Estimation of Cardiac Function with Rotary Blood Pump

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Background: A rotary blood pump may be implanted as a bridge to cardiac transplantation. Also, mechanical, histological, and biochemical improvements have been described in cardiac function after the implantation of a left ventricular assists device (LVAD). Thus there is considerable enthusiasm that LVAD might be used as a bridge to the recovery of myocardial function. Unlike a pulsatile pump, however, we cannot stop the rotary blood pump to estimate cardiac function. If the rotary blood pump stops, back flow will occur. In this study, a new method was examined that can estimate cardiac function without stopping the pump.

Materials and Methods: Twelve pigs were subjected to this acute study. The pump was implanted as an LVAD with an inlet cannula inserted into the left ventricle and the outlet cannula into the ascending aorta. The assist ratio was changed to 75%, from 25%. The relationship between the dp/dt of the left ventricle pressure and the differentiated pump flow rate was examined. Also, cardiac function was changed by epinephrine loading to estimate this method under hyperdynamic heart conditions.

Results: There was high positive correlation between the dp/dt of left ventricle pressure and differentiated the pump flow rate to 75% assisted ratio, from 25%. This relationship was established under hyperdynamic conditions.

Conclusion: This method is simple and useful for estimating the cardiac function without pump stoppage. (Ann Thorac Cardiovasc Surg 2007; 13: 240–246)

Key words: left ventricular assists device, rotary blood pumps, cardiac transplantation

Introduction

Rotary blood pumps can be used as a left ventricular assists device (LVAD).1,2 These pumps have several advantages over conventional pulsatile pumps, such as smaller size, higher efficiency, and simple design and construction.3,4 The rotary blood pump has already been implanted as a LVAD clinically.5 Recently, several institutions reported that in selected patients under special conditions, cardiac function has the ability to recover when supported by an LVAD.6–8 Several patients with LVAD were weaned from it, and the cardiac function of the native heart is a very important factor at that time. The pulsatile pump can be stopped to estimate cardiac function because a pulsatile pump has a valve that can prevent regurgitative flow.9 If the rotary blood pump is stopped during weaning from the device, there is a backflow through the pump, endangering the patient by regurgitation into the left ventricle. This can also make it more difficult to judge the recovery of heart function because of the volume load on the left ventricle.10

In this study, the native heart cardiac function was examined from the centrifugal pump flow waveform without pump stoppage or a special sensor.
Materials and Methods

Twelve pigs (40–45 kg) were used in this study (9 for normal heart condition and 3 for the hypercardiac condition). Each animal was anesthetized with intravenous sodium pentobarbital (20 mL/kg) and ketamine chloride (1 mg/h). After a tracheotomy and intubation, controlled mechanical ventilation was established under a tidal volume of 10–5 mL/kg. After a median sternotomy, the inflow cannula of the LVAD was inserted into the left ventricle from the apex, and the outflow cannula was inserted into the ascending aorta.

A central venous line was introduced via the right internal jugular vein. Two fluid-filled arterial catheters were placed via the right and left common carotid arteries to measure blood pressure in the ascending aorta and left ventricle. An ultrasound flow probe (Transonic Systems Inc., New York, USA) was placed in the ascending aorta to measure the native cardiac output.

The centrifugal pump (Gyro Pump, Kyocera, Kyoto, Japan) was used as the LVAD. The pump flow rate was measured via an ultrasound flowmeter (Transonic Systems Inc.). Two disposable pressure transducers were placed proximally to the pump inflow and the pump outflow (Fig. 1).

Experiments were conducted according to the Guide for the Care and Use of Laboratory Animals prepared by the National Institutes of Health (NIH Publication No. 86-23, revised 1985).

(1) The normal heart condition study
The assisted ratio (pump flow rate/native cardiac output + pump flow rate) was changed from 25, 50, and 75%. Three pigs were subjected to each assisted ratio.

The correlation between the dp/dt of left ventricular pressure and the differentiated pump flow wave was examined to estimate the native cardiac function from the rotary blood pump parameters. One data set consisted of 4 heartbeats at an assist ratio of 25, 50, and 75% in 6 pigs.

