

Limitation of Venoarterial Bypass. Early Predictor and Optimal Conversion

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ABSTRACT

Conversion from venoarterial bypass to a ventricular assist device may be life-saving for patients with severe heart failure, but the criteria for conversion have not yet been established. Forty patients who underwent venoarterial bypass for cardiac failure were reviewed. Of these, 18 (45%) could be weaned from venoarterial bypass, and 11 survived for more than 30 days after weaning (survival rate, 27.5%). Liver dysfunction, renal dysfunction, and the need for left-sided cardiac venting were risk factors for mortality. The appearance of patient's own cardiac pulse wave within 24 hours after the introduction of venoarterial bypass was a good indication for weaning. Delayed appearance of the cardiac pulse wave was considered to be a risk factor for death. According to these indices, conversion from venoarterial bypass to a ventricular assist device should be considered to prevent deterioration in the function of systemic organs.

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INTRODUCTION

Venoarterial bypass (VAB) including extracorporeal membrane oxygenation is a well-established method of providing emergency circulatory support to patients suffering from severe cardiac and respiratory failure. The advantages of VAB include ease of set-up and low cost.¹ However, when cardiac function fails to recover, this system cannot sustain adequate systemic circulation, and patients tend to fall into an unrecoverable state due to multiorgan failure (MOF).^{2–5} Thus, VAB is not suitable for long-term use. A ventricular assist device (VAD) is superior for long-term use and also demonstrates some advantages regarding recovery of systemic organ function as it provides greater output than VAB.^{1,2,4,6} A VAD is useful not only as a bridge to transplantation but also as a bridge to recovery.^{7–9}

Since 1991, we have used VAB on patients who could not be weaned from cardiopulmonary bypass due to low-output syndrome or cardiogenic shock. All of these

patients would have died without introducing VAB, but while half of them could be weaned from VAB, only a quarter of them survived. We now believe that we could have saved many of the non-survivors if VAB had been converted to VAD support before the development of irreversible systemic organ damage. The critical question is how to determine which patients may recover on VAB support alone. The indications for conversion from VAB to a VAD and the optimal timing have not yet been fully elucidated. The aim of this study was to clarify the limitations of VAB and establish the optimal timing for conversion.

PATIENTS AND METHODS

Forty patients (9 children and 31 adults) who had undergone VAB after open heart surgery between February 1991 and June 2002, at Kyushu University Hospital, were retrospectively reviewed. The criteria for instituting VAB were a shock state or cardiac index less than 2.0 L·min⁻¹·m⁻² despite high-dose catecholamine

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Table 1. Profile of 40 Patients Supported by Venoarterial Bypass

Variable	Survivors	Non-Survivors
No. of patients	11	29
Age (years)	42.6 ± 7.7	47.9 ± 5.2
Adults:children	9:2	22:7
Male:female	6:5	23:7
Preoperative diagnosis		
Ischemic heart disease	5	11
Valvular heart disease	3	4
Aortic aneurysm	0	7
Congenital heart disease	3	7
Indication for support		
CPB weaning failure	7	18
Cardiogenic shock	4	11

CPB = cardiopulmonary bypass.

Table 2. Complications and Causes of Death

Complications	Survivors	Non-Survivors
Infection	1	9
Neurological damage	2	20
Liver dysfunction	1	21
Renal dysfunction	4	22
Massive bleeding	3	18
Thrombus formation	1	7
Cause of death		
Multiorgan failure		13
Sepsis		3
Respiratory failure		4
Brain death		5
Bleeding		3
Arrhythmia		1

administration, adequate preload, and intraaortic balloon pump (IABP) insertion when applicable. The VAB system consisted of a centrifugal pump or a roller pump, a membrane oxygenator, and a heparin-coated circuit. In 8 children, a venous cannula was inserted into the right atrium, and an arterial cannula was placed into the ascending aorta. In 1 child and 22 adults, a venous cannula was inserted into the femoral vein up to the right atrium, and an arterial cannula was placed in the femoral artery. In 7 adults, a venous cannula was inserted into the femoral vein or right atrium, and an arterial cannula was placed into the ascending aorta or the subclavian artery. When left atrial pressure was highly elevated or pulmonary congestion developed, a cannula was placed into the left atrium, left ventricle, or the pulmonary artery for venting. An additional perfusion catheter was inserted into the distal part of the femoral artery when there was a sign of ischemia in the lower leg. As an anticoagulant

regimen, nafamostat mesylate with or without heparin was administrated intravenously to maintain activated clotting time at approximately 200 seconds. The patients were divided into two groups according to survival. Survivors were defined as patients who lived for more than 30 days after weaning from VAB. The appearance of the patient's own cardiac pulse wave was defined as when the pulse wave exceeded 30 mm Hg in adults and 20 mm Hg in children. Liver dysfunction was diagnosed when total bilirubin was elevated above 4.0 mg·dL⁻¹ or alanine transaminase exceeded 100 U·L⁻¹. Renal dysfunction was defined as serum creatinine > 3.0 mg·dL⁻¹ or the introduction of hemodialysis.

