performed are listed in Table 1. Five patients had valvular heart disease, one annuloaortic ectasia, and another ischemic heart disease. Four patients underwent double valve replacement which was the third operation for two

patients and a second time for one patient. Another patient underwent Cabrol's operation for annuloaortic ectasia, one patient had aortic valve replacement, and one had triple coronary artery bypass grafting. The cardiopulmonary bypass times ranged from 243 to 422 min (mean 379 min), and the aortic clamp times ranged from 178 to 313 min (mean 231 min). All patients were in New York Heart Association (NYHA) functional class IV.

Results

The results of VAD support are noted in Table 2. The devices were used in 6 patients who could not be weaned from cardiopulmonary bypass and in one who developed cardiogenic shock after surgery. Six recipients received left ventricular assist devices (LVAD) and one received a biventricular assist device (BVAD). The diaphragm type pump was used as an LVAD in 3 patients while the Bio-pump was used as an LVAD in 3 patients. In the BVAD case, the Bio-pump was used on the left and the diaphragm-type on the right. In one patient, the Bio-pump was used as an LVAD but later replaced by a pusher-plate pump. Four patients had an IABP inserted during the operation, and one patient had aortic coarctation which prohibited IABP placement. In 2 patients, the femoral

Table 1 Diagnoses and operations of patients who underwent VAD support

Patient no.	Age	Sex	Diagnosis	Operation	Aortic clamp time (min)	CPB time (min)
1	59	F	IE	DVR	308	422
2	22	M	AR&MR AAE Asce. aortic dissection	Cabrol's procedure	229	412
3	40	M	AR&MR	DVR	313	391
4	58	F	ASR&MS	DVR	178	243
5	39	F	AAE&MR	DVR	213	389
6	58	M	OMI	CABG(3)	237	422
7	54	F	AS	AVR	139	375

CPB : cardiopulmonary bypass, IE : infective endocarditis, AAE : annulo-aortic ectasia, AR : aortic regurgitation, AS : aortic stenosis, MR : mitral regurgitation, MS : mitral stenosis, OMI : old myocardial infarction, DVR : double valve replacement, AVR : aortic valve replacement, CABG : coronary artery bypass graft.

Table 2 Type of VAD, duration of support and clinical outcome

Patient no.	Type of support	Type of device	IABP	Duration of VAD support (days)	Weaned	Outcome	Cause of Death
1	Left	Diaphragm	-	7	Yes	Death (POD 21)	Renal failure Sepsis
2	Left	Centrifugal ↓ Pusher-plate	+	4.5	Yes	Death (POD 62)	Renal failure Sepsis
3	Left	Diaphragm	-	8	Yes	Alive	
4	Biventricular	L: Centrifugal R: Diaphragm	+	L: 4.5 R: 9	Yes	Death (POD 59)	Renal failure Sepsis
5	Left	Diaphragm	-	4.5	Yes	Alive	
6	Left	Centrifugal	+	6	Yes	Death (POD 64)	Arrhythmia Ileus
7	Left	Centrifugal	+	4	Yes	Alive	

VAD : ventricular assist device, IABP : intraaortic balloon pump, POD : post operative day.

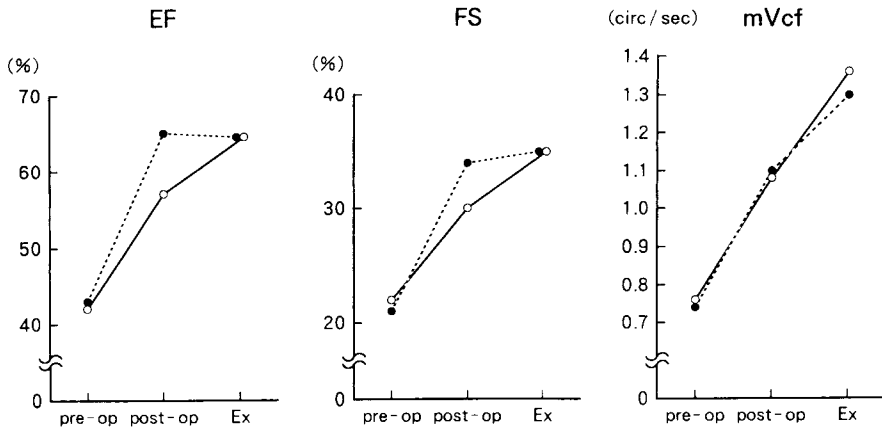


Fig. 1 Changes in cardiac functions of two long-term survivors. EF: ejection fraction, FS: fractional shortening, mVcf: mean velocity of circumferential fiber shortening, Ex: exercise. (○) ventricular assist device (VAD) NO.3, (●) VAD NO.5.