(2) The hyperdynamic condition study
After recording the parameters under the normal heart condition, we induced a hyperdynamic heart condition by injecting epinephrine (0.5 mg).

This study was performed at a 50% assist ratio.

Experimental readings of the study were made on a Macintosh personal computer using Acknowledge III for the MP 1000 WS (Biopac Systems, Inc., Goleta, CA, USA). Statistical analysis was performed with the Statview program. All results were expressed as mean ± standard error the mean.

Results

(1) Normal heart
The relationship between the native heart cardiac output, total cardiac output (native cardiac output + pump flow rate), and the pump flow rate were examined at an assist ratio of 25% and 75%. The actual aortic pressure and pump flow rate are shown in Fig. 2 at the assist ratio of 50%.
The correlation of dp/dt of the left ventricle and the differentiated pump flow rate was examined. Sampling data were recorded during 4 heartbeats in a stable condition at an assist ratio of 25, 50, or 75% in 3 pigs. There was a high correlation between the dp/dt and the differentiated pump flow rate (Figs. 3–5). From this result, we calculated the estimated dp/dt from the differentiated pump flow rate (Figs. 6–8).

Fig. 3. Correlation between the dp/dt and the differentiated pump flow rate at an assist ratio of 25%.

Fig. 4. Correlation between the dp/dt and the estimated dp/dt at an assist ratio of 50%.
(2) Hyperdynamic condition
Three pigs were used to examine the hyperdynamic condition.
Epinephrine (0.5 mg) was injected to induce a hyperdynamic condition. Sampling data were recorded of four heartbeats in a stable condition at an assist ratio of 50%.
After epinephrine loading, maximum dp/dt, aortic pressure, and native cardiac output increased immediately.

Fig. 5. Correlation between the dp/dt and the differentiated pump flow rate at an assist ratio of 75%.

Fig. 6. Correlation between the dp/dt and the estimated dp/dt at an assist ratio of 25%.
There was a high correlation between the $\frac{dp}{dt}$ and the differentiated pump flow rate (Fig. 10). From this result, the estimated $\frac{dp}{dt}$ from the differentiated pump flow rate was calculated (Fig. 11).

(p<0.05). Mean aortic pressure increased to 148.7±30.3, from 89.5±4.7. Max $\frac{dp}{dt}$ increased to 7,839.3±331.5, from 4,636.2±33.6. The aortic pressure and pump flow rate were shown in Fig. 9.

Fig. 7. Correlation between the $\frac{dp}{dt}$ and the differentiated pump flow rate at an assist ratio of 50%.

Fig. 8. Correlation between the $\frac{dp}{dt}$ and the estimated $\frac{dp}{dt}$ at an assist ratio of 75%.
Comment

Basically, the rotary blood pump produces a nonpulsatile flow wave. However, the pump flow wave of rotary blood pumps as an LVAD has a pulsatility that was produced by the left ventricle. This mean suggests that the pulsatility of the pump flow wave depends on the contraction of the left ventricle. Therefore if the waveform is analyzed, the cardiac function will be detected. This is our concept that can estimate the cardiac function from the rotary blood pump.

We cannot stop the rotary blood pump as an LVAD as we can a pulsatile pump to estimate the cardiac function; if the rotary blood pump is stopped, backflow will occur. Therefore the estimation of an accurate cardiac function is impossible. The method of analyzing the pump flow was used as the differentiation method.

Because this method does not require a large volume of sampling data, the calculation is simple and we can determine the result immediately.

There is a high correlation between the differentiated pump flow rate and the dp/dt of the left ventricular pressure. Also, this method was indicated when the cardiac function changed. If we try a weaning from the rotary
blood pump, the pump speed should be decreased until the pump flow rate is 0 mL/min during diastolic phase because the total head pressure is then maximum. At that time if the peak dp/dt can maintain 2,340 mmHg from 930 mmHg, which is normal value, we think a patient can be weaned from a pump.

In this study, we can estimate the cardiac function without pump stoppage and without a special sensor. This method could be useful for managing an implantable rotary blood pump.

References