Effect of changes in heart rate on pressure half time in normally functioning mitral valve prostheses

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SUMMARY To test the validity of a relation between the pressure half time and the diastolic time interval, previously shown in a pulse duplication system, eight patients with prosthetic mitral valves and permanent pacemaker systems were studied. Recordings were made from the apex by continuous wave or pulsed Doppler echocardiography at heart rates between 75 and 150 beats/min. The pressure half time was found to be closely correlated with the diastolic time interval although there was individual variation and in three prostheses the pressure half time attained a plateau when the diastolic time interval was more than 300 ms.

It is likely that the orifice area is the main controller of pressure half time where there is stenosis of the prosthesis, but that other factors such as ventricular or atrial compliance and the diastolic time interval may modify or obscure the effect of orifice area in normally functioning prosthetic valves.

The pressure half time is a measure of the rate of depressurisation of the left atrium and it is thought to be a comparatively flow independent indicator of orifice area in native mitral stenosis.¹⁻³ There are, however, inconsistencies where pressure half time is considered in normally functioning mitral prostheses. The pressure half time correlates poorly with annulus diameter and may vary widely for one valve type between studies.^{4,5} There may be little difference in pressure half time in valves of widely different design.⁶ It is therefore likely that where the area of the orifice is comparatively large, other factors such as ventricular or atrial compliance and diastolic filling time may have a disproportionate effect on pressure half time.^{7,8} Most studies, however, that have attempted to establish normal ranges for prosthetic function did not report information about flow or ventricular function.^{4,6,9}

We showed in a pulse duplicator system with a regular cycle rate and stroke volume that pressure half time is independent of stroke volume but directly related to the diastolic time interval.⁷ In the present study we used patients with permanent pacemaker generators as a model with constant cycle length to test the effect of changing diastolic length on pressure half time.

Patients and methods

PATIENTS AND PROCEDURE

All nine patients on the King's College Hospital database with both mitral prostheses and permanent implanted multiprogrammable pacemaker generators were recruited. In one, differences in the timing of atrial activity made the shape of the Doppler waveform too variable for analysis. The table shows details of the remaining eight patients. All had VVI systems. No patient had symptoms or signs of either heart failure or prosthetic dysfunction although one (case 2) had a dilated, hypokinetic left ventricle on echocardiography. Imaging and Doppler echocardiography showed normal cusp or occluder motion in all patients and no appreciable regurgitation.

The procedure was explained and the patient asked to lie semi-recumbent in the left lateral position. A 1.9 MHz continuous wave transducer was used except in one patient with a bioprosthesis in whom pulsed Doppler with a duplex 2.5 MHz transducer with the sample volume at the level of the stent tips gave better signals. The probes were placed in the apical position and oriented with the forward flow by means of colour flow mapping. An assistant increased the pacemaker rate by 10 beats/min up to the highest programmable rate and then reduced it below the normally set rate until the patient's spontaneous rhythm supervened. After a delay of 20 seconds at each increment at least 20 Doppler signals were recorded onto thermal paper run at 100 ms/s.

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Table Demographic data in patients with permanent pacemaker generators and mitral prostheses

Case	Valve type	Pacemaker type	LV function	Rhythm before pacing
1	B-S	Teletronics Optima	Normal	CHB
2	B-S	Teletronics Optima	Poor	CHB
3	S-E	Teletronics Optima	Normal	Slow AF
4	C-E	Teletronics Optima	Normal	Slow AF
5	C-E	Biotronic Neos	Normal	Sinus pauses
6	C-E	Cordis Stanicor Gamma	Normal	Slow AF
7	S-E	Siemens 748T Dialog	Normal	Sinus pauses
8	S-E	Teletronics Optima	Normal	CHB

AF, atrial fibrillation; B-S, Björk-Shiley; C-E, Carpentier-Edwards; CHB, complete heart block; LV, left ventricular; S-E, Starr-Edwards.

DATA ANALYSIS AND STATISTICAL ANALYSIS

Pressure half time was taken as the time for peak left ventricular inflow velocity to fall to $0.7 \times$ peak.¹ Many of the recordings had nonlinear deceleration slopes so we made measurements directly from the outline of the envelope rather than attempting to rule lines tangential to the waveform. Pressure half time was measured over 5–8 complexes at each cycle length and the mean and standard deviation were calculated. The diastolic time interval was measured from the start of the opening artefact to the midpoint of the closing artefact on each complex and the mean value was taken. Regression lines were drawn with standard commercially available computer software (Amstat1).

