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Echocardiographic prediction of postoperative low cardiac output syndrome in patients with mitral stenosis.

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Echocardiographic prediction of postoperative low cardiac output syndrome in patients with mitral stenosis.*

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Abstract

Thirty-eight patients were operated on for mitral stenosis between March 1979 and September 1981. Thirty-six of them were examined as to their age, symptom duration, chest roentgenograms, electrocardiograms and echocardiograms to obtain various indices of left ventricular function. The usefulness of these indices as preoperative risk factors for predicting postoperative low cardiac output syndrome (LOS) was investigated. Cases which had values of ejection fraction, cardiac index, percent fiber shortening or mean velocity of circumferential fiber shortening less than 0.45, 2.0 l/min/m2, 25% and 0.80 circ/sec, respectively, in the preoperative echocardiographic examination were associated with a greater chance of postoperative LOS. Each of these factors was independently useful as a risk factor in cardiac surgery for mitral stenosis. Moreover, it was revealed that the combination of a preoperative percent fractional shortening (%FS) of less than 30% and a cardiac index smaller than 2.0 l/min/m2 indicated a strong predisposition toward postoperative LOS.

KEYWORDS: mitral stenosis, low cardiac output syndrome, risk factor, echocardiography

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Echocardiographic Prediction of Postoperative Low Cardiac Output Syndrome in Patients with Mitral Stenosis

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Thirty-eight patients were operated on for mitral stenosis between March 1979 and September 1981. Thirty-six of them were examined as to their age, symptom duration, chest roentgenograms, electrocardiograms and echocardiograms to obtain various indices of left ventricular function. The usefulness of these indices as preoperative risk factors for predicting postoperative low cardiac output syndrome (LOS) was investigated. Cases which had values of ejection fraction, cardiac index, percent fiber shortening or mean velocity of circumferential fiber shortening less than 0.45, 2.0 l/min/m^2, 25% and 0.80 circ/sec, respectively, in the preoperative echocardiographic examination were associated with a greater chance of postoperative LOS. Each of these factors was independently useful as a risk factor in cardiac surgery for mitral stenosis. Moreover, it was revealed that the combination of a preoperative percent fractional shortening (%FS) of less than 30% and a cardiac index smaller than 2.0 l/min/m^2 indicated a strong predisposition toward postoperative LOS.

Key words : mitral stenosis, low cardiac output syndrome, risk factor, echocardiography

The postoperative low cardiac output syndrome (LOS) is a serious complication of cardiac surgery. Recently, patients with as well as without preoperative impairment of cardiac functions have been uniformly recommended to undergo cardiac surgery. In such condition, it is very important to predict preoperatively the probability of developing LOS and consequently to prepare appropriate measures for peri- and postoperative patient management. In the present study, we investigated the risk factors of postoperative LOS using non-invasive methods, particularly echocardiography, in surgical cases of mitral stenosis (MS).

Subjects and Methods

A total of 38 patients who underwent operations for MS at the Second Department of Surgery, Okayama University Hospital during the period from March 1979 to September 1981 were included in this study. Patients with very mild mitral regurgitation were included, but those having coronary arterial disorders were excluded. Among these 38 patients, 3 underwent closed mitral commissurotomy (CMC), 18 underwent open mitral commissurotomy (OMC), and 17 underwent mitral valve replacement (MVR). Two of the 17 patients with MVR underwent simultaneous tricuspid annuloplasty. The ages of the patients ranged from 24 to 65 years (average, 44 years). Sixteen patients were male, and 22 were female. One patient in the OMC group and 7 in the MVR group, developed postoperative LOS and required more than 3 days administration of catecholamines. One patient in the OMC group and 2 in the MVR group died in the hospital. LOS in the present study was defined as a serious state with peripheral circulatory failures associated with postoperative de-