All data are presented as the mean ± standard error. Statistical analysis was performed using the unpaired *t* test or Fischer's exact test. Nonparametric estimates of the appearance of the patient's own pulse was achieved

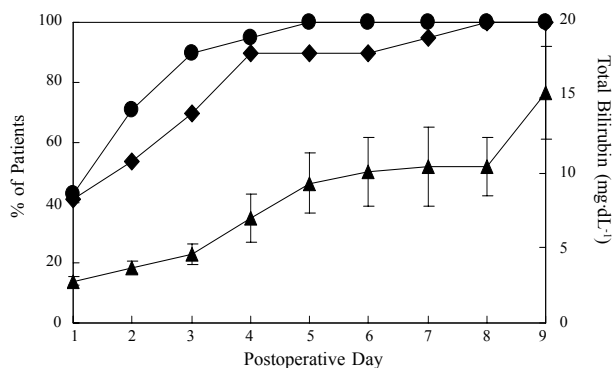


Figure 1. Onset of liver dysfunction (closed circle) and renal dysfunction (closed square), and change in total bilirubin level (closed triangle) after instituting venoarterial bypass in non-survivors.

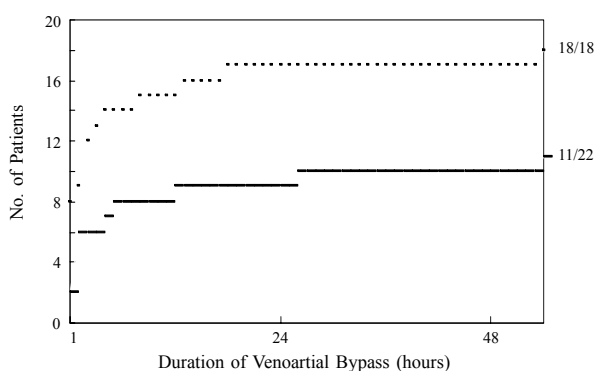


Figure 2. Appearance of the patient's own cardiac pulse wave in weaned (broken line) and un-weaned cases (unbroken line).

Table 3. Parameters of Cardiac Support

Variable	Survivors	Non-Survivors	<i>p</i> -Value
CPB time (min)	300.8 ± 54.2	405.3 ± 44.2	NS
Crossclamp time (min)	125.6 ± 32.8	103.8 ± 21.5	NS
Venoarterial bypass duration (h)	72.0 ± 9.6	139.6 ± 15.6	< 0.01
Maximum output (L·min ⁻¹ ·m ⁻²)	2.25 ± 0.17	2.73 ± 0.14	< 0.05
LV or LA venting (n)	0	13	< 0.01
Intraaortic balloon pump (n)	3	18	< 0.05

CPB = cardiopulmonary bypass, LA = left atrial, LV = left ventricular, NS = not significant.

using the method of Kaplan and Meier, followed by the Wilcoxon test. A probability value less than 0.05 was considered statistically significant.

RESULTS

Of the 40 patients who underwent VAB, 18 (45%) could be weaned from the system, and 11 survived for more than 30 days after weaning (survival rate, 27.5%). The survivors consisted of 2 children and 9 adults. The primary diagnosis was ischemic heart disease in 5, valvular heart disease in 3, and congenital heart disease in 3. Indications for VAB were failure to wean from cardiopulmonary bypass in 7, and cardiogenic shock after open heart surgery in 4. The non-survivors consisted of 7 children and 22 adults with a primary diagnosis of ischemic heart disease in 11, valve disease in 4, aortic aneurysm in 7, and congenital heart disease in 7. Their indications for VAB were failure to wean from cardiopulmonary bypass in 18, and cardiogenic shock in 11 (Table 1).

Complications occurring during VAB are listed in Table 2. Non-survivors had significantly higher incidences of infection, neurological damage, liver dysfunction, renal dysfunction and massive bleeding. There were no significant differences between the survivors and non-survivors in the incidence of thrombus formation. Most non-survivors manifested liver and/or renal dysfunction within 4 days of VAB support (Figure 1). The total bilirubin level gradually increased on VAB support (Figure 1). Operative details are listed in Table 3. Bypass duration of the non-survivors was significantly longer than that of the survivors. Bypass duration of the survivors ranged between 36 and 137 hours. Maximum support flow was significantly different between the 2 groups. Left ventricular or left atrial venting was necessary in 13 cases; however, none survived. An IABP was employed in 3 of the survivors and in 18 of the non-survivors.

The time at which the patient's own cardiac pulse wave appeared in the weaned and un-weaned cases is shown

in Figure 2. In all weaned cases, the patient's own cardiac pulse wave appeared within 24 hours, except in 1 case where it appeared at 54 hours. Of the 22 un-weaned cases, the cardiac pulse wave appeared within 24 hours in only 9 cases. All of these 9 patients were lost due to non-cardiac causes: brain death in 4, respiratory failure in 3, sepsis in 1, and massive bleeding in 1. The time at which patient's own cardiac pulse wave appeared, showed a significant difference between the weaned and un-weaned cases ($p < 0.01$).