artery was not suitable for IABP insertion due to previous surgical interventions. The duration of VAD support ranged from 4 to 9 days (mean 6.1 days). All patients were eventually weaned and three were discharged from the hospital. One patient who underwent DVR died of renal failure, infection and disseminated intravascular coagulation. Two patients who had Cabrol's operation and DVR died of renal failure and sepsis. One patient who received triple coronary artery bypass grafts died of intractable arrhythmia and ileus. Bleeding necessitated reoperation in 3 patients. The 3 long term survivors have been followed for

7 to 21 months (mean 15 months). They are all in NYHA functional class I.

Figs 1 and 2 demonstrate changes in the cardiac function of patients 3 and 5. One year after surgery, the ejection fraction (EF), fractional shortening (FS) and mean velocity of circumferential fiber shortening (mVcf) have increased dramatically in both cases. These parameters increased further during exercise, especially in patient 3 (Fig. 1). Left ventricular diastolic dimension (LVDD) and left ventricular systolic dimension (LVDS) decreased after the operation in both patients. Again, they decreased further

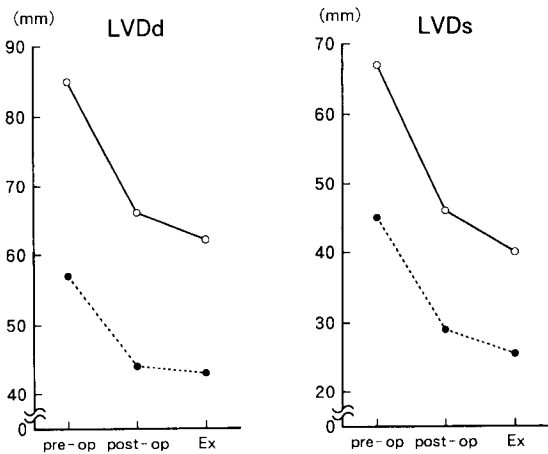


Fig. 2 Changes in cardiac functions of two long-term survivors. LVDD: left ventricular diastolic dimension, LVDS: left ventricular systolic dimension. (○) Ventricular assist device (VAD) NO.3, (●) VAD NO.5.

with exercise (Fig. 2).

Fig. 3 illustrates serum free hemoglobin levels obtained from 3 survivors and 3 nonsurvivors. Maximal free hemoglobin level in nonsurvivors was 38 mg/dl, while they were below 13 mg/dl in survivors. Lactate levels remained high in nonsurvivors but those in survivors declined after the third postoperative day (Fig. 4). Antithrombin III levels in one survivor and one nonsurvivor were below 50%, but those in the other 4 patients were kept above 50% (Fig. 5). Although maximal polymorphonuclear elastase levels in 2 nonsurvivors were 862 and 1340 $\mu\text{g/l}$, those in survivors were kept below 300 $\mu\text{g/l}$ after separation from the VAD (Fig. 6).

Fig. 7 illustrates the course of biventricular bypass in patient 4. She was weaned from cardiopulmonary bypass with the aid of the LVAD

