Doppler sonographic evaluation of mechanical and bioprosthetic mitral valve prostheses during exercise with a rate corrected pressure half time

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Abstract

Objective—To compare the effect of exercise on pressure half time in patients with mechanical or bioprosthetic mitral valves. A relative pressure half time (pressure half time as a percentage of RR interval) was used in an attempt to correct for the shortening of the diastolic time interval caused by the increase in heart rate during exercise and thus to uncover the effects of valve design on pressure half time during exercise.

Patients—Twenty clinically stable (New York Heart Association grade I-II) patients with mechanical ($n = 12$) or bioprosthetic ($n = 8$) mitral valves (median age 51) years. The median time since valve replacement was 42 months.

Methods—Continuous wave Doppler echocardiography from the apical view at rest and during moderate supine bicycle exercise (50 W).

Results—During exercise the mean (SD) heart rate increased from 79 (12) to 101 (12) beats per minute (95% confidence interval (95% CI) of difference, 15 to 29/min) and the peak pressure gradient from 11 (5) to 18 (6) mm Hg (95% CI of difference 5 to 9 mm Hg). The pressure half time decreased from 114 (30) to 78 (26) ms (95% CI of difference 30–42 ms). There was no difference between the valve types. The relative pressure half time remained unchanged in patients with mechanical valves during exercise (13 (4) rest and 13 (5)% exercise, respectively) and decreased in patients with bioprostheses (17 (3) and 12 (3)%, respectively (95% CI of difference 2 to 8%, $p = 0.025$).

Conclusions—In patients with mechanical mitral valves the decrease in the pressure half time during exercise is probably mostly the result of the shortening of the diastolic time interval with increasing heart rate whereas in patients with bioprosthetic valves an increase in functional valve area may contribute to the shortening of pressure half time during exercise.

Exercise Doppler echocardiography may be useful in the evaluation of prosthetic mitral valves.¹ In native valves pressure gradients tend to increase and pressure half time tends to decrease during exercise.² In patients with

mitral valve prostheses the calculation of pressure gradients from flow velocities has been shown to yield reliable results.^{3,4} Though the area of the bioprosthetic mitral valve as calculated from the pressure half time at rest did not show a significant correlation with an in vitro model⁵ it was useful in distinguishing normal from obstructed mitral bioprostheses.^{4,6} In patients with mitral prostheses pressure half time at rest has been shown to be dependent on diastolic filling time but only 19% of the changes of the pressure half time could be explained by this factor.⁷ The influence of increasing heart rates during exercise on pressure half time in patients with mechanical or bioprosthetic mitral valves has not been reported yet to our knowledge.

We therefore compared the Doppler sonographic performance of clinically normal mechanical and bioprosthetic mitral valves in exercising patients and corrected the pressure half time for heart rate in an attempt to uncover effects of exercise and valve design on pressure half time.

METHODS

Twelve patients with mechanical mitral valves (five with St Jude Medical prostheses, five with Omniscarbon tilting disc, and two with Starr-Edwards ball prostheses) and eight patients with Ionescu-Shiley mitral bioprostheses were examined. All patients were clinically stable and in New York Heart Association functional class I-II. Patients were studied at rest and during moderate exercise in supine position by a non-imaging continuous wave Doppler transducer from the apical approach (Hewlett-Packard 77070A). Appropriate care was taken to record the maximal velocities and clearest signals possible. The exercise consisted of two minutes at 25 W followed by two minutes at 50 W of supine bicycle exercise. The position of the Doppler probe was held constant during exercise. Recordings were made at 50 mm/s paper speed at rest and during the last minute of exercise. When the recordings during exercise were not of satisfactory quality we replaced them with those made immediately after exercise (three patients). At least three beats in patients in sinus rhythm (17 patients) and five beats in patients with atrial fibrillation (three patients) were averaged. In all patients peak gradients (by the modified Bernoulli equation) and pressure half time were obtained by two investigators by hand.² The relative pressure half time ($t_{1/2}$) as percentage of the total RR interval

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was calculated to correct for changes in heart rate and corresponding shortening of diastole^{7 8}:

$$\text{relative } t_{\frac{1}{2}} = t_{\frac{1}{2}} \times 100/\text{R interval.}$$

M mode echocardiography of the parasternal long axis view at the level of the papillary muscles was used to obtain the end diastolic left ventricular diameter and the shortening fraction.

STATISTICAL ANALYSIS

All values are expressed as mean (SD). Rest and exercise values were compared by the Wilcoxon signed rank test and the two valve types were compared by the Mann-Whitney U test. A p value of ≤ 0.05 was regarded as significant (two tailed test). Confidence intervals (95%) were calculated where appropriate.

