

# Evaluation of Native Left Ventricular Function During Mechanical Circulatory Support.: Theoretical Basis and Clinical Limitations

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**Left ventricular function on patients with heart disease is now evaluated by echocardiography, but these dimensional changes are erroneous in the patient supported by left ventricular assist device because of mechanical unloading for the failing heart. Left ventricular end-systolic pressure-volume relationship provides theoretically most reliable left ventricular contractility.**

**Recently, some patients have weaned from the device because of unexpected recovery of myocardial contractility. But it is very important to evaluate the left ventricular function just before the weaning, and to predict the longevity of the recovered function to keep the good quality of life.**

**Current clinical situation in the patients with ventricular assist device, and theoretical limitations to evaluate the recovering myocardium are discussed. (Ann Thorac Cardiovasc Surg 2002; 8: 1–6)**

**Key words:** ventricular assist device, bridge to recovery, left ventricular pressure-loop study, left ventricular mechanics

Various tools have been used to treat patients with profound cardiogenic shock. Fig. 1 shows the current pathway of treatment. Such patients have been treated recently with heart transplantation, sometimes following a period of mechanical circulatory support. A small number of patients recover enough left ventricular (LV) function to survive after being weaned from a mechanical left ventricular assist device (LVAD), used as a so-called bridge to recovery. Worldwide data concerning use of a LVAD as a bridge to recovery are shown in Table 1. The incidence of recovery from profoundly depressed LV function in patients supported by a LVAD was about 2.1-2.4 % in the large series registry based on Novacor or HeartMate VAD. Patients with long-term acceptable results were younger in age, had a shorter history of heart

failure, and showed rapid and complete recovery of LV function during mechanical support<sup>1)</sup>, and I estimate that the current recovery rate has increased to about 5%.

Although precise evaluation of the native left ventricle is very important when weaning a patient from LVAD support, the commonly used clinical contractile parameters can not be applied in the patient with a LVAD because the left ventricle has been unloaded by the device, and the intraventricular hemodynamics are very different from those of a patient without the device. Preload, afterload, and isovolumic contraction period undergo various changes in response to the LVAD drainage site (Table 2) and to the assist ratio.

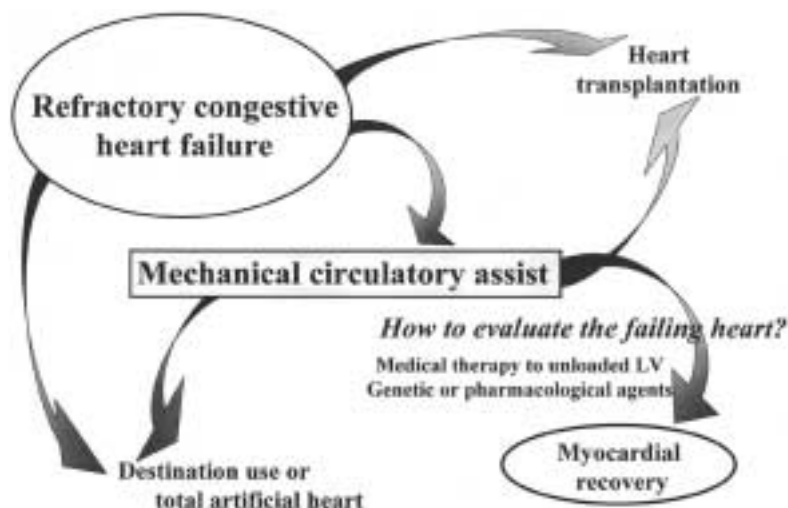
Presently, many institutions are attempting to estimate the native LV function for the bridge to recovery therapy by one or more of the following methods:

- (1) dobutamine infusion test during reduced LVAD support.
- (2) exercise test with minimum LVAD flow assistance.<sup>2)</sup>
- (3) hemodynamic evaluation during a short interval without VAD support (temporary stoppage up to 20-30

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**Fig. 1.** Clinical pathway for the treatment of refractory congestive heart failure and the current problem in the bridge to recovery via mechanical circulatory assist.

