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What is the ideal orientation of a mitral disc prosthesis? An in vivo haemodynamic study based on colour flow imaging and continuous wave Doppler

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Doppler colour flow imaging demonstrates normal laminar flow to enter the left ventricle in diastole through the mitral inflow tract located posteriorly in the left ventricle. Laminar flow then passes around the left ventricular apex to the anteriorly located outflow tract. As this is the normal physiologic flow pattern, it would seem appropriate that in the surgical implantation of a mitral tilting disc prosthesis the greater orifice should be directed posteriorly to mimic the normal native valve flow pattern.

To determine whether variable positioning of the greater orifice had any significant haemodynamic consequences, intracavitary blood flow patterns were studied in 30 patients with mitral Björk-Shiley prostheses variously orientated in the mitral orifice. The orientation of the greater orifice (OGO) of the prosthesis was determined by fluoroscopy and the pattern of the left ventricular inflow from Doppler colour flow imaging. Twelve patients had their OGO and inflow directed towards the inflow tract (orientation I): nine patients had their OGO and inflow directed anteriorly towards the outflow tract (orientation II) and nine patients had their prosthesis with OGO and inflow in an intermediate position (orientation III). The mean prosthetic diastolic gradient, calculated using continuous wave Doppler, averaged 2·8 mmHg (±0·5 mmHg) for the 25-mm prosthesis in orientation I, but 6·0 mmHg (±0·7 mmHg) for the same size prosthesis in orientation II and 5·8 mmHg (±0·9 mmHg) with a 25-mm prosthesis in orientation III. Similarly, for prostheses of 27 mm and 29–31 mm the lowest mean diastolic gradient was found in orientation I (2·7 mmHg ± 0·8 and 2·8 mmHg ± 0·5, respectively). However, the difference in mean gradient between orientations I, II (5·6 mmHg ± 0·2 and 3·6 mmHg) and III (5·1 mmHg ± 0·7 and 3·8 mmHg ± 0·4) was less pronounced for the larger prostheses. From these results, it was concluded that the best haemodynamic result is obtained by a mitral disc prosthesis when its greater orifice is orientated posteriorly. This would appear to be especially important for the smaller disc prosthesis.

Introduction

An inherent property of a tilting disc valve prosthesis is that it has a greater and smaller orifice. A consequence of the asymmetry required in the construction of such disc valves is that a larger part of the flow is directed through the greater orifice. Because of this preferential flow pattern some cardiac surgeons routinely place a mitral disc prosthesis with the greater orifice orientated posteriorly and others place it with the latter orientated anteriorly. The former position is that which, in theory, best approximates to normal physiologic transvalvular flow.

Controversy still exists whether the orientation of a mitral tilting disc prosthesis is of any haemodynamic importance[1,2]. Previous studies on the function of mitral tilting disc prostheses have paid little attention to prosthesis orientation when analysing their results[3–5]. Cross-sectional echocardiography is limited in the investigation of prosthetic valve function, both in determining the normal opening and closing patterns of a prosthesis as well as in detecting prosthetic malfunction. Precordial Doppler studies (both continuous wave and pulsed Doppler) have added quantitative information about the presence of prosthesis stenosis, but are limited in their evaluation of

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prosthetic regurgitation because of the 'flow masking' properties of the prosthetic material from which the valves are constructed. More recently the introduction of colour flow imaging (CFI) has allowed visualization of the precise characteristics of diastolic blood flow crossing a prosthesis. Colour flow imaging is also able to visualize the subsequent patterns of blood flow through the left ventricle in diastole[6]. It was therefore the aim of our study to investigate (using continuous wave Doppler and CFI) whether the orientation of a mitral tilting disc prosthesis produced significant changes in transprosthetic and intracavitary blood flow patterns and whether any changes in flow in turn provoke any difference in transprosthetic gradient. In addition, recent studies have demonstrated that the mean diastolic gradient of a mitral valve prosthesis can increase up to 130% after exercise[7]. In order to determine whether exercise would induce any further flow abnormalities in each of the differing prosthesis orientation groups we submitted a subset of the patients to a moderate exercise protocol.