The causes of death are listed in Table 2. Thirteen patients died from MOF, 1 from severe arrhythmia after weaning from VAB, 4 from respiratory failure, 5 from brain death, 3 from sepsis, and 3 due to uncontrollable bleeding.

In 2 cases other than these 40 cases, one with dilated cardiomyopathy and the other with myocarditis, conversion from VAB to VAD was attempted. Both died because of pulmonary dysfunction due to pulmonary congestion, which developed before conversion to the VAD.

DISCUSSION

Since 1991, the first choice of mechanical support for cardiac collapse in our institute has been an IABP or VAB. Venoarterial bypass is easy to introduce and it is preferable in cases of acute cardiogenic shock. It also costs less than a VAD.¹ In addition, it can be used for acute respiratory failure as well as cardiogenic shock because the VAB circuit contains a membrane oxygenator. However, VAB alone does not provide sufficient flow to maintain all organs in the case of complete deterioration of cardiac function, so the effectiveness of circulatory support by VAB is limited. Moreover, VAB does not contribute substantially to decompression of the left side of heart. As a result, VAB cannot prevent the development of pulmonary edema.^{2-4,6,10} On the other hand, a VAD gives better support during long-term usage, and allows greater recovery of the damaged systemic organs because it provides higher blood flow.

A number of studies have described the advantages of a VAD for patients who fail to recover despite VAB.^{2,4,6,11} The criteria for conversion from VAB to a VAD are liver dysfunction and duration of support.^{2,4,6} Several studies have attempted to define the limits of prolonged VAB.^{2-4,6,12} In our study, the maximum length of support in survivors was 137 hours, but cardiac function had already recovered in the early periods after applying VAB. The extended support was necessary because of late recovery of respiratory function. When the myocardium was unable to recover, irreversible MOF and respiratory failure were already established during the prolonged support. Therefore, bypass duration is not suitable as a parameter to decide the best time to convert, and we focused on the appearance of the patient's own cardiac pulse wave. In weanable patients, the latest appearance of such a pulse was 54 hours; in this case, the child died from severe heart failure after weaning from VAB. In the other 17 weanable cases, the patient's own cardiac pulse wave appeared within 24 hours of support. The patient's cardiac pulse wave also appeared within 24 hours in 9 unweanable cases; all of these patients died due to non-cardiac causes (uncontrolled bleeding, sepsis, and respiratory failure). It was concluded from these results that when the cardiac pulse wave appeared within 24 hours, there was sufficient cardiac function for these patients to be weaned from VAB and survive. Therefore, when the patient's own cardiac pulse wave does not appear within 24 hours, it is time to convert from VAB to a VAD.

Maximum support flow was significantly lower in survivors than non-survivors. In addition, none of the patients who required left atrial or left ventricular venting for left-sided cardiac decompression survived. These results indicate that severe myocardial damage is a risk factor for death in patients on VAB. Bavaria and colleagues¹³ reported that extracorporeal life support increases left ventricular wall stress and oxygen consumption in the postischemic heart by increasing afterload. Thus, VAB adds to the mechanical burden of a poorly contracting left ventricle without improving contractility, and it may delay functional recovery of the myocardium. Antegrade flow is more beneficial for systemic blood flow and disturbing the afterload of heart; however, in the case of a severely failing heart, left ventricular afterload cannot be reduced by employing the antegrade flow method. On the other hand, a VAD has some advantages regarding myocardial recovery, which are related to the amelioration of circulatory insufficiency with an attenuation of perturbed humoral networks and reduction of myocardial wall stress.⁹ Therefore, conversion to a VAD should be implemented in patients who need left heart venting.

In previous studies, the weaning rate from VAB ranged from 39% to 58%, and survival ranged from 14% to 36%.^{3,5,10,12,14-15} In our study, the weaning rate of 45% and survival of 27.5% are in agreement with the previous results. We found that non-survivors had more complications than survivors, such as neurological damage, liver dysfunction, renal dysfunction, and bleeding. These results were similar to those of others, and indicate that MOF due to liver dysfunction and renal dysfunction is the main cause of death in these supported patients.^{2,4-5,12,14} In addition, massive transfusions due to bleeding have been reported to induce organ dysfunction.⁵ Avoidance of MOF seems to be one of the most important factors in the management of circulatory support. Because organ dysfunction is recognized in the early phase of VAB support, it might be initiated before institution of support (Figure 1). Early conversion to a VAD is essential and appropriate management during VAB support.¹⁴⁻¹⁵ When recovery of cardiac function is delayed, as in patients needing decompression of the left heart or in those lacking their own cardiac pulse during the initial 48 hours of VAB support, there is a high risk of mortality. These patients should be assessed as to whether they fulfill the criteria for long-term VAD support or heart transplantation, on the basis of age, brain damage, or other organ failure. To prevent the deterioration of systemic organ function, conversion from VAB to a VAD in the early phase may improve the survival of such patients.

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