**Table 1** Worldwide bridge to recovery data

Device	Implants	Heart transplants	Bridge to recovery
HeartMate (to June 1999)	total 1837	1064 (58%)	27 (1.5%)
	Pneumatic	1152	
	Electric	685	
Novacor (to May 2000)	1146	607 (53%)	39 (3.4%)

\* Numbers are number of cases, and Baxter Company and Thoratec Company recorded these data.

minutes).<sup>3)</sup>

(4) daily systolic time interval evaluation to judge recovery of LV contractility during stepwise reduction in LVAD flow.<sup>4)</sup>

(5) training-mode program to wean the patient from the pump has also been used under monitored echocardiographic parameters, and the pump rate is increased up to 140 beats/minute, and the ejection interval is prolonged up to 70% of each systole.<sup>5)</sup> Another program is an asynchronous drive mode between the native heart and assist pump. The LVAD is firstly driven with synchronization with the native heart to obtain complete unloading and reduction of the LV size, and LVAD ejection timing asynchronously to give some loading to the recovering left ventricle for training to enable wean from the LVAD.<sup>6)</sup>

Methods 1 and 2 estimate the potential power of the recovering left ventricle during certain loading conditions. Method 3 directly evaluates actual LV function

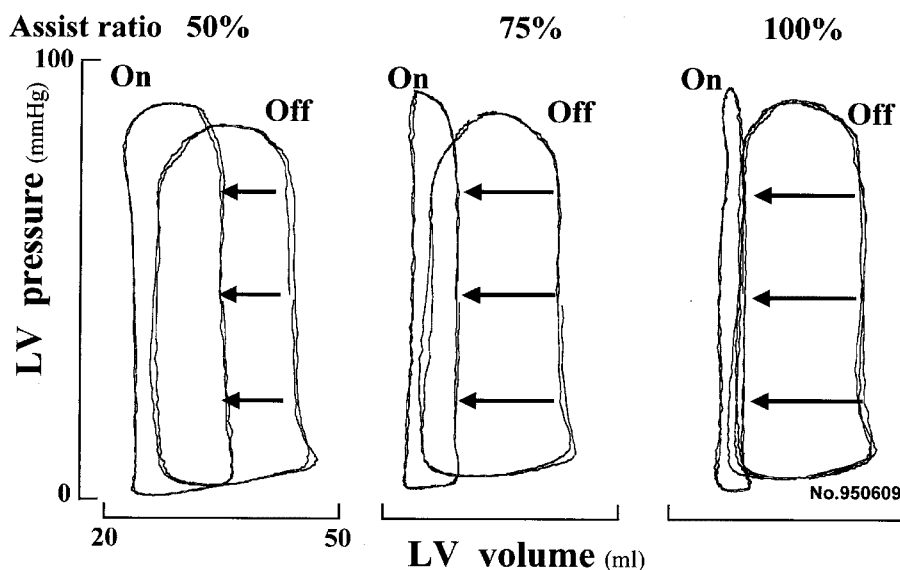
**Table 2** Changes in left ventricular function during left ventricular assist

Drainage site	Preload	Afterload	Isovolumic contraction period
LA	Decrease	No change/Increase	Present
LV	Decrease	Decrease	Not present

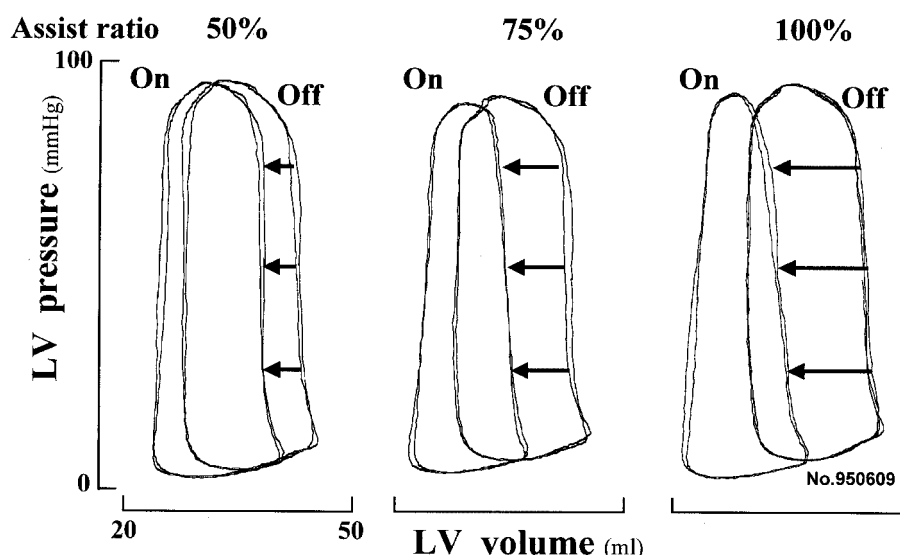
LA, left atrium; LV, left ventricle.

without LVAD support. Method 4 is a theoretically acceptable procedure, and method 5 uses a special mode to apply a given load to the recovering myocardium. Unfortunately, none of these methods can predict the ability of the native left ventricle to sustain systemic circulation just after weaning from the LVAD.