Patients and methods

The study group consisted of 30 patients, of whom 19 were women and 11 men; their age varied between 20 and 55 years (mean age 39 years). All patients were studied between 6 and 18 months after mitral valve replacement. Atrial fibrillation was present in 16 patients and sinus rhythm in 14. The heart rate varied between 60 and 82 beats min^{-1} at the time of study. All had received a Björk-Shiley tilting disc valve with a 60° angled opening and none had any other important associated valve defect. The diastolic function of all the mitral prostheses appeared normal, as far as could be judged on clinical grounds. The implanted disc valve varied in orientation. For analysis the patients were divided into the following subgroups on the basis of both prosthesis size and orientation. First, as previous studies have demonstrated that the size of the prosthesis is related to the transprosthetic gradient, we divided the patients into three subgroups related to valve size. Groups A, B and C had a 25-mm, 27-mm and 29–31-mm prosthesis, respectively. The 29- and 31-mm prostheses were analysed together because only the sewing ring diameter differed and the effective orifice area did not. A second sub-division was then made within each group depending on the orientation of the disc prosthesis. The orientation of each mitral disc valve prosthesis was determined by a chest X-ray taken in the left anterior oblique position. In this oblique view the mitral valve is seen almost as a circle, just opposite to the outflow tract and aorta. Patients with the greater orifice of their disc prosthesis orientated posteriorly were designated orientation I; those designated orientation II had the greater orifice positioned anteriorly; and those designated orientation III had an intermediate position (Fig. 1). Each patient underwent a CFI study to examine the left ventricular intracavitary flow patterns from both the apical long axis and four-chamber views. The colour flow studies were recorded using a Toshiba SSH-65A ultrasound system in the variance mode, which encodes any laminar flow approaching the transducer as red and flow that is receding as blue. Turbulence is encoded as a mosaic of mainly yellow and green colours added to the display. The transprosthesis velocity waveforms were recorded in the standard manner using continuous wave Doppler. The mean transprosthetic gradient was then derived from the continuous wave Doppler studies. In patients with sinus rhythm the mean transprosthetic gradient was calculated from 10 consecutive beats and in patients with atrial fibrillation the mean transprosthetic gradient was calculated from 15 consecutive beats. An important factor which influences gradient is the cardiac output. In our study cardiac output was not measured, but to overcome this problem, we had selected patients in NYHA classes I–II, thus assuming that cardiac output in our patients was normal.

Results

Colour flow imaging demonstrated three differing diastolic flow patterns within the left ventricle, each specific for each of the three tilts of disc valve orientations. In Fig. 2 the characteristic inflow pattern recorded in orientation I is demonstrated. Laminar diastolic inflow, seen as red, occurs predominately through the larger posterior valve orifice and is directed laterally towards the ventricular free wall. Flow then passes down the posterolateral wall to the ventricular apex. The flow then turns around the apex and passes up the ventricular septal aspect towards the left ventricular outflow tract (this flow direction is represented in blue). Patients with orientation II demonstrated a very different inflow pattern (Fig. 3) with the majority of inflow (red) directed anteriorly towards the septum. Flow then passed along the septum to the apex, turned in the