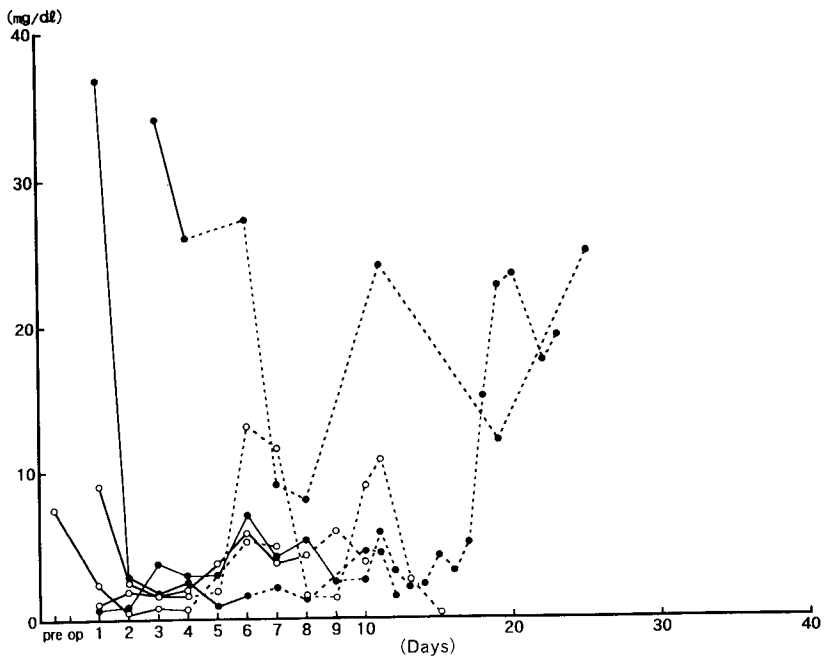


Fig. 3 Serum free hemoglobin levels in 3 survivors (○) and 3 nonsurvivors (●).

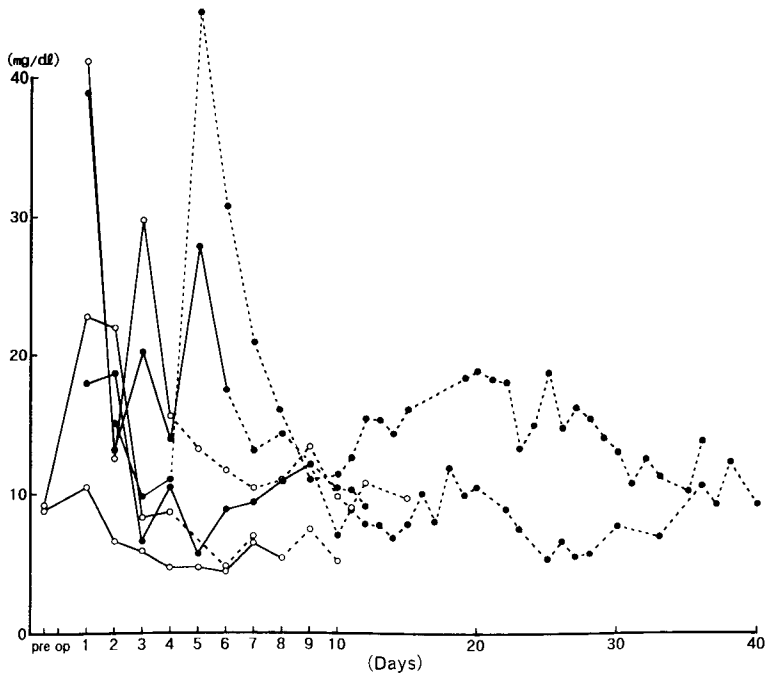


Fig. 4 Venous lactate levels in 3 survivors (○) and 3 nonsurvivors (●).

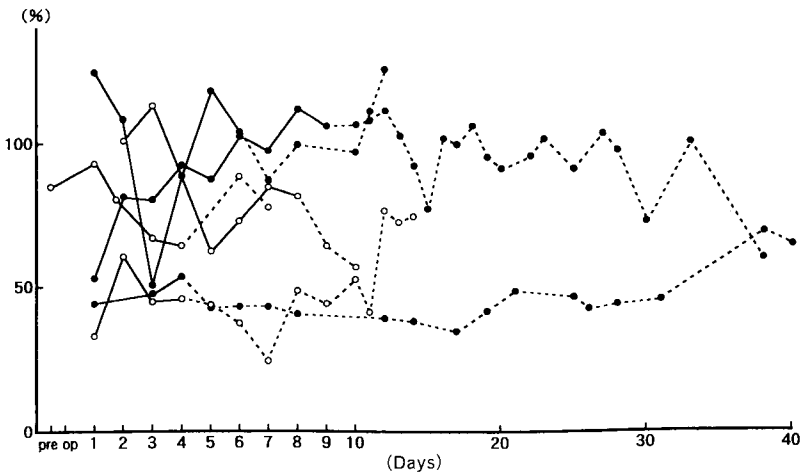


Fig. 5 Antithrombin III levels in 3 survivors (○) and 3 nonsurvivors (●).