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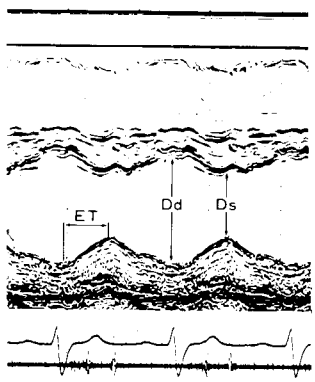

$$EDV=\frac{7.0}{2.4+Dd}Dd^3 \quad (cm^3)$$

$$ESV=\frac{7.0}{2.4+Ds}Ds^3 \quad (cm^3)$$

$$SV=EDV-ESV \quad (cm^3)$$

$$CO=SV\times HR \quad (l/min.)$$

$$EF=\frac{EDV-ESV}{EDV}$$

$$\%FS=\frac{Dd-Ds}{Dd}\times 100 \quad (\%)$$

$$mV_{CF}=\frac{Dd-Ds}{Dd\times ET} \quad (circ/sec)$$

Fig. 1 Equations for calculating various indices from the M-mode echocardiogram. EDV, end-diastolic volume; ESV, end-systolic volume; SV, stroke volume; CO, cardiac output; EF, ejection fraction; %FS, % fractional shortening; mVcf, mean velocity of circumferential fiber shortening.

crease in cardiac output (CI $<$ 2.0 l/min/m^2), oligulia, coldness of the extremities, cyanosis, and the unavoidable use of noradrenaline, isoproterenol, dopamine, *etc*.

Two of the 8 patients with postoperative LOS were excluded because their postoperative disorders were caused by peri- or postoperative troubles. The remaining 6 cases were grouped into the LOS group. A total of 36 cases were examined as to age, symptom duration, chest roentgenogram, ECG and echocardiogram. Echocardiograms were taken using a real time, phased array, ultrasonic sector scanner (Model SSH-11A, Toshiba, Inc., Tokyo, Japan), and M-mode echos were recorded at a paper speed of 50 mm/sec using a line scan recorder (Honeywell, Inc., Denver, Colorado, U. S. A.).

In this study, analysis was limited to tracings of high quality. The mean value of more than five cardiac cycles was adopted as the estimated value, and premature ventricular contractions were excluded. The mean value obtained over a five-minute period was used to calculate the heart rate. For evaluation of the left ventricular function, Teicholtz's equation was employed as shown in Fig. 1. The ejection fraction (EF) and the cardiac index (CI) were calculated for use as indices of pump function. The percent fractional shortening (%FS) and the mean velocity of circumferential fiber shortening (mVcf) were used as indices of myocardial function.

Surgery was performed, in principle, with mild hypothermia using topical cooling and cold cardioplegia. The time to perform the cardiopulmonary bypass for the OMC group was 66$\pm$24 min, which was significantly shorter than the 123$\pm$19 min for the MVR group. In the MVR group, however, there was no significant difference in the cardiopulmonary bypass time between the non-LOS group (123$\pm$20 min) and the LOS group (123$\pm$16 min).

All data are presented as the mean$\pm$SD. Statistical analysis of the variables was made by unpaired Student's t test, and that for the incidences in the two groups was by Chi-square test. P values of less than 0.05 were considered to indicate significance.

Results

Age. Four (17%) out of the 24 patients over 40 years of age were in the LOS group, and 2 (17%) out of the 12 patients under 40 years of age were in the LOS group, indicating that there was no difference due to age (Tables 1 and 2, and Fig. 2).

Symptom duration. There was a tendency for patients in the LOS group to have slightly longer symptom duration than those in the non-LOS group (Tables 1 and 2, and Fig. 2). However, three out of the 5 cases with symptom duration of more than 15 years developed LOS.

Atrial fibrillation (Af). Af was observed in 27 out of the 36 cases (Table 2). In 15 MVR cases, 14 showed Af, and all 6 cases of LOS had Af.

Table 1 Comparison between groups with and without low cardiac output syndrome (LOS)

	Non-LOS group	LOS group	Statistical significance
No. of cases			
CMC	3	0	
OMC	17	1(1)	
MVR	10	5(2)	
Sex			
Male	12	3	
Female	18	3	
	(Mean±S.D.)	(Mean±S.D.)	
Age (years)	44±9	45±7	N.S.
Symptom duration (months)	63±58	128±72	N.S.
Cardio-thoracic ratio (%)	57±8	64±9	N.S.
ECC time (min.) OMC	66±24	174	
MVR	123±20	123±16	N.S.
Ejection fraction	0.60±0.11	0.51±0.08	N.S.
Cardiac index (l/min/m^2)	2.78±0.87	1.93±0.27	$p < 0.01$
Percent fractional shortening	32.2±7.6	26.0±4.9	$p < 0.05$
mVcf (circ/sec)	1.05±0.25	0.87±0.16	N.S.

