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Doppler echocardiographic evaluation of Bjork-Shiley and St. Jude Medical prostheses in the mitral position.

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Abstract

The left ventricular studies by Doppler echocardiography were performed in 50 patients with a Bjork-Shiley (B-S) mitral valve and 50 patients after implantation of a St. Jude Medical (SJM) mitral valve; the effect of valve replacement on the hemodynamic performance at rest and during bicycle exercise was determined from serial echocardiographic data. Twenty-eight patients (56%) of the B-S group and 42 patients (84%) of the SJM group showed a good response to the exercise. There was no significant difference in the effective orifice area at rest among each sizes of the B-S valve. In the SJM valve, on the contrary, the effective valve orifice area increases in parallel to the size of the SJM valve. There was a clear relation between the valve size and pressure gradient. The pressure gradient directly depends on the valve size and the effective orifice area in the SJM valve. High pressure gradient group in both prostheses had a tendency to take negative values of percent increase in stroke volume. Further, there were no cases showing positive values of percent increase in end-diastolic volume among the patients whose pressure gradients were assumed to be more than 10 mmHg at rest. It is suggested that impairment of inflow caused by the artificial valve, prosthetic valve stenosis, is possibly a significant factor causing left ventricular dysfunction, notably a decrease in stroke volume during exercise.(ABSTRACT TRUNCATED AT 250 WORDS)

KEYWORDS: prosthetic mitral valve stenosis, Bjork-Shiley valve, St. Jude Medical valve, Doppler echocardiography

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Doppler Echocardiographic Evaluation of Björk-Shiley and St. Jude Medical Prostheses in the Mitral Position

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The left ventricular studies by Doppler echocardiography were performed in 50 patients with a Björk-Shiley (B-S) mitral valve and 50 patients after implantation of a St. Jude Medical (SJM) mitral valve; the effect of valve replacement on the hemodynamic performance at rest and during bicycle exercise was determined from serial echocardiographic data. Twenty-eight patients (56%) of the B-S group and 42 patients (84%) of the SJM group showed a good response to the exercise. There was no significant difference in the effective orifice area at rest among each sizes of the B-S valve. In the SJM valve, on the contrary, the effective valve orifice area increases in parallel to the size of the SJM valve. There was a clear relation between the valve size and pressure gradient. The pressure gradient directly depends on the valve size and the effective orifice area in the SJM valve. High pressure gradient group in both prostheses had a tendency to take negative values of percent increase in stroke volume. Further, there were no cases showing positive values of percent increase in enddiastolic volume among the patients whose pressure gradients were assumed to be more than 10mmHg at rest. It is suggested that impairment of inflow caused by the artificial valve, prosthetic valve stenosis, is possibly a significant factor causing left ventricular dysfunction, notably a decrease in stroke volume during exercise. In the B-S group, 8 out of 50 patients underwent reoperation because of unacceptably high pressure gradients across the mitral valve prosthesis caused by the thrombus and tissue ingrowth, while reoperation was not required in the SJM group. We conclude that the high pressure gradient group is considered to be a reserved cohort of reoperative surgery and Doppler echocardiography can detect those patients before they become significantly impaired.

Key words : **prosthetic mitral valve stenosis, Björk-Shiley valve, St. Jude Medical valve, Doppler echocardiography**

In assessing the relative performance of mechanical valves, it is important to note that many mechanical valves are mildly or moderately stenotic even when operating to their full capacity. Recent technical progress in the design of cardiac valve prostheses has not eliminated the problem of valve dysfunction including the prosthetic valve stenosis. The diagnosis is often difficult and in-

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complete by the classical noninvasive techniques of phonocardiography and echocardiography. Doppler echocardiography is a sensitive and specific diagnostic method of assessing prosthetic valve function.

There have been few studies in Doppler echocardiographic evaluation of the prosthetic valve function long after mitral valve replacement. The purpose of this study is to evaluate the function of the 100% pyrolytic carbon St. Jude Medical (SJM) bileaflet valve and the Björk-Shiley (B-S) tilting disc prosthesis in the mitral position by Doppler echocardiography.