I have been experimentally studying LV mechanics via LV loop analysis during various methods of LV support. With non-pulsatile pump assist, the LV ejection fraction (EF) from 39% to 20% in response to an increase in the assist flow ratio from 50% to 100% in a left atrial drainage group (LA group) (Fig. 2) because LV end-diastolic volume (EDV) decreased prominently with the increase in the assist flow and LV end-systolic volume (ESV) showed a small decrease. However, during the pump assist in the LV apical drainage group (LV group) (Fig. 3), LVEF increased from 49% to 58% because both LVEDV and LVESV decreased as assist flow increased. The LV loops in the LA group changed in shape from wide and oblong to narrow, with no change in the LV isovolumic contraction state (Fig. 2). In contrast, in the LV group, the loops were triangular in shape and were



**Fig. 2.** Effects of non-pulsatile assist pumping drained from the left atrium on left ventricular pressure-volume loops. Decrease in left ventricular end-diastolic volume (marked by black arrows) was larger than that in left ventricular end-systolic volume, and both systolic and diastolic isovolumic phases maintained straight upward or downward lines within the loops during assist. LV: left ventricular, On: during pump assist and Off: without pump assist.



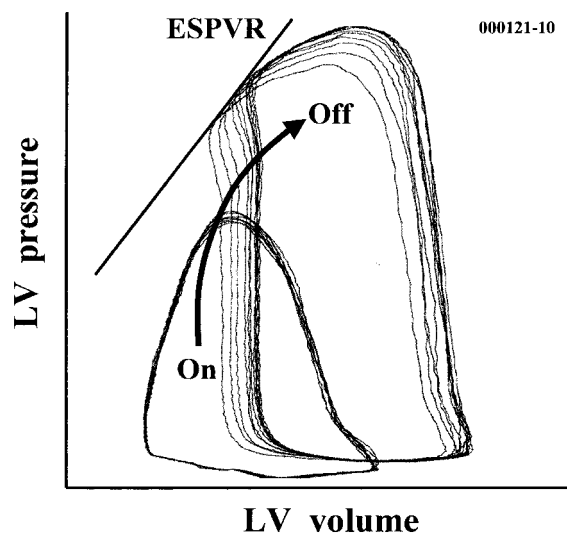
**Fig. 3.** Effects of non-pulsatile assist pumping drained from the left ventricle on left ventricular pressure-volume loops. Both left ventricular end-diastolic and end-systolic volumes were equally reduced, but isovolumic phases were absent in all loops during pump assist showing oblique upward or downward line. Abbreviations are the same as in Fig.2.

shifted to the left because of a reduction in LVEDV and LVESV in response to increases in assist flow (Fig. 3). Non-pulsatile pumping continuously drains blood from the left ventricle, which cause the up and down strokes to disappear in the isovolumic phase, and to form a triangular shaped loop. Several loops were recorded during return to native heart work just after the temporary stoppage of pump assist (on-off test), because the LV preload increased gradually from unloaded LVEDV by LVAD to fully loaded LVEDV without pump assist. Use of the on-off test just before weaning is helpful for obtaining the end-systolic pressure-volume relationship (ESPVR) only after increasing the assist flow because change in preload is magnified (Fig. 4).

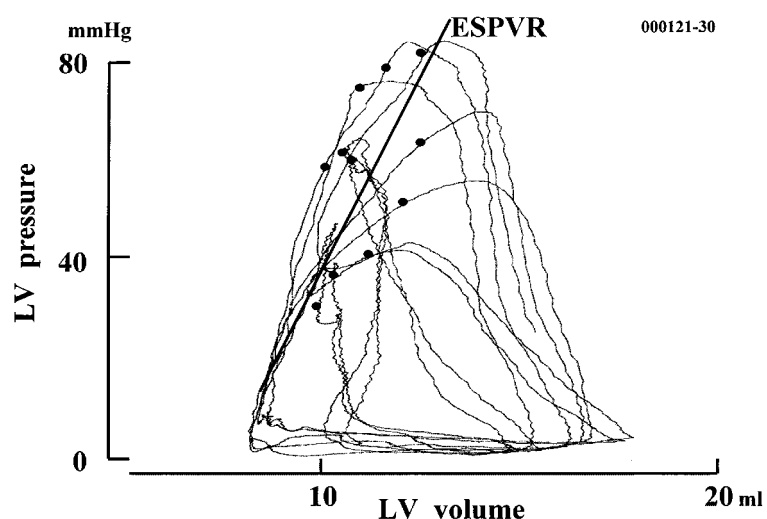
In pulsatile assist pumping, the LV loops were of vari-