Numbers in parentheses show deaths in the hospital.
Abbreviations: CMC, closed mitral commissurotomy; ECC, extracorporeal circulation; MVR, mitral valve replacement; mVcf, mean velocity of circumferential fiber shortening; OMC, open mitral commissurotomy. N.S., not significant.

Table 2 Comparison between groups with and without low cardiac output syndrome (LOS)

Conditions		Number of cases[a] Non-LOS group	LOS group
		30(100)	6(100)
Age	≧40years	20(67)	4(67)
	<40years	10(33)	2(33)
Symptom duration	≧180months	2(7)	3(50)
	<180months	28(93)	3(50)
ECG	Af	21(70)	6(100)
	NSR	9(30)	0
Cardio-thoracic ratio	≧60%	9(30)	5(83)
	<60%	21(70)	1(17)
Ejection fraction	≧0.45	27(90)	3(50)
	<0.45	3(10)	3(50)
Cardiac index	≧2.0l/min/m^2	28(93)	2(33)
	<2.0l/min/m^2	2(7)	4(67)
Percent fractional	≧25	26(87)	3(50)
shortening	<25	4(13)	3(50)
mVcf	≧0.80circ/sec	25(83)	3(50)
	<0.80circ/sec	5(17)	3(50)

Abbreviations: AF, atrial fibrillation; mVcf, mean velocity of circumferential fiber shortening; NSR, normal sinus rhythm.
a : Numbers in parentheses indicate %.

Cardio-thoracic ratio (CTR). The LOS group tended to show larger CTR values than the non-LOS group (Tables 1 and 2, and Fig. 2). Five (36%) out of the 14 cases with CTR ≧ 60% were in the LOS group, while only 1 (5%) out of the 22 cases with CTR < 60% was in the LOS group.

Ejection fraction (EF). The LOS group tended to have smaller EF values than the non-LOS group (Tables 1 and 2, and Fig. 3). EF values less than 0.45 were observed in 3 (10%) out of the 30 non-LOS cases, while EF values less than 0.45 were observed in 3 (50%) out of the 6 LOS cases. Moreover, 3 (50%) out of the 6 patients with EF values smaller than 0.45 suffered from LOS.

Cardiac index (CI). The LOS group showed significantly ($p < 0.01$) lower CI values than the non-LOS group (Tables 1 and 2, and Fig. 4). Preoperative CI values less than 2.0 l/min/m^2 were seen in 2 (7%) out of the 30 non-LOS cases, and in 4 (67%)