Materials and Methods

In the last 6 years, isolated mitral valve replacement with the SJM valve was performed in 95 patients. Fifty of these patients could be restudied serially after operation. Thirty-five females and fifteen males were ages 35–65 (mean 52 years). The average observation time was 48 months (range 12–72 months). The data was compared with the results in 50 patients with a B-S mitral valve (the standard spherical valve with a Pyrolyte carbon disc in 9 patients, the convexo-concave valve with a Pyrolyte carbon disc in 41 patients). The B-S group was composed of 38 females and 12 males, with an average age of 50 years (range 40–62 years). The average observation time was 90 months (range 72–156 months). Valve sizes used were 25-mm tissue annulus diameter in 21 patients (B-S; 9 patients, SJM; 12 patients), 27-mm in 54 patients (B-S; 25 patients, SJM; 29 patients) and 29-mm in 25 patients (B-S; 16 patients, SJM; 9 patients) (Table 1).

The following hemodynamic variables were determined: left ventricular enddiastolic volume (LVEDV), left ventricular endsystolic volume (LVESV), stroke volume (SV), cardiac output (CO), ejection fraction (EF) and mean left ventricular circumferential fiber shortening (mVcf). Supine bicycle exercise testing was performed. The exercise test consisted of two stages of 3-min intervals, starting at a work load of 25 W and finished at 50 W. During the exercise test, electrocardiogram was continuously monitored. Blood pressure was measured every one minute. Just after the exercise test, the echocardiographic examination was performed. The index of percent increase in SV (% ΔSV) was calculated as:

$$\%\Delta SV = \frac{SVex - SVr}{SVr} \times 100,$$

where SVex = stroke volume on exercise and SVr = stroke volume at rest. The index of percent increase in EDV (% ΔEDV) was calculated with the same method. We also evaluated the pressure gradient (1–4) in the prosthetic mitral valve position and the effective valve orifice area (1) by using Doppler echocardiography. In both groups, all patients were classified into two groups: 1) the high pressure gradient group; patients who showed pressure gradients more than 10 mmHg, 2) the low pressure gradient group; patients who showed pressure gradients less than 10 mmHg.

Although the two groups represented different time spans, the St. Jude Medical valve prostheses have been used since 1984, whereas the Björk-Shiley valve prostheses were implanted between 1975 and 1983, the extracorporeal circulation, myocardial protection and implantation techniques did not change.

Analysis of data. The average value of five cycles of echocardiographic recording was used. All results were expressed as the mean ± SD. A t test was used and differences were considered significant if $p < 0.05$.

Table 1 Clinical characteristics of the Björk-Shiley valve and the St. Jude Medical valve

	Björk-Shiley (n = 50)	St. Jude Medical (n = 50)
Valve lesion : MS[a]	19	21
MR[b]	31	29
Size of valve prosthesis		
25 mm	9	12
27	25	29
29	16	9
Pressure gradient of valve prosthesis		
Mean (mmHg)	11.6 ± 3.2	9.7 ± 2.4
≧ 10 mmHg	30	18
< 10 mmHg	20	32
Effective orifice area (cm^2)	1.9 ± 0.2	2.4 ± 0.3
Response to exercise		
Good	28	42
Poor	22	8

a: Mitral stenosis, *b*: Mitral regurgitation, *c*: Tricuspid regurgitation

Results

In the B-S group, nineteen of the patients (38 %) suffered from mitral stenosis (MS) and 31 (62 %) from mitral regurgitation (MR). In the SJM group, 21 patients (42 %) had mitral valve stenosis and 29 patients (58 %) had mitral regurgitation (Table 1). There were no significant differences in rhythm, duration of complaint, preoperative functional capacity in the two groups.

Postoperative hemodynamic assessment. The average pressure gradient was 11.6 ± 3.2 mmHg in the B-S group and 9.7 ± 2.4 mmHg in the SJM group ($P < 0.05$). In the B-S group, 30 patients (60 %) were classified into the high pressure group and 20 patients (40 %) to the low pressure gradient group. In the SJM group, 18 patients (36 %) were classified to the high pressure gradient group and 32 patients (64 %) to the low pressure gradient group. The exercise response of a left ventricle was good in 28 patients and poor in 22 patients in the B-S group, whereas 42 patients showed good response in the SJM group (Table 1).