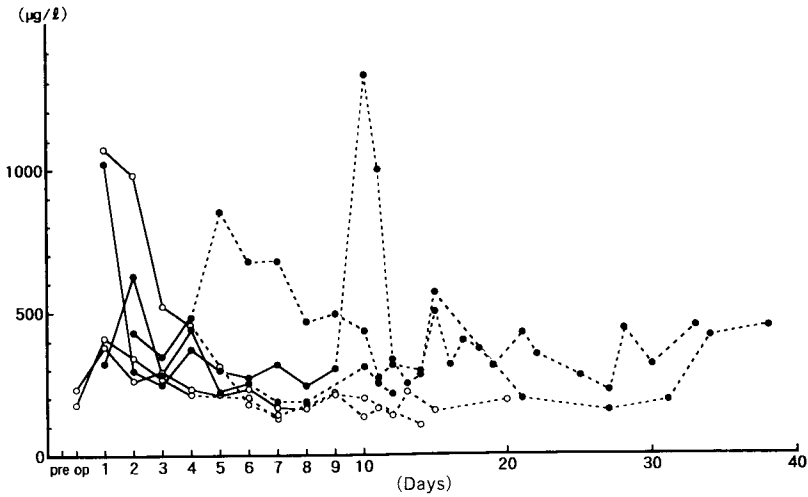


Fig. 6 Polymorphonuclear leucocyte elastase levels in 3 survivors (○) and 3 nonsurvivors (●).

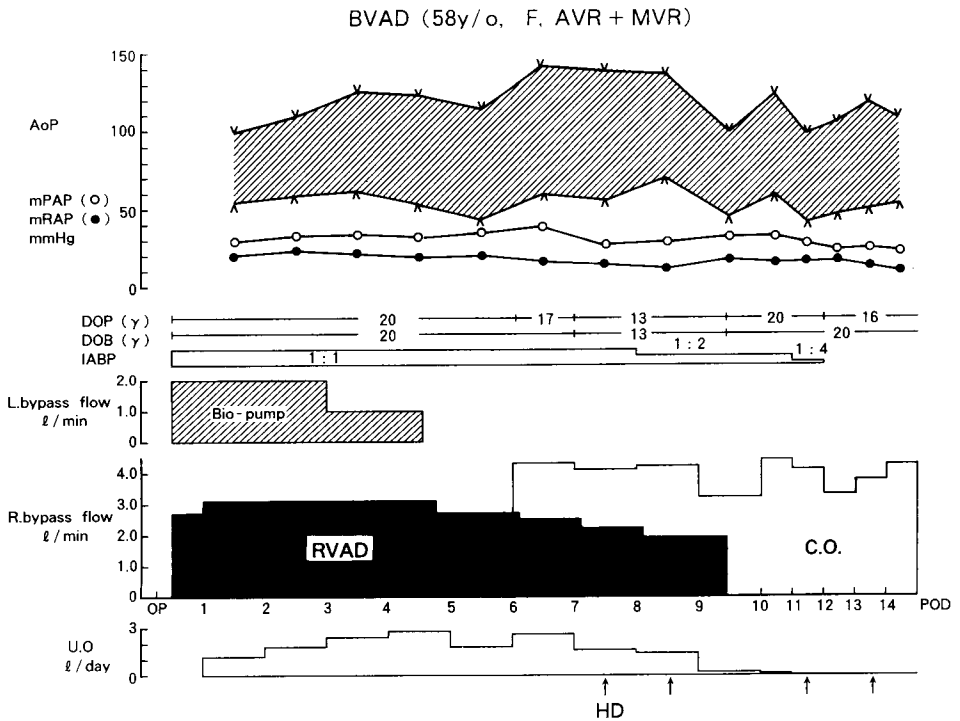


Fig. 7 Postoperative course of the patient who underwent biventricular bypass. Duration of VAD support was 9 days. She was successfully weaned from the VAD, but died of renal failure and sepsis.