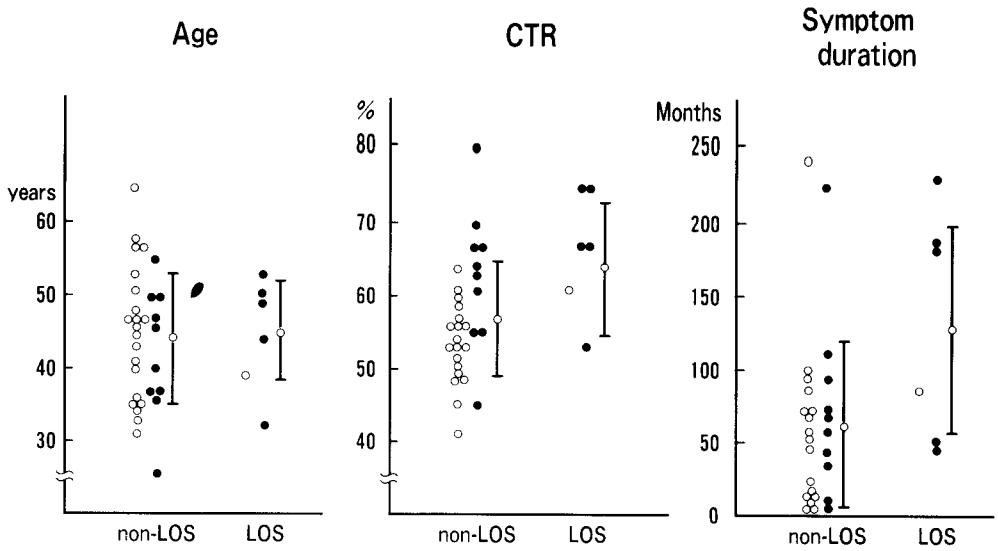

Fig. 2 Distributions of patients' ages, cardio-thoracic ratios and symptom durations in groups with and without low cardiac output syndrome (LOS), LOS and non-LOS groups. CTR, cardiothoracic ratio; MC, mitral commissurotomy (○); MVR, mitral valve replacement (●).

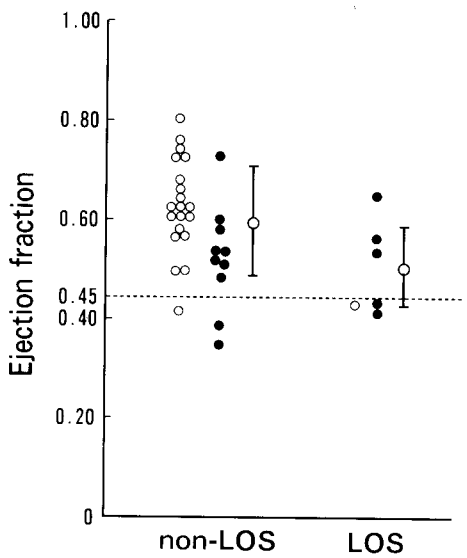

Fig. 3 Ejection fraction in the non-LOS and LOS groups. For abbreviations, see Fig 2. MC, ○; MVR, ●.

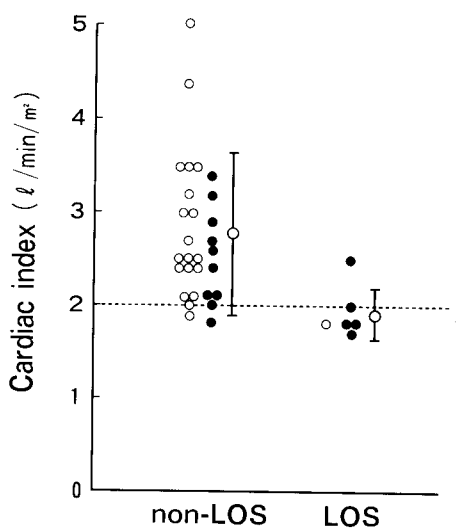

Fig. 4 Cardiac index in the non-LOS and LOS groups. Both groups were significantly different ($P < 0.01$). For abbreviations, see Fig 2. MC, ○; MVR, ●.

out of the 6 LOS cases. In the 6 cases with CI values less than 2.0 l/min/m², 4 cases (67%) postoperatively belonged to the LOS group.

The percent fractional shortening (%FS). The LOS group showed significantly ($p < 0.05$) smaller %FS values than the non-LOS group (Tables 1 and 2, and Fig. 5). Four (13%) out of the 30 non-LOS patients had %FS less than 25%, while 3 (50%) out

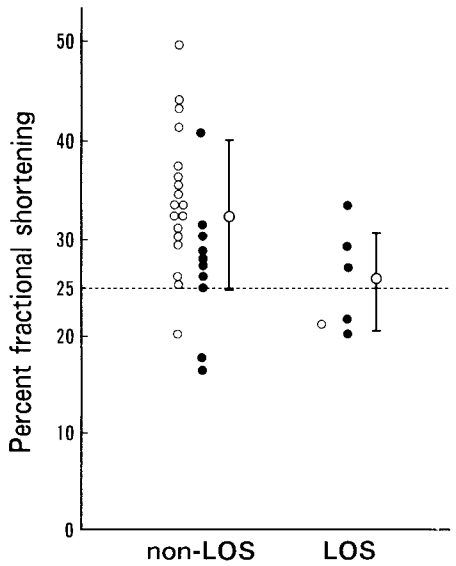

Fig. 5 Percent fractional shortening of the non-LOS and LOS groups. Both groups were significantly different ($P < 0.05$). For Abbreviations, see Fig 2. MC, ○; MVR, ●.