ous shapes in relation to the drainage site and to synchronization with the native cardiac beat. In the LA drainage group without synchronization, LV loops changed shape from beat to beat in response to cyclic preload reduction, and it was possible to estimate ESPVR only if both the assist flow and the LV volume change were large.

In the LV drainage group, however, the LV loops changed in shape from beat to beat, and these changes are shown in Fig. 5, with the end-systolic pressure point on each loop marked with a closed circle. The ESPVR slope was determined by single regression analysis of the point data, but the value of this line is questionable. Stroke volume was different for each cycle in response to afterload change, which is induced by mismatch with the native heart ejection. These cyclic changes were dis-



**Fig. 4.** Effects of sudden cessation of non-pulsatile pumping, that the blood was drained from the left ventricle, on end-systolic pressure-volume relationship. The larger the assist flow is, the more pressure-volume loops are obtained after sudden stoppage of pumping.



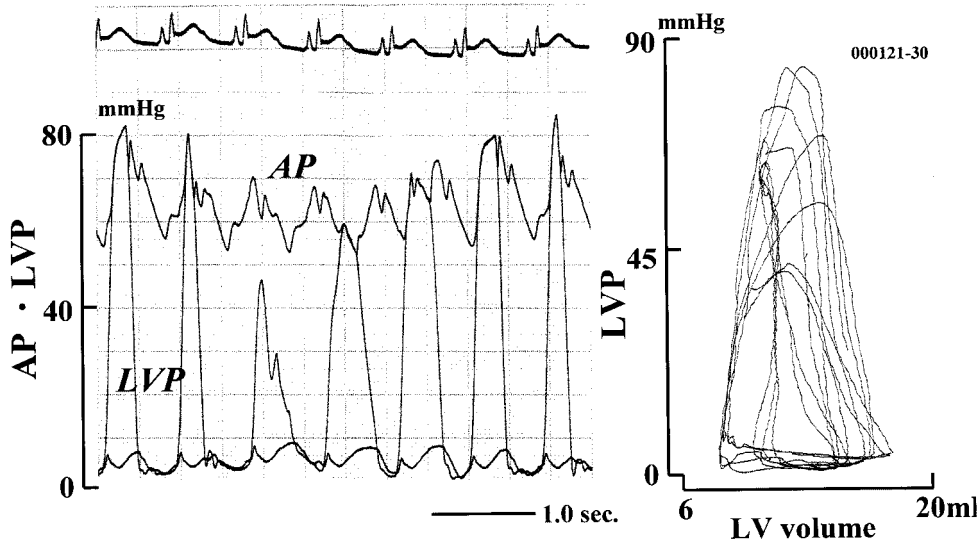
**Fig. 5.** End-systolic pressure volume relationship (ESPVR) during pulsatile pump assist drainage from the left ventricle, with asynchronous drive mode. The loops deformed in each native ventricular contraction, and points of end-systolic left ventricular pressure (closed circle) were scattered. Abbreviation is the same as in Fig.2.

advantageous to determine the ESPVR regression line of pulsatile pumping in the asynchronous mode (Fig. 6). Slide 21.