Results

PATIENTS

Patients with mechanical valves were 30–61 years old (mean 51, median 51 years) and had the valve implanted 12–192 months previously (mean 63, median 42 months). In patients with bioprostheses the respective values were 30–71 years (mean 51, median 50) and 12–153 months (mean 57, median 42). The left ventricular end diastolic diameter was 51 (9) mm (range 36–66 mm) and the shortening fraction was 33 (8)% (range 22–46%) in the patients with mechanical prostheses. In patients with bioprostheses the corresponding values were 48 (11) mm (range 35–65 mm) and 36 (7)% (range 25–46%). There were no significant differences in valve size, patient’s age, left ventricular diameter, shortening fraction or time elapsed since implantation of the prosthesis between the two groups. Two patients in each group had mild aortic regurgitation detected

by Doppler sonography. Tables 1 and 2 show the values of pressure gradient and pressure half time in patients with mechanical and bioprosthetic valves.

HEART RATE AND PRESSURE GRADIENTS

Two patients with mechanical and one with a bioprosthetic mitral valve were in chronic atrial fibrillation. During exercise the heart rate increased from 75 (9) at rest to 100 (10) beats per minute in patients with mechanical valves and from 84 (13) to 102 (14) beats per minute in patients with bioprostheses (95% CI of difference, 15 to 34 and 5 to 30 respectively). The peak pressure gradient in patients with mechanical valves rose from 9 (2) to 16 (3) mm Hg; in patients with bioprostheses it increased from 14 (8) to 21 (9) mm Hg (95% CI of difference 5 to 8 and 3 to 12 respectively). In both groups the increase in heart rate and peak pressure gradient during exercise was statistically significant (p ≤ 0.012).

PRESSURE HALF TIME

In patients with mechanical valves the pressure half time decreased from 106 (26) ms to 80 (25) ms and in patients with bioprostheses it fell from 124 (33) ms to 83 (27) ms (95% CI of difference 13 to 39 and 23 to 79 respectively). In both groups the difference in pressure half time between rest and exercise was significant (p ≤ 0.012) but no difference was detected between the groups. However, when the pressure half time was expressed as a percentage of the RR interval (relative pressure half time) to correct for heart rate increase and shortening of the diastolic time interval, patients with mechanical prostheses showed no change in relative pressure half time (13 (4) % at rest and 13 (5)% during exercise) in contrast to the patients with bioprostheses who had a significant (p = 0.025) decrease from 17 (3)% at

Table 1 Data on patients with mechanical prostheses

Patient	Type	Size (mm)	dp rest (mm Hg)	dp ex (mm Hg)	t½ rest (ms)	t½ ex (ms)	t½% rest (%)	t½% ex (%)
1	OC	25	12	22	110	90	16	14
2	OC	27	8	12	138	138	17	28
3	OC	29	7	14	71	52	8	9
4	OC	27	11	19	138	55	20	9
5	OC	24	8	15	124	92	17	15
6	SE	30	11	14	86	65	12	10
7	SE	30	7	13	148	115	15	17
8	SJM	29	7	13	92	62	11	11
9	SJM	29	10	21	100	77	11	12
10	SJM	27	9	14	113	85	16	13
11	SJM	27	13	19	79	74	9	14
12	SJM	25	9	18	75	62	9	9

dp, pressure gradient; ex, exercise; OC, Omnicarbon valve; SE, Starr-Edward; SJM, St Jude mechanical; t½, pressure half time; t½%, relative pressure half time as a percentage of RR interval.

Table 2 Data on patients with bioprostheses

Patient	Type*	Size (mm)	dp rest (mm Hg)	dp ex (mm Hg)	t½ rest (ms)	t½ ex (ms)	t½% rest (%)	t½% ex (%)
1	Bio	25	14	21	175	87	18	14
2	Bio	24	7	13	129	62	19	10
3	Bio	25	11	32	130	47	18	9
4	Bio	27	12	14	105	92	15	15
5	Bio	29	8	15	81	67	12	11
6	Bio	25	21	24	157	129	20	16
7	Bio	27	29	36	138	50	19	10
8	Bio	29	9	16	85	59	16	11

*All Ionescu-Shiley bioprostheses. See footnote to table 1 for abbreviations.

Figure 1 Relation between pressure half time and heart rate in patients with mechanical mitral valves at rest and during exercise (paired points for each patient are connected with line).

Figure 2 Relation between pressure half time and heart rate in patients with bioprosthetic mitral valves at rest and during exercise (paired points for each patient are connected with line).

rest to 12 (3)% during exercise (95% CI of difference, 2 to 8%). Figure 1 shows the relation between the pressure half time and the rate for mechanical prostheses and fig 2 shows the relation for bioprostheses).