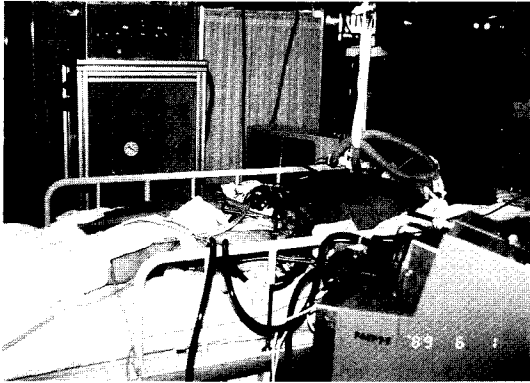


Fig. 8 The biventricular bypass patient. A Biopump was used on the left and a diaphragm-type pump was used on the right. BVAD: biventricular assist device, AVR: aortic valve replacement, MVR: mitral valve replacement.

(Bio-pump), but right ventricular failure necessitated insertion of the RVAD (diaphragm pump). The total duration of VAD perfusion was 9 days, and though she was weaned from the VAD, died of renal failure and sepsis on the 59th postoperative day. Fig. 8 depicts the patient who received a BVAD.

Discussion

VADs have been applied to many patients in postcardiotomy shock, and they have proved to be effective to support failing ventricles and to maintain adequate perfusion to vital organs (11). During the two year period 1986 and 1987, 24 centers in the United States reported left ventricular assistance for treatment of postcardiotomy shock in 154 patients. Forty-nine per cent (75) were weaned, and 23% (36) survived. Most of the patients (139, or 83%) were supported by centrifugal pumps (7). Pennington reported that since 1981, 30 patients with profound cardiogenic shock after cardiotomy were supported with the Pierce-Donachy ventricular assist device. Fifteen patients (50%) were weaned and 11 (37%) were discharged (6). In

our experience, 7 patients (100%) were weaned from the VADs and 3 (43%) were discharged. Pennington (6, 12) reported that his increasing success was attributed to improved patient selection, earlier application of devices, better control of postoperative bleeding, and more aggressive treatment of biventricular failure. He also pointed out that important factors influencing the survival of VAD patients were perioperative myocardial infarction, infection and renal failure necessitating dialysis. In our VAD patients, we have encountered one biventricular failure, 3 cases of bleeding, 3 cases of major infection, and 3 cases of renal failure. Reoperation was performed in 3 patients because of bleeding. Pennington (6) recommended sternal closure which decreases the chance of bleeding and allows for endotracheal tube removal. In our patients, only the skin was closed because the two large cannulae made sternal closure difficult. These patients received fresh frozen plasma and platelets every day until sternum was closed.

Infection is an important event that can influence survival. One patient had mediastinitis which developed into sepsis. A second had pneumonia that led to sepsis and a third patient had prolonged high fever. Laboratory data demonstrated that polymorphonuclear (PMN) leucocyte elastase levels in nonsurvivors were higher than in survivors. Likewise, antithrombin III levels in one nonsurvivor were extremely low (below 50%) during the entire postoperative period. PMN leucocyte elastase is contained in cytoplasmic granules and functions in the mediation of defense responses to inflammation. However, this elastase degrades connective tissue proteins, dissolves coagulation factors, and also inactivates antithrombin III. Hence, at the time of major infection, excessively secreted elastase may rapidly damage connective tissue, cause disseminated intravascular coagulation and multiorgan failure (13). For these reasons, PMN leucocyte elastase and antithrombin III levels are useful for detecting the development of major infection.

Renal failure is also an important factor

influencing survival. In our series, 3 patients had renal failure necessitating dialysis. These 3 patients developed major infection and one patient had DIC. All 3 patients died of multiorgan failure. Pennington (12) reported that in 48 patients, 18 had renal failure and 13 underwent dialysis, with one survivor. Our data likewise suggest that renal failure necessitating dialysis and major infection are serious complications.

Published results suggest the possibility of satisfactory long-term survival in patients with refractory postcardiotomy cardiogenic shock. Kanter has followed up 23 survivors of mechanical circulatory support for 3 to 79 months (mean 29 months), and 17 (74 %) were in NYHA class I and 2 (9 %) were in class II (14). We have followed 3 patients for 7 to 21 months (mean 15 months) and they all are in class I. Kanter (14) stated that if there is no evidence of myocardial infarction, severely depressed cardiac function after cardiac surgery may be due to a "stunned" myocardium (15) rather than to myocardial necrosis. In our 3 long-term survivors, they all had valvular heart disease and there was no evidence of myocardial infarction during and after surgery. Therefore, if one has performed a technically satisfactory operation, it is reasonable to attempt mechanical circulatory assistance to allow for myocardial rest and repair with expectation of a good long-term result.

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