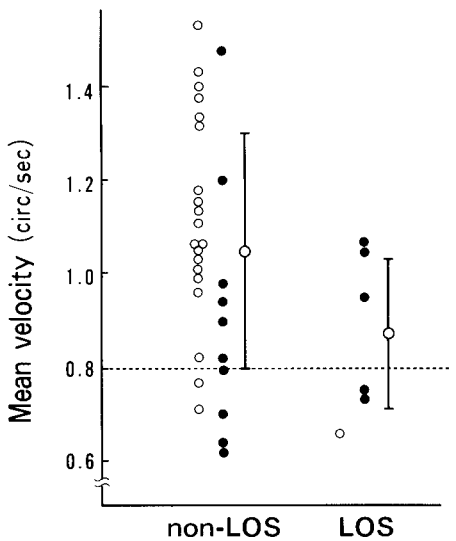

Fig. 6 Mean velocity of circumferential fiber shortening in the non-LOS and LOS groups. For abbreviations, see Fig 2. MC, ○; MVR, ●.

of the 6 LOS cases had %FS less than 25%. Further, 3 (43%) out of the 7 cases with %FS less than 25% were in the LOS group.

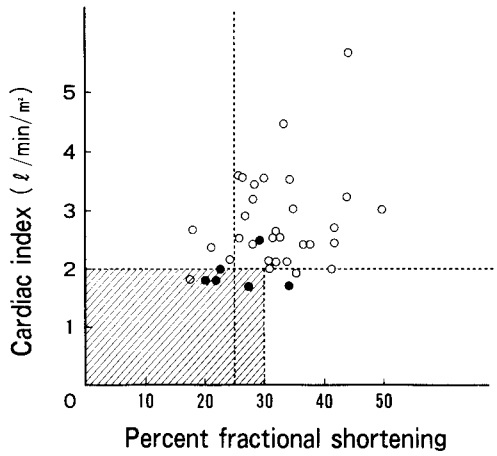

Fig. 7 Correlation between the percent fractional shortening and the cardiac index in patients with and without postoperative low cardiac output syndrome (LOS). When the rate of postoperative LOS was examined in relation to the values of a myocardial function index (percent fractional shortening, %FS) and a pump function index (cardiac index, CI) 4 out of 6 cases having CI < 2.0 l/min/m² and %FS < 30% were found to have developed postoperative LOS. Patients with LOS, ●; patients without LOS, ○.

The mean velocity of circumferential fiber shortening (mVcf). The LOS group tended to have smaller mVcf values than the non-LOS group (Tables 1 and 2, and Fig. 6).

Values of mVcf smaller than 0.80 circ/sec were observed in 5 (17%) out of the 30 non-LOS cases, but such values were observed in 3 (50%) out of the 6 LOS cases. LOS was noted in 3 cases (38%) out of the 8 cases having mVcf values smaller than 0.80 circ/sec.

Relation between myocardial function (%FS) and pump function (CI). Correlations among the postoperative occurrence of LOS, %FS (an index of myocardial function), and CI (an index of pump function) were examined (Fig. 7). Four out of the 5 cases having CI values under 2.0 l/min/m² and %FS values less than 30% were found in the LOS group, while those with CI values greater than 2.5 l/min/m² and %FS values larger than 35% were all in the non-LOS

group.

Discussion

Pump function and myocardial function have long been proposed as quantitative measures for evaluating preoperative severity and surgical risk factors in heart diseases (1,2). For measuring these parameters, invasive methods such as cardiac catheterization and cineangiography have been utilized. Recently, however, echocardiography which can be performed easily and non-invasively has become more popular (2,3). There are several limitations to the echocardiographic estimation of left ventricular volumes. First, measurements of the diameters of left ventricles are strictly dependent on the quality of the recorded echocardiograms. Second, it has been reported that M-mode echocardiography tends to underestimate end-diastolic and end-systolic dimensions and to overestimate ejection phase indices in the patient with a markedly dilated left ventricle (5). However, M-mode echocardiography is an excellent technique for defining minor axis dimensions of left ventricles, and the technique generally correlates well with cineangiography in patients with normal-sized or mildly-to-moderately dilated left ventricle(4). On the other hand, there are many papers describing significant correlations between echocardiographic and cineangiographic measurements of cardiac functions(6,7). Thus, echocardiographic measurements still provide important information about the size as well as the function of the left ventricle even with a dilated heart, particularly when meticulous care is taken to minimize potential misreading.