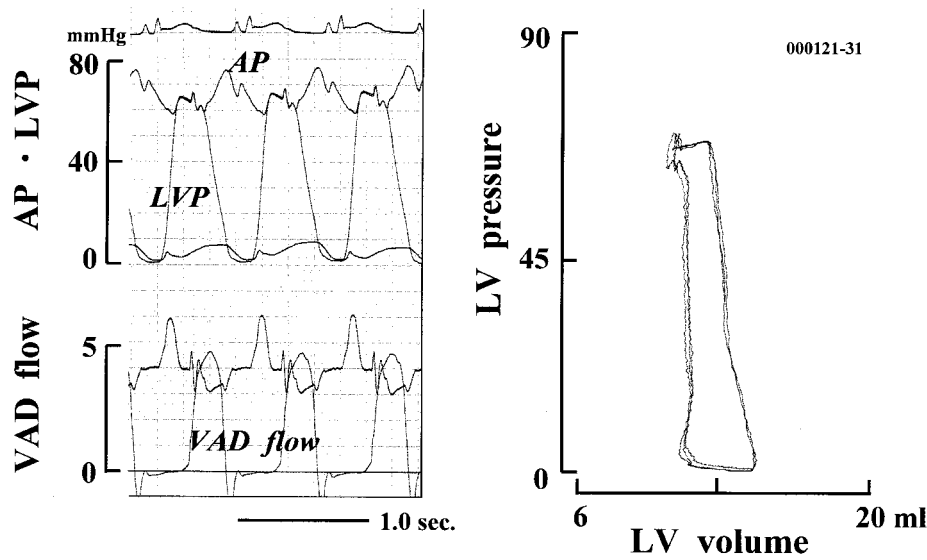
I used the synchronous mode in the LV drainage group to create an isovolumic contraction period during LVAD support. Fig. 7 shows the results of synchronous ejection from the pump during the native heart diastole: the isovolumic phase can be seen within the LV loop. The loop is very narrow, and the loop is deformed at the end-systolic point. Nevertheless, it may be possible to obtain an ESPVR if the pump stroke volume is kept constant with each ejection to induce fixed LV preload reduction. This method may be the only way to determine the ESPVR in LV drainage pulsatile pumping, but the time delay between flow in the circuit and actual blood ejec-

tion may affect the results. I also tested pumping when blood was ejected synchronously with the native heart systole (Fig. 8). In this mode, the isovolumic phase of the native cardiac cycle disappeared. Pump ejection timing is very important when calculating ESPVR in pulsatile pumping with LV drainage, which unloads the failing heart better than does pumping with the LA drainage.

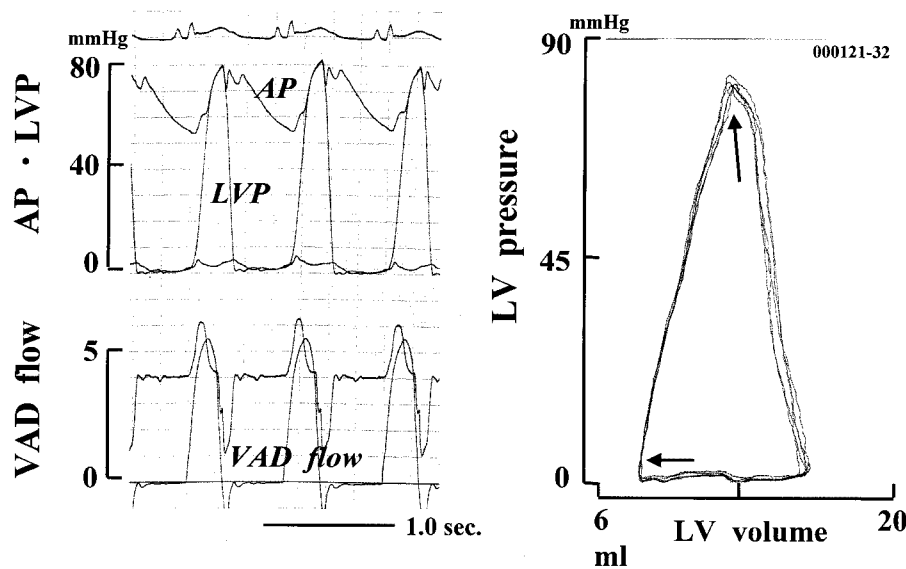
It is necessary to establish new predictors for myocardial contractility in patients on mechanical support and to evaluate the potential reserve power of the recovering myocardium to achieve long-term survival and avoid reinstitution of mechanical circulatory support or heart transplantation.



**Fig. 6.** Hemodynamic tracing (left) and loops (right) during pulsatile pump assist drained from the left ventricle, with asynchronous drive mode. AP: aortic pressure, LVP: left ventricular pressure, and LV: is the same as in Fig.2.



**Fig. 7.** Pressure waveform tracing (left) and loops (right) during pulsatile pump assist drained from the left ventricle, with synchronous pump ejection to the diastolic phase of the native left ventricle. VAD: ventricular assist device, and other abbreviations are the same as in Fig.5.



**Fig. 8.** Pressure waveform tracing (left) and loops (right) during pulsatile pump assist drained from the left ventricle, with synchronous pump ejection to the systolic phase of the native left ventricle. Abbreviations are the same as in Fig.5 and Fig.6.

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