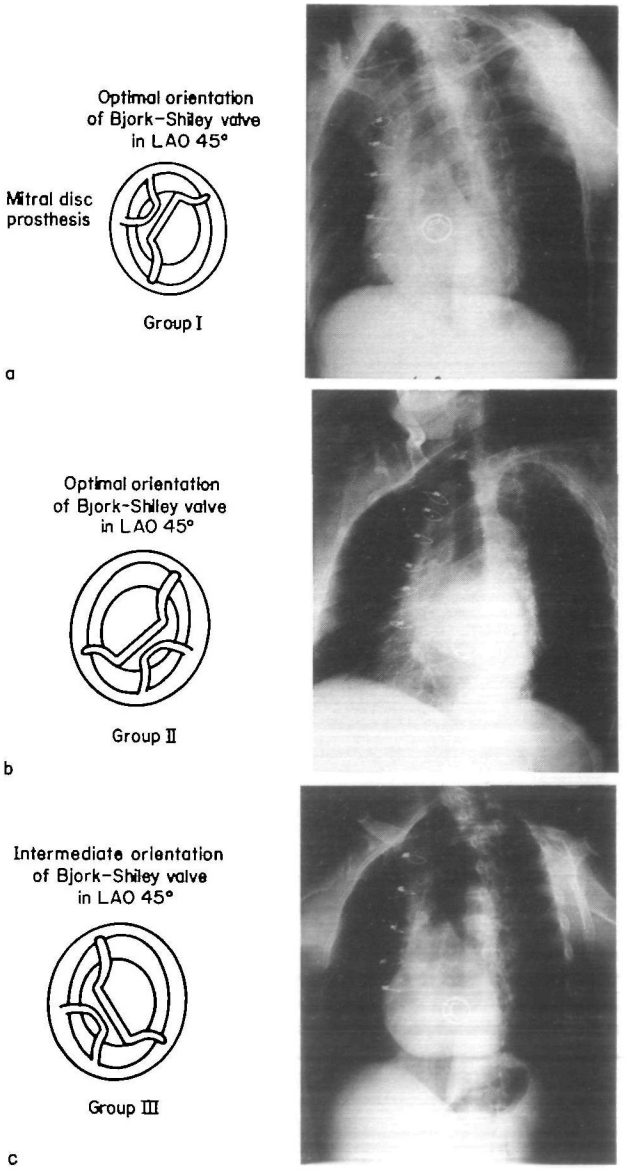
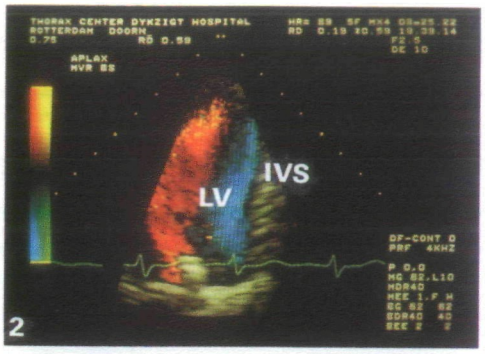
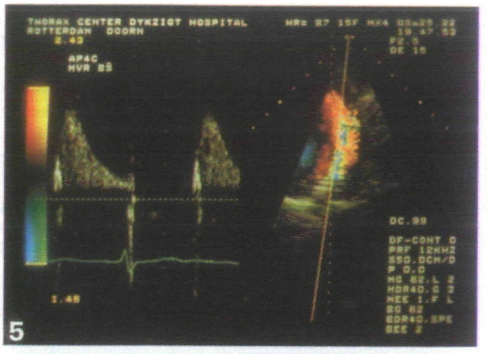
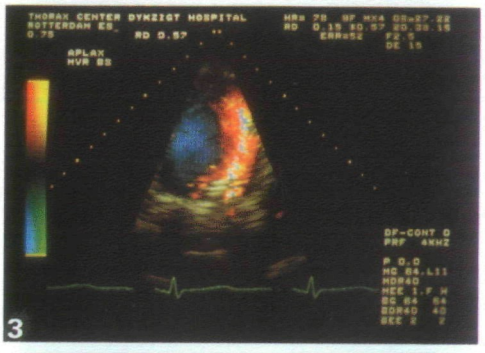


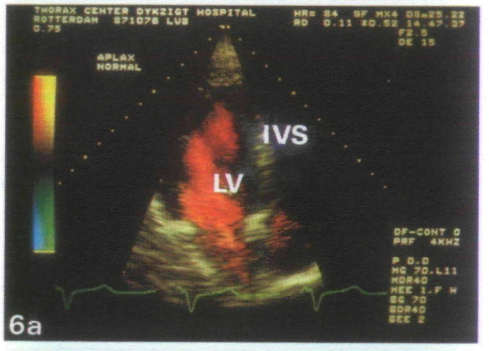
Figure 1 The radiological method of determining the Björk-Shiley prosthesis orientation in the mitral position. The chest X-ray is taken in the left anterior oblique position. a, The radiological appearance of the prosthesis with the greater orifice positioned posteriorly. b, The radiological appearance in Group II patients with the larger orifice positioned anteriorly towards the left ventricular outflow tract. c, The radiological appearance of the prosthesis orientation in Group III patients with an intermediate location of the greater orifice.