The postoperative data for the LVEDV, LVESV, SV, CO, EF and mVcf are presented in Table 2. The intergroup differences of the left ventricular function at rest were not significant. During the bicycle exercise the LVEDV of the

Table 2 Comparison of prostheses in left ventricular function at rest and exercise

	Björk-Shiley		St. Jude Medical	
	High PG[a] (n = 30)	Low PG (n = 20)	High PG (n = 18)	Low PG (n = 32)
Blood pressure (mmHg)				
Rest	120 ±15	125 ±20	124 ±18	128 ±19
Exercise	140 ±19	156 ±15	146 ±12	150 ±16
Pulse rate (/min)				
Rest	74 ±12	78 ±10	69 ±10	76 ± 8
Exercise	130 ±17	126 ±14	129 ±14	138 ±11
LVEDV[b](ml)				
Rest	130 ±20	112 ±14	108 ±25	98 ±20
Exercise	102 ±18	108 ±13	98 ±20	99 ±18
LVESV[c](ml)				
Rest	55 ± 8	49 ± 6	38 ± 6	44 ± 4
Exercise	50 ± 6	42 ± 7	25 ± 6	43 ± 5
SV[d](ml)				
Rest	76 ± 4 ┐*	63 ± 5	70 ± 6 ┐*	54 ± 5
Exercise	52 ± 6 ┘	66 ± 4	57 ± 7 ┘	56 ± 8
CO[e](ml)				
Rest	5.1 ± 0.8	4.2 ± 0.6 ┐*	4.7 ± 1.0 ┐*	4.1 ± 0.8 ┐*
Exercise	6.5 ± 0.7	7.0 ± 0.9 ┘	7.3 ± 1.2 ┘	6.7 ± 0.9 ┘
EF[f](%)				
Rest	61 ± 8	59 ± 7	66 ± 8	59 ± 9
Exercise	56 ± 6	65 ± 8	68 ± 7	61 ± 6
mVcf[g](circ/sec)				
Rest	1.15± 0.23	1.03± 0.12 ┐*	1.24± 0.28 ┐*	1.22± 0.10 ┐*
Exercise	1.36± 0.21	1.38± 0.26 ┘	1.80± 0.25 ┘	1.60± 0.29 ┘

a: Pressure gradient, *b*: Left ventricular enddiastolic volume, *c*: Left ventricular endsystolic volume, *d*: Stroke volume, *e*: Cardiac output, *f*: Ejection fraction, *g*: Mean velocity of circumferential fiber shortening, * $P < 0.05$

high pressure gradient group was reduced from 130 ± 20 to 102 ± 18 ml in the B-S group and from 108 ± 25 to 98 ± 20 ml in the SJM group. The LVEDV in the low pressure gradient group was reduced from 112 ± 14 to 108 ± 13 ml in the B-S group, whereas the LVEDV in the low pressure gradient group increased from 98 ± 20 to 99 ± 18 ml in the SJM group. The LVESV of the high pressure gradient group was reduced from 55 ± 8 to 50 ± 6 ml in the B-S group and from 38 ± 6 to 25 ± 6 ml in the SJM group. The LVESV of the low pressure gradient group was reduced from 49 ± 6 to 42 ± 7 ml in the B-S group and from 44 ± 4 to 43 ± 5 ml in the SJM group. The SV of the high pressure group was reduced from 76 ± 4 to 52 ± 6 ml in the B-S group ($P < 0.05$), and from 70 ± 6 to 57 ± 7 ml in the SJM group ($P < 0.05$). The SV of the low pressure gradient group increased from 63 ± 5 to 66 ± 4 ml in the B-S group and from 54 ± 5 to 56 ± 8 ml in the SJM group. The CO of the high pressure gradient group increased from 5.1 ± 0.8 to 6.5 ± 0.7 l/min in the B-S group and 4.7 ± 1.0 to 7.3 ± 1.2 l/min in the SJM group ($P < 0.05$). The CO of the low pressure gradient group increased from 4.2 ± 0.6 to 7.0 ± 0.9 l/min in the B-S group ($P < 0.05$) and from 4.1 ± 0.8 to 6.7 ± 0.9 l/min in the SJM group ($P < 0.05$). The EF of the high pressure gradient group was reducd from 61 ± 8 to 56 ± 6 % in the B-S group, whereas increased from 66 ± 8 to 68 ± 7 % in the SJM group. The EF of the low pressure gradient group from 59 ± 7 to 65 ± 8 % in the B-S group and from 59 ± 9 to 61 ± 6