Results

RELATION BETWEEN DIASTOLIC INTERVAL AND CYCLE LENGTH

The diastolic time interval was directly related to cycle length ($r = 0.97$, $y = 0.80x - 222.64$, 95%

Fig 1 Diastolic time interval plotted against RR interval. The regression line is shown in bold.

confidence interval for the slope 0.76 to 0.84 and for the intercept 188.75 to 256.53 ($p < 0.00001$) (fig 1).

RELATION BETWEEN PRESSURE HALF TIME AND DIASTOLIC TIME INTERVAL

Spectral recordings were generally satisfactory except in some patients at high rates when dense valve artefacts made measurement of pressure half time difficult. These traces were not measured. Examples of spectral recordings are given in fig 2a and b. In patient 3, the waveform had a fast deceleration phase and a subsequent slower phase which was seen only at lower heart rates. In the other patients, the basic configuration did not change but the waveform became wider at lower rates.

The pressure half time was directly related to the diastolic time interval ($r = 0.81$, $y = 8.77 + 0.28x$, 95% confidence interval for intercept -5.71 to 23.25 and slope 0.23 to 0.33 , $p < 0.00001$) (fig 3). In most patients the relation between the pressure half time and the diastolic time interval was linear, although in two patients (cases 4 and 6) with a bioprosthesis and one with a Starr-Edwards prosthesis (case 7), it was curvilinear (fig 4). The slope of the relation was not dependent on valve type.

Discussion

In native mitral stenosis the pressure half time correlates well with the orifice area assessed by the Gorlin formula at simultaneous catheterisation.¹⁰ The same assumption underlies the universal use of pressure half time in the numerous studies attempting to define normal ranges for prosthetic mitral function.^{4-6,9,11,12} Some⁶ have even estimated orifice area from pressure half time by an empirical formula ($220/\text{pressure half time}$) derived specifically for native stenosis that has never been validated adequately for prostheses.¹ In fact, it has long been known from echocardiographic studies that the diastolic filling rate is dependent on left ventricular function as well as resistance to flow offered by the mitral valve.^{13,14} Thomas and Weyman⁸ have derived an expression

Fig 2 Two sets of left ventricular inflow recordings. (a) Continuous wave recordings from patient 3 who had a Starr-Edwards prosthesis and (b) pulsed Doppler recordings from patient 4 who had a Carpentier-Edwards prosthesis.

Fig 3 Pressure half-time plotted against diastolic time interval for all eight prostheses. The regression line from this pooled study is shown as a bold line. That from an experimental circuit is shown as a dotted line.

for pressure half time based on hydrodynamic theory which can be generalised to:

Pressure half time proportional to $(C \cdot \sqrt{\Delta p}) / MVA$

C is combined atrial and ventricular compliance, Δp is the pressure difference between atrium and ventricle at the start of diastole, and MVA is mitral orifice

area. These three factors are likely to interact to a degree that varies both with physiological and pathological state. The orifice area may be the main determinant of the pressure half time where there is a prosthetic stenosis, but in normally functioning prostheses its effect may be modified or obscured by the other factors. Thus Panidis *et al* found no difference in the pressure half time between normally functioning Starr-Edwards, Björk-Shiley, and biological prostheses in the mitral position⁶ although these valves have widely different behaviour in experimental circuits.¹⁵ The variability in the pressure half time between studies of one prosthesis may partly reflect statistical sampling or differences in technique, but it seems probable that differences in flow and ventricular function must also contribute. The mean pressure half time for Carpentier-Edwards prostheses was 90 ms in a series of 38 reported by Gibbs *et al*,⁵ 128 ms in a series reported by Hatle and Angelsen,¹⁶ and 136 ms in 29 cases reported by Ryan *et al*⁴ (which however included some Hancock prostheses).

Similarly the effect of rate on atrial or ventricular compliance, atrial pressure, and orifice area is likely to vary with valve type and the presence of ventricular dysfunction. Thus although the relation between pressure half time and diastolic interval in this study was similar to that previously shown in an experimental circuit,⁷ there was increased scatter at comparatively long cycle lengths, and in some prostheses the pressure half time reached a plateau when

Fig 4 Pressure half time plotted against diastolic time interval for prostheses in eight patients.

the diastolic interval was > 300 ms.⁷ The relation was not tested at cycle rates below 75 beats/min. The effect of diastolic length may be different in a patient in atrial fibrillation rather than paced rhythm, although when Libanoff and Rodbard used cardiac catheterisation to study patients with mitral stenosis, the pressure half time varied from 110 ms to 170 ms over cycle lengths from 500 ms to 1000 ms.³

Pressure half time may be less useful as a measure of orifice area in normally functioning prostheses than has previously been assumed. This is because it may be controlled partly by atrial or ventricular factors and varies with diastolic time interval. This study suggests that if the pressure half time of different valves is compared, cardiac cycles with a diastolic time interval of ≥ 300 ms should be chosen.

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