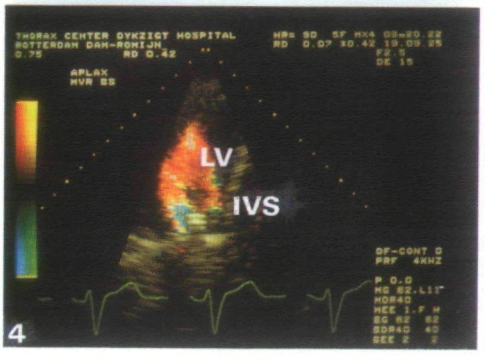
apex and then was directed superiorly for some distance along the lateral ventricular wall before turning medially towards the subaortic area. In this 'figure of eight' flow pattern, inflow and outflow clearly cross. In patients with orientation III with an intermediate prosthesis orientation inflow entered











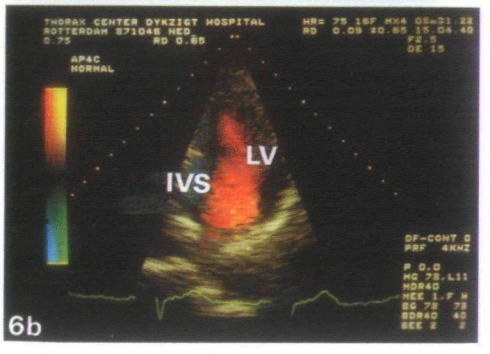


Figure 2 The characteristic intraventricular flow pattern recorded in the apical long axis view in patients with a posterior orientation of the greater orifice of the mitral prosthesis. Note the red inflow initially detected towards the lateral free wall and then turning round the apex and visualized in blue when directed towards the left ventricular outflow (LV = left ventricle, IVS = interventricular septum).

Figure 3 The characteristic colour flow pattern recorded in the apical long axis view in patients with an anterior orientation of the greater orifice of the mitral prosthesis. Note the mitral inflow is directed towards the interventricular septum.

Figure 4 The colour flow pattern in an apical long axis view from a patient with an intermediate orientation of the mitral prosthesis. Inflow is now directed towards the centre of the left ventricular cavity.

Figure 5 Björk-Shiley mitral valve prosthesis. Apical four-chamber view. The transprosthetic mitral gradient is determined by continuous wave Doppler by parallel alignment of the interrogating ultrasound beam with the mitral inflow (right panel). The recorded maximal velocity envelope is demonstrated in the left panel.

Figure 6 a, Colour flow imaging of normal transmitral flow as seen from the apical long axis view. b, Normal transmitral colour flow map — apical four-chamber view.

Table 1 Transprosthetic mean gradient of Björk-Shiley mitral disc prostheses

	Mean gradient Bj-Sh no 25	Mean gradient Bj-Sh no 27	Mean gradient Bj-Sh no 29+31
Group I	2·8 mmHg ± 0·5	2·7 mmHg ± 0·8	2·8 mmHg ± 0·5
Posterior orientation	2 PT*	5 PT*	5 PT*
Group II	6·0 mmHg ± 0·7	5·6 mmHg ± 0·2	3·6 mmHg
Anterior orientation	3 PT*	2 PT*	1 PT*
Group III	5·8 mmHg ± 0·9	5·1 mmHg ± 0·7	3·8 mmHg ± 0·4
Intermediate orientation	3 PT*	4 PT*	5 PT*

* = number of patients in each group
± = standard deviation

Table 2 Transprosthetic mean gradient of Björk-Shiley mitral disc prosthesis with diameter of 27 mm at rest and after exercise

	Mean gradient at rest Bj-Sh no 27	Mean gradient after exercise Bj-Sh no 27
Good orientation of disc prosthesis	2·7 mmHg ± 0·8 ($\overline{HR}$ = 76 beats min^{-1})	4·2 mmHg ± 0·8 ($\overline{HR}$ = 102 beats min^{-1})
Bad orientation of disc prosthesis	5·3 mmHg ± 0·2 ($\overline{HR}$ = 75 beats min^{-1})	8·2 mmHg ± 0·9 ($\overline{HR}$ = 101 beats min^{-1})

± = standard deviation
$\overline{HR}$ = mean heart rate

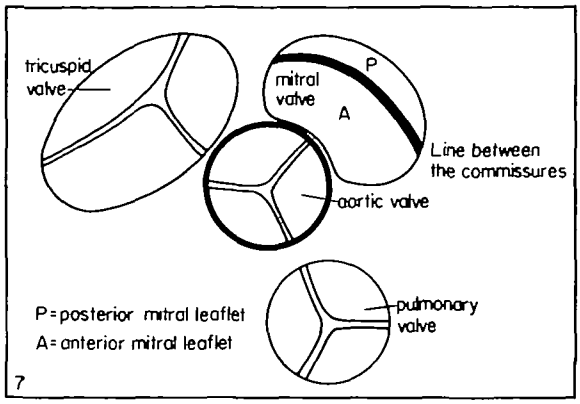
centrally into the ventricle with flow directed directly downwards towards the apex (Fig. 4). There was no clear distinction between inflow and outflow pathways in this group (c.f. orientations I and II).