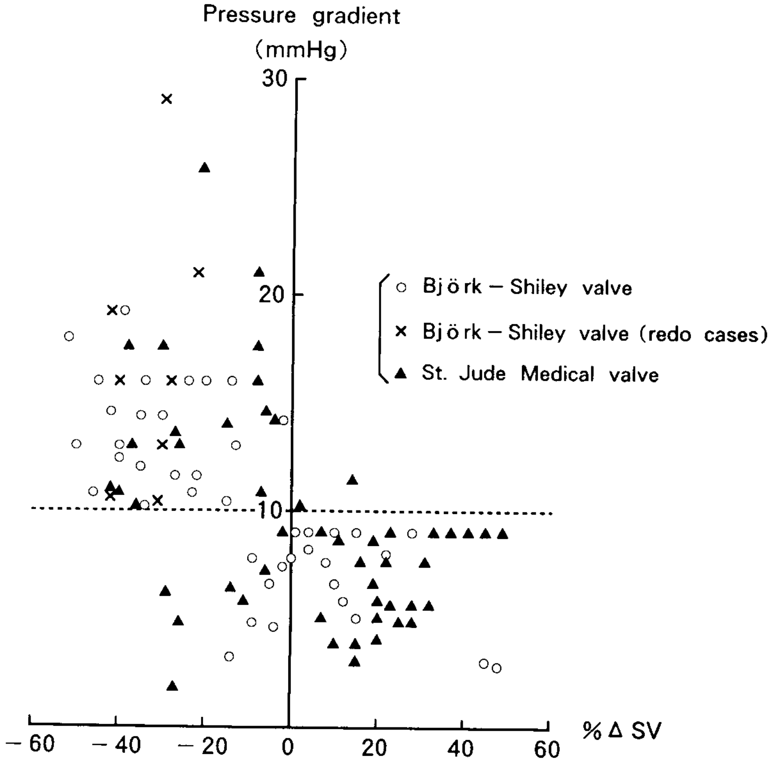

Fig. 1 Correlation between pressure gradients and index of percent increase in stroke volume (% ΔSV) in Björk-Shiley and St. Jude Medical mitral prostheses.

% in the SJM group. The mVcf of the high pressure gradient group increased from 1.15 ± 0.23 to 1.36 ± 0.21 circ/sec in the B-S group, and from 1.24 ± 0.28 to 1.80 ± 0.25 circ/sec in the SJM group ($P < 0.05$). The mVcf of the low pressure gradient group increased 1.03 ± 0.12 to 1.38 ± 0.26 circ/sec in the B-S group ($P < 0.05$), and, from 1.22 ± 0.10 to 1.60 ± 0.29 circ/sec in the SJM group ($P < 0.05$).

During the bicycle exercise, the index of percent increase in SV (% ΔSV) showed negative values in 36 (72 %) out of 50 B-S patients. All of the high pressure gradient group showed the reduction of SV. Fourteen (28 %) B-S patients who showed the increase of SV belonged to the low pressure gradient group (Fig. 1). The index of percent increase in EDV (% ΔEDV) showed negative values in 35 (70 %) patients with the B-S prosthesis. Twenty-seven (77 %) of them were classified to the high pressure gradient group (Fig. 2). Twelve (80 %) out of 15 B-S patients who showed the increase of SV belong to the low pressure group (Fig. 1). In the SJM group, 23 (46 %) out of 50 patients revealed negative values of % ΔSV (Fig. 1). Sixteen (70 %) of them were classified to the high pressure gradient group. All of the high pressure gradient group showed the reduction of % ΔEDV (Fig. 2). In both % ΔSV and % ΔEDV, the high pressure gradient group had a tendency to show negative values, whereas the low pressure gradient group did positive values (Figs. 1, 2).

When two kinds of valves with equal tissue annulus diameters were compared, differences in