Discussion

Mitral prostheses are slightly stenotic at rest.^{9 10} Exercise testing during cardiac catheterisation is commonly used to assess the physiological relevance of stenosis of the native mitral valve. When exercise Doppler echocardiography was used in patients with mechanical mitral valve prostheses a significant increase of peak and mean pressure gradients was seen.¹ However, the behaviour of the pressure half time in mechanical and bioprosthetic valves during exercise has not been compared and the potential influence of the increase of heart rate during exercise has not been taken into account.

INFLUENCE OF EXERCISE ON PRESSURE GRADIENTS
In our patients with bioprosthetic or mechanical mitral valve prostheses moderate exercise significantly increased peak pressure gradients by about 70%. Despite their different designs, during exercise the peak pressure gradients of mechanical and bioprosthetic valves increased to the same extent. This finding accords with

the results from Reisner *et al*¹ and resembles the in vitro and in vivo data reviewed by Rashtian *et al*.^{9 10}

INFLUENCE OF EXERCISE ON PRESSURE HALF TIME
Cardiac output can influence pressure half time at rest in patients with mechanical mitral prostheses.⁷ However, the assumed increase in cardiac output during exercise did not lead to an increase in the calculated mitral valve area in the patients investigated by Reisner *et al*¹ and the relative pressure half time in our patients with mechanical mitral prostheses remained unchanged during exercise. Thus cardiac output may be a factor of minor importance in influencing pressure half time at higher heart rates in patients with prosthetic mitral valves.

Several other factors, such as the loading conditions of the ventricles, compliance of the atria and ventricles, as well as the diastolic time interval influence atrial emptying and thus pressure half time.^{7 8 11} Of these only the diastolic time interval is easily measured. A linear relation between the RR interval and the diastolic time interval was confirmed recently.⁸ We therefore attempted to correct for the decrease in diastolic time interval by calculating a relative pressure half time as a percentage of the RR interval. The analysis of the changes in the pressure half time induced by exercise in our patients showed a significant decrease of about 30% in both groups. However, when the relative pressure half time was calculated a different pattern was found: in patients with mechanical mitral prostheses there were no significant changes during exercise but in patients with bioprostheses there was a significant ($p = 0.025$) decrease of 27%. This shows that the pressure half time was shortened more than that of the RR interval during exercise in patients with bioprostheses. The lack of changes in the relative pressure half time during exercise in patients with mechanical mitral valves accords with data generated by cineradiographic methods and with in vitro data¹²⁻¹⁴ which showed an unchanged fully open valve at rest and during exercise in these prostheses. This contrasts with invasive studies based on the Gorlin formula that repeatedly showed an increase in the valve area of mechanical mitral prostheses during exercise.⁹ Conversely, high speed photography and video analysis of bioprosthetic valves showed a flow dependent increase of their opening area over a physiological flow range in vitro.^{15 16} This increase in functional opening area of mitral bioprostheses with higher flow rates accords well with our finding of a decrease in relative pressure half time during exercise in patients with bioprostheses.

LIMITATIONS OF THE STUDY

Technical aspects

The Doppler echocardiography of patients during or after exercise is technically demanding. Respiration and high heart rates make it difficult to record and interpret. We tried to avoid these problems by using moderate exercise that produced a mean increase in heart rate of 28%. In all our patients the E wave was

sufficiently well delineated to allow the analysis of pressure half time during or immediately after exercise in at least 3–5 heart beats. The nature of this study made it difficult to assess inter and intra observer errors without repeating the exercise test on a different day; and variation over time would have added an error of unknown magnitude. However, we believe that the examination of all patients by the same two investigators together will have distributed any methodological variability equally in both groups and will have enabled us to draw valid conclusions about differences between the groups.

DIASTOLIC TIME INTERVAL AND PRESSURE HALF TIME

Although the pressure half time seems to be related to the diastolic filling period, in a previous study, the relation was weak⁷ explaining only 19% of its variability. In our patients we did not directly measure the diastolic time interval: we replaced it with the RR interval because of the evidence of a linear relation between these two variables.⁸ Both of these limitations preclude our drawing any firm conclusions about the mechanisms of the different behaviour of the relative pressure half time in the two patient groups. Nevertheless, in bioprostheses, a flow dependent mitral valve area, as seen in vitro, would be a possible and plausible explanation.

CONCLUSIONS

In patients with mechanical or bioprosthetic mitral valve prostheses peak pressure gradients increased considerably during moderate exercise. The pressure half time shortened significantly in both groups, but when the pressure half time was calculated as a percentage of the RR interval only the bioprosthetic valve group showed a decrease. Therefore in patients with mechanical mitral valves most of the decrease of the pressure half time during exercise is

probably the result of a shortening of the diastolic time interval with increasing heart rates whereas in patients with bioprosthetic valves a true increase in functional valve area may contribute to the shortening of the pressure half time during exercise.

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