In each group of patients the mitral inflow was interrogated by continuous wave Doppler (Fig. 5). The results for each of the three orientations are shown in Table 1. The patients with orientation I (with greater valve orifice orientated posteriorly) had a lower mean diastolic gradient (2·8 mmHg range) when compared with patients in group II (6·0 mmHg range) and III (5·8 mmHg range). The variation in the gradient in each of the three orientations was not related to a specific part of diastole but was a pan-diastolic increase. The effect of valve orientation on the transprosthetic mean gradient was more pronounced in patients with a smaller prosthesis (25 and 27 mm) when compared with a larger prosthesis (29 and 31 mm) (Table 1).

In order to assess the effect of exercise on the differently orientated disc prosthesis in patients with 27-mm valves the mean diastolic gradient was measured at rest and post-exercise. The patients in the 27-mm group were selected for the exercise study as they constituted the largest subgroup (it was not possible for logistic reasons to restudy all 30 patients with an exercise protocol). Exercise consisted of changing from a supine position to a sitting position as rapidly as possible over several minutes, the aims being (1) a peak heart rate of at least 100 beats min^{-1} and (2) at least a 30% increase on the resting heart rate. The effect of this exercise protocol on the transprosthetic gradient in the patients studied is shown in Table 2. The difference in mean transprosthetic gradient already present between the patients with orientation I and those in the other two groups (orientations II–III) become even more pronounced following exercise. Orientation I had a mean gradient at rest of 2·7 mmHg range which became 4·2 mmHg range after exercise and orientation II and III had mean gradient at rest of 5·3 mmHg range which became 8·2 mmHg range after exercise.

Discussion

When considering whether the orientation of a mitral tilting disc prosthesis is an important factor in valve haemodynamics, it seems useful first to look



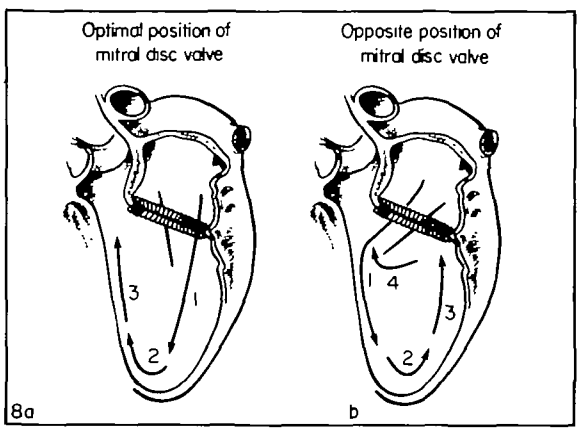


Figure 7 A schematic diagram of the heart at the level of the inlet and outlet valves. The anterior mitral leaflet is very large and broad when compared with the posterior leaflet. Note that the line between the mitral commissures is parallel to the dividing place between the inflow and outflow tracts.

Figure 8 A schematic representation of the intracavity blood flow patterns (arrowed) in patients with differently orientated Björk tilting disc prostheses. a, In patients with a posterior orientation of the greater orifice of the mitral prosthesis. b, In patients with an anterior orientation of the greater orifice. (See text for full discussion of these flow patterns).

at the diastolic flow pattern of the normal native mitral valve[8–11]. Special attention should be paid to a number of important aspects of valve function. The first aspect to be considered is the normal opening pattern of the native mitral valve. Native valve opening is an active process and is not solely due to the pressure difference which exists between the left atrium and left ventricle in early diastole. Two major factors play a role in the active process of opening the valve: (1) the downward motion of the papillary muscles, occurring during the relaxation period of the left ventricles initiates the active opening of the valve and (2) the sphincteric action of the mitral orifice relaxes during early diastole to increase the inflow area. The subsequent mitral flow across the valve orifice is then posteriorly into the left ventricle inflow tract. Colour Doppler flow imaging of a normal mitral valve from the apical long axis view (Fig. 6a) or four-chamber view clearly demonstrates (Fig. 6b) the posteriorly directed laminar flow (in red) entering the left ventricle in early diastole, turning around in the apex and continuing as a laminar blue stream towards the outflow tract in mid-diastole.