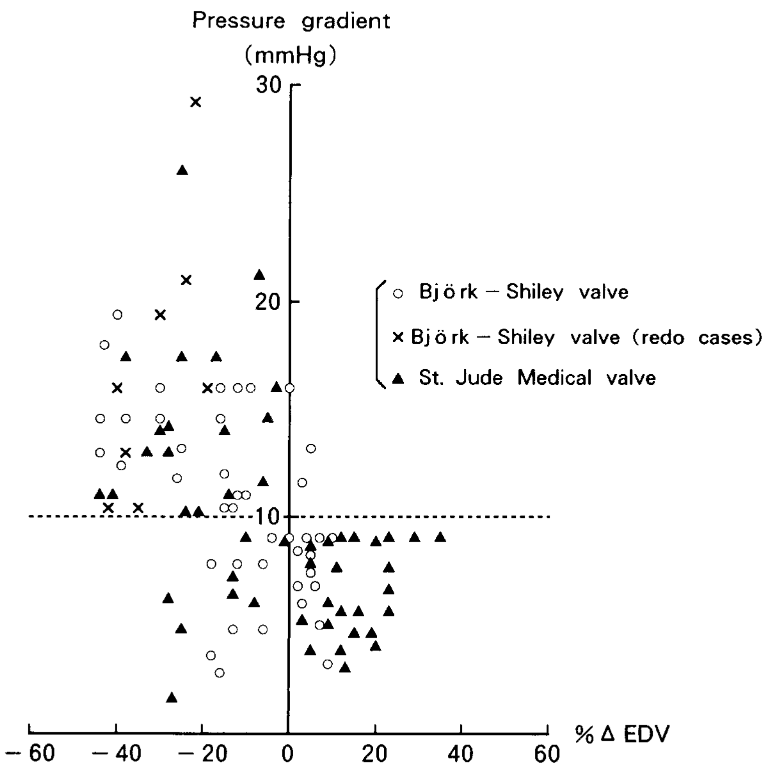

Fig. 2 Correlation between pressure gradients and index of percent increase in enddiastolic volume (% ΔEDV) in Björk-Shiley and St. Jude Medical mitral prostheses.

Table 3 Comparison of prostheses with each tissue annulus diameters

		Börk-Shiley	St. Jude Medical	
Effective orifice area (cm^2)				
Valve size	25 mm	1.85 ± 0.30	2.10 ± 0.30	P < 0.05
	27	1.85 ± 0.40	2.40 ± 0.35	P < 0.05
	29	1.87 ± 0.26	2.60 ± 0.38	P < 0.05
Geometric orifice area (cm^2)				
	25	2.48	3.09	
	27	3.03	3.67	
	29	3.95	4.41	
Pressure gradient (mmHg)				
	25	12.5 ± 3.2	12.5 ± 3.8	NS
	27	10.9 ± 4.2	9.8 ± 4.0	NS
	29	12.1 ± 3.6	7.2 ± 3.2	P < 0.05

NS: not significant

valve area were evident. In the 25-mm prostheses, the effective orifice area was 1.85 ± 0.30 cm^2 in the B-S group (spherical valve; 1.80 ± 0.03 cm^2, convexo-concave valve 1.86 ± 0.04 cm^2) and 2.10 ± 0.30 cm^2 in the SJM group ($P < 0.05$), 1.85 ± 0.04 cm^2 (B-S; spherical valve; 1.84 ± 0.03 cm^2, convexo-concave valve; 1.86 ± 0.03 cm^2) and 2.40 ± 0.35 cm^2 (SJM) in 27-mm prostheses ($P < 0.05$), and 1.87 ± 0.26 cm^2 (B-S; spherical valve; 1.83 ± 0.30 cm^2, convexo-concave valve; 1.88 ± 0.27 cm^2) and 2.60 ± 0.38 cm^2 (SJM) in 29-mm prostheses ($P < 0.05$) (Table 3). Differences in the pressure gradient across the prosthesis were also evident, when two kinds of valves with equal tissue annulus diameters were compared. In 25-mm prosthesis, the average pressure gradient was 12.5 ± 3.2 mmHg (B-S; spherical valve; 12.6 ± 2.4 mmHg, convexo-concave valve; 12.4 ± 3.0 mmHg) and 12.5 ± 3.8 mmHg (SJM), 10.9 ± 4.2 mmHg (B-S; spherical valve; 11.0 ± 3.8 mmHg, convexo-concave valve; 10.8 ± 4.0 mmHg) and 9.8 ± 4.0 mmHg (SJM) in 27-mm prostheses, and 12.1 ± 3.6 mmHg (B-S; spherical valve; 13.2 ± 3.2 mmHg, convexo-cocave valve; 12.4 ± 3.5 mmHg) and 7.2 ± 3.2 mmHg (SJM) in 29-mm prostheses ($P < 0.05$) (Table 3).

In the B-S group, 8 out of 50 patients underwent reoperation because of unacceptably high pressure gradients across the mitral valve prosthesis caused by the thrombus and tissue ingrowth, while similar surgery was not required in the SJM group.