In the evaluation of the left ventricular function by echocardiography, pump and myocardial functions have been separately discussed. In the present study, EF and CI were utilized as indices of the former function, while %FS and mVcf were utilized for the latter.

CI reflects the final pump function of the heart, and various compensatory mechanisms are thought to take place before the CI value shows some changes. In other words, the CI value does not become abnormal unless cardiac functions deteriorate to a certain extent. For this reason, CI has long been regarded as an important risk factor for LOS. Critical CI values proposed by several investigators are as follows: 1.9 l/min/m^2 (Litwak *et al.*(8)), 2.5 l/min/m^2 (Haneda *et al.*(9)) and 2.0 l/min/m^2 (Shiguma *et al.*(10)). In agreement with these previous findings, the CI values of the LOS group in the present study were significantly smaller than those of the non-LOS group. Moreover, 4 out of the 6 cases with CI $<$ 2.0 l/min/m^2 showed postoperative LOS. The results of the present study support the importance of CI as a risk factor.

EF is a good index of the contractility of the left ventricle as a whole, and has been regarded as an important factor by many investigators. Thompson *et al.*(11) stated that when EF was smaller than 0.45, there was an apparent rise in the mortality rate at an early stage. Shiguma *et al.*(10) also reported that high mortality rate at an early stage was associated with EF values smaller than 0.40. In our cases, 3 (50%) out of the 6 cases with EF smaller than 0.45 developed postoperative LOS. Thus, EF is another important risk factor for LOS.

Since % FS and mVcf clearly reflect the myocardial function of the left ventricle, and can easily be obtained by the echocardiographic technique, these parameters have widely been utilized clinically. Gault *et al.* (12) pointed out that mVcf was a sensitive index reflecting the deterioration of myocardial contractility, based on their finding that the mVcf of patients having left ven-

tricular dysfunction was in the range of 0.11-0.87 circ/sec, and significantly smaller than that of normal subjects. In our cases, half of the LOS patients showed %FS < 25% or mVcf < 0.85 circ/sec, indicating the importance of these factors as indices of myocardial contractility.

What factors are responsible for LOS in MS? The etiology of left ventricular dysfunction in pure MS remains controversial. Rheumatic inflammation of the myocardium is common in adult patients with MS. Horwitz *et al.*(13) found reduced posterobasal shortening and also abnormalities of anterior wall motion. Posterobasal contractile abnormalities were seen in almost all patients with LOS even after surgery. Heller and Carleton (14) suggested that the rigid mitral complex results in decreased contractility of the posterobasal area.

Left ventricular pump indices (EF, CI) depend not only on the contractile state but also on preload and afterload. Reduced end-diastolic volume (EDV), subnormal EF and posterobasal, anterior and long-axis shortening abnormalities are often observed in MS patients. The reduction in EDV among MS patients is probably related to underfilling of the left ventricle.

When the development of postoperative LOS was examined in relation to %FS (myocardial index) and CI (pump function index), 4 out of 5 cases with CI < 2.0 l/min/m^2 and %FS < 30% were found in the LOS group. This result indicates that the risk of developing postoperative LOS is very high in cases with the deterioration of both myocardial function and pump function, *i.e.*, in cases whose CI is smaller than 2.0 l/min/m^2 and %FS is less than 30%.

However, no significant correlations were observed in this study between postoperative LOS and the left atrial dimension, pre- and postoperative mitral valve area, and subvalvular mitral complex, respectively.

As described above, preoperative risk factors for postoperative LOS were investigated using non-invasive methods including echocardiography. When possible development of postoperative LOS is predicted, the myocardium must, of course, be protected carefully during surgery, and postoperative subsidiary care such as the administration of catecholamines or circulatory assist with intra-aortic balloon pumping should be applied.

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