A further aspect of normal mitral valve function in diastole is that the preferential posterior direction of inflow is maintained throughout diastole by the anterior mitral valve leaflets. This leaflet is very large and broad when compared with the posterior one (Fig. 7), thus enabling it to separate the left ventricular inflow from the outflow tract. In fact the line between the mitral commissures lies parallel to the dividing plane between the left ventricular inflow tract and outflow tract (Fig. 7). By the end of diastole the inflow has turned around the apex and has reached the subaortic region, thus aiding the closure of the anterior mitral valve leaflet.

When considering the replacement of a native mitral valve by a prosthesis the above illustrated physiologic flow pattern and function of the native mitral valve should be kept in mind. Active opening of a mitral valve prosthesis is not possible as there are neither papillary muscles to assist in valve opening nor can the prosthetic mitral ring widen in early diastole. Mitral prosthetic opening occurs merely as a consequence of the pressure difference between left atrium and left ventricle. On the other hand, the normal direction of inflow and the separation of inflow and outflow tracts can be partially mimicked by a mitral disc prosthesis when the larger of the two orifices is directed towards the left ventricle posterior wall (Fig. 8). By inserting the disc prosthesis so that the larger of the two openings is directed towards the posterior wall and the axis of the disc is parallel with the line between the two commissures of the excised mitral valve, the intracavitary flow pattern can in theory be made to resemble that of normal left ventricular diastolic flow. With the greater opening of the disc prosthesis in the opposite direction (Fig. 8), that is anteriorly, the direction of flow will be reversed when compared with the normal flow pattern. With this prosthesis orientation the transprosthetic mitral flow enters first the outflow tract, continues to the apex, where it runs around towards the inflow tract and finally tries to find its way back across towards the outflow tract, thus travelling in a 'figure of eight' manner.

Many years ago Björk advised the placement of a mitral disc prosthesis with its greater orifice directed posteriorly [1,2]. He found more postoperative paroxysmal atrial fibrillation and slightly higher pulmonary wedge pressures after exercise in patients who had their major orifice orientated anteriorly. However some surgeons have not accepted his claims for the apparent better haemodynamic properties of the posteriorly orientated disc valves, and many still insert mitral prosthesis with the major orifice orientated anteriorly. Our study has demonstrated clearly that the flow pattern of the posteriorly orientated disc valves correspond best with the normal transmitral flow pattern. It is probable that this accounts for the lower transprosthetic gradient in orientation I patients. We are aware of the relatively small number of patients studied, but the differences found seem convincing enough with no patient of each subgroup demonstrating an important deviation from the mean diastolic gradient.

In various studies, especially those carried out from the transoesophageal approach, it has been demonstrated that mitral disc prostheses with apparently good function often have a slight insufficiency, best seen in early systole[12]. When looking at the flow pattern of the posteriorly orientated disc valves, as demonstrated in Fig. 8, it seems possible that the early systolic flow directed towards the left ventricular outflow tract may escape into the left atrium through the smaller orifice of the disc, which lies very close to the outflow tract.

It may be that in the anteriorly orientated mitral disc prosthesis such small amounts of incompetence do not exist, as the early systolic flow towards the outflow tract tends, in this orientation, to cause early closure of the disc in the greater orifice (Fig. 8). Any difference between the variously orientated disc prostheses with respect to this so-called 'physiologic' incompetence has not as yet been reported. When examining the flow pattern of the anteriorly (Fig. 8) or intermediately orientated mitral disc prosthesis it seems possible that the abnormal diastolic flow direction within the ventricle could either cause sub-maximal opening of the valve or an early partial closure, as the diastolic flow directed from the apex must strike the disc as flow crosses from the lateral ventricular wall to the left ventricular outflow tract. We postulate that this mechanism is the cause of the increased mean transprosthetic gradient in the anteriorly and intermediately orientated discs. We conclude from these findings that the ideal position of a mitral disc prosthesis is the greater orifice orientated posteriorly. Thus when comparing prosthetic function (including transprosthetic gradient) in differing mitral valve tilting disc prostheses, one must always take into account the orientation of the disc valve.

The importance of correct orientation was most marked in the smaller prosthesis studied in this series. In this group a striking increase in the mean

diastolic transprosthetic gradient was noted on only moderate exercise. The echocardiographic study described above on the ideal orientation of mitral disc prostheses, has led us to revise our thoughts on some aspects of mitral disc valve function. The clinical importance of these aspects needs to be clarified in further investigations.

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