Discussion

In the SJM prosthesis, central flow is obtained by the leaflets opening parallel to the blood stream to a full angle of 85 degrees. Therefore, the occluders create minimal obstruction to forward flow and minimize turbulance. The valve design allows for a high ratio of orifice to tissue annulus diameter (5). The B-S tilting disc valve consists of a free-floating disc suspended in a Stellite cage with one inflow (major) and one outflow (minor) strut (6). We used the standard valve with a Pyrolyte disc and the convexo-concave valve with a Pyrolyte carbon disc during 1975 and 1983. Both types of the B-S valve open to 60 degrees.

Previous reports (1–4) have described a noninvasive ultrasound Doppler technique that can determine the pressure gradient in the mitral position with an accuracy sufficient for diagnostic purposes. Noninvasive ultrasound Doppler data have also been used to evaluate B-S mitral prosthesis (7). The results indicated that the gradient in the implant might be determined noninvasively. From our experience, 60 % of the B-S group showed the high pressure gradient at rest, compared with 36 % of the SJM group. Horstkotte (8) reported that *in vivo* mean pressure gradient of the mitral position was 5.5 ± 2.7 mmHg in the B-S valve and 2.3 ± 1.4 mmHg in the SJM valve by using Doppler echocardiography. The follow-up periods in this study are much longer than in Horstkotte's, allowing more tissue ingrowth and endothelialization in the prosthesis to reduce the mitral valve area which makes pressure gradient increase. This is the reason the pressure gradient in our study showed higher values than Horstkotte's results.

An important causal factor in the differential pressure gradients is the effective valve area of the two valves. Regarding the geographic valve orifice area, the sizes of 25, 27 and 29-mm tissue annulus diameters in the B-S valve have the orifice areas of 2.48, 3.03 and 3.95 cm^2 respectively, and the sizes of 25, 27 and 29-mm in the SJM valve show 3.09, 3.67 and 4.41 cm^2 respectively. This indicates that the SJM valve orifice area is greater than the B-S type, when valves with equal tissue annulus diameters of the two kinds of prostheses are compared.

In the B-S group, the incidence of reoperation in the 29-mm B-S valve prostheses was much higher than the smaller sizes of 25 and 27-mm tissue annulus diameters. When improvement of the cardiac function was studied, the 27-mm B-S valve showed the most favorable outcome, as compared with the results of 25 and 29-mm B-S valve. From these results, it suggests that the improvement of the cardiac function and the increase of valve orifice area does not depend on the valve size itself in the B-S valve. The increase of calculated effective orifice area during exercise in the B-S valve suggests that the B-S valve is not always opening fully to the design specifications under rest condition (9). When both types (the standard spherical valve and the convexo-concave valve) of the B-S valve were compared, there were no significant differences in either the effective valve orifice area or the pressure gradient under rest condition.

In the SJM valve, on the contrary, there was a clear relation between the valve size and the pressure gradient. The SJM valve showed full opening of the leaflet even under rest condition. The effective valve orifice area increases in parallel to the size of the SJM valve. The left ventricular response to exercise was excellent in the low pressure gradient group of the SJM valve. Therefore, the pressure gradient directly depends on the valve size and the effective orifice area in the SJM valve. The diastolic pressure gradient in the SJM valve is the lowest we have found in a substantial population of artificial valves of comparable sizes.

When the relation between the indices of %ΔSV and transvalvular pressure gradients were studied, some cases (59 patients), which were assumed to have more than 10 mmHg of mitral valvular gradient at rest, have a tendency to take negative values of %ΔSV in both valves. Further, there were no cases showing positive values of %ΔEDV among the patients whose pressure gradients were more than 10 mmHg at rest. These results suggest that impairment of inflow caused by the artificial valve, namely, prosthetic valve stenosis, is possibly a significant factor causing left ventricular dysfunction, especially a decrease in stroke volume during exercise.

When the prognosis of the two valves is compared, 8 patients (16%) of the B-S group underwent reoperation, while similar surgery was not required in the SJM group. Differences in the incidence of reoperation between both types of valves is possibly due to the length of the follow-up periods. The follow-up periods of the B-S group was much longer than those of the SJM group. Although all 8 of these patients received anticoagulant therapy, the causes of subsequent surgery were mainly due to thrombosed valve or tissue ingrowth of the prosthetic valve. Those complications of the prosthetic valve could be detected by the serial measurement of the pressure gradients in the long-term postoperative periods. The high pressure gradient group may be a reserved cohort of reoperation. For this reason, the high pressure gradient group should be followed up carefully after mitral valve replacement. We conclude that the long-term follow-up of patients with mitral prosthetic valves by using Doppler echocardiography is valuable in detecting prosthetic valve stenosis.

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