Progressive Functional Deterioration of Bioprostheses Assessed by Doppler Ultrasonography*

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Doppler echocardiography was used to study the function of bioprosthetic heart valves by noninvasive means in 32 patients aged 29 to 72 years at various postoperative intervals. There were 24 Ionescu-Shiley, four Hancock, and four Carpentier-Edwards prostheses, 19 in the aortic and 13 in the mitral position. Initial studies were performed at a mean of 2.3 years after implantation and were repeated one, two, and three years thereafter. Flow velocities in the mitral orifice, left ventricular outflow tract, and ascending aorta, as well as mitral pressure half-time, were measured from pulsed-wave or continuous-wave Doppler recordings. Mitral and aortic valve areas and aortic pressure gradients were calculated. In aortic prostheses the valve area decreased and pressure gradient increased progressively in relation to the time from implantation. The mean value (±SD) of the aortic valve area was 67±17 percent of the manufacturer’s nominal value at the first examination and 57±20 percent one year later, 51±14 percent two years later, and 46±11 percent three years later (overall differences, p<0.01). In mitral prostheses, reduction of the valve area was not related to the time from implantation. The mean mitral valve area was 45±12 percent of the nominal value at rest and increased to 68±18 percent during exercise at a mean of 45 months after implantation. There was no change in these values at the one-year repeat study. It is concluded that in a population with predominantly pericardial bioprostheses, (1) aortic tissue prostheses showed a progressive functional deterioration demonstrable by Doppler echocardiography, most probably due to degenerative changes; and (2) in mitral tissue prostheses, there was no significant reduction of orifice area in relation to time from implantation. Reduction of mitral valve areas may, to some extent, reflect a less than full opening at rest.

(Chest 1990; 98:1165-68)

Tissue cardiac valve prostheses have important advantages over mechanical devices, such as the lack of need for anticoagulation in most patients; however, the major concern with their use is durability, and it has become apparent that structural failure occurs in 50 to 70 percent of bioprostheses, generally after a decade. Nevertheless, the onset and time course of this functional deterioration are largely unknown.1,4

Doppler echocardiography is now widely accepted as a valuable tool for noninvasive quantification of intracardiac blood flow and valve orifice characteristics.5,6 This study is concerned with the results of the noninvasive assessment of bioprosthetic function at various intervals up to ten years after implantation.

Materials and Methods

Patients

A total of 32 patients (20 men and 12 women) were studied, whose ages ranged from 29 to 72 years (median, 53 years). The interval from implantation to the first examination ranged from 2 to 108 months (mean, 27.5 months).

Repeat measurements were made in eight patients with MVR and in 13 patients with AVR after one year, in nine patients with AVR after two years, and in 16 patients with AVR after three years from the initial measurements. The type, size, and position of the prostheses are shown in Table 1.

Table 1—Position, Type, Size, and Manufacturers’ Nominal Valve Areas of Bioprosthetic Cardiac Valves in 32 Patients Studied by Doppler Echocardiography

<table>
<thead>
<tr>
<th>Value</th>
<th>Aortic</th>
<th>Mitral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data</td>
<td>21</td>
<td>23</td>
</tr>
<tr>
<td>Hancock (porcine valve)</td>
<td>. . . . . 1</td>
<td>1</td>
</tr>
<tr>
<td>Nominal valve area (cm²)</td>
<td>. . . . . 3.80</td>
<td>4.16</td>
</tr>
<tr>
<td>Carpentier-Edwards (porcine valve)</td>
<td>1</td>
<td>. . . . . 1</td>
</tr>
<tr>
<td>Nominal valve area (cm²)</td>
<td>. . . . . 3.24</td>
<td>4.34</td>
</tr>
<tr>
<td>Ionescu-Shiley (bovine pericardial)</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Nominal valve area (cm²)</td>
<td>2.38</td>
<td>2.96</td>
</tr>
</tbody>
</table>
Deterioration of Bioprostheses by Doppler Ultrasound (Hoffmann et al)

Doppler Studies

A Hewlett-Packard 7702 AC Duplex instrument and a Vingmed stand-alone unit were used. The patients were studied in the supine and left lateral position. In aortic prostheses the maximum flow velocity was measured in the left ventricular outflow tract (V_L) 1.0 to 1.5 cm below the suture ring by the pulsed-wave technique (Fig 1). Maximum flow velocity in the ascending aorta (V_A) was measured from the continuous-wave Doppler spectrum from different positions, attempting to find the highest flow velocities. From these measurements, maximum pressure gradients were calculated using the simplified Bernoulli equation (\( \Delta P = 4V_L^2 \)), and the functional aortic valve area (AVA) was calculated using the following formula:

\[
AVA = \frac{V_A \times R^4}{V_L^2}
\]

where R is the suture ring radius of the prosthesis.

The performance index was calculated by dividing peak velocity in the left ventricular outflow tract by peak velocity in the aorta. This value represents the ratio of the effective orifice area to the external mounting area (the latter being considered equal to the area of the left ventricular outflow tract).

In mitral prostheses, pressure half-time (\( t_{1/2} \)) was determined from a continuous-wave Doppler spectrum recorded from the apex. Mitral valve area (MVA) was calculated using the empiric formula:

\[
MVA = \frac{220}{t_{1/2}}
\]

In eight patients with MVR, Doppler measurements were repeated during supine bicycle exercise (5 minutes at 50 W) in order to elevate blood flow through the mitral orifice.

The valve areas are expressed as a percentage of the manufacturers’ nominal valve areas, in order to account for different actual diameters.

Statistical analyses were performed by the Friedman test on the group mean values at four different follow-up intervals.

Results

In aortic bioprostheses, there was a significant stepwise decrease of functional valve orifice area (AVA) as compared to the time from implantation (Fig 2). At the first visit, a mean of 2.3 years after implantation, the mean values (± SD) of AVA were 67 ± 17 percent (range, 32 to 95 percent) of the manufacturers’ nominal values. One, two, and three years later, the values of AVA fell to 57 ± 20 percent, 51 ± 14 percent, and 46 ± 11 percent, respectively (p < 0.01).

Peak aortic pressure gradients showed a stepwise increase with time (Fig 3), and the mean values (± SD) were 17 ± 8 mm Hg at the first visit, 22 ± 17 mm Hg one year later, 26 ± 14 mm Hg two years later, and 29 ± 10 mm Hg three years later (p < 0.01).

The performance index also decreased significantly at each follow-up interval (Fig 4). Mean values (± SD) were 0.47 ± 0.12 at the first visit, 0.40 ± 0.13 at the second visit, 0.36 ± 0.09 at the third visit, and 0.33 ± 0.09 at the fourth visit (p < 0.01).

Regurgitation was detected by the Doppler tech-
nique in two of 13 patients with aortic bioprostheses. In only one patient of this series did a clinically relevant reduction of AVA necessitate a reoperation after ten years (AVA, 0.7 cm² or 18 percent of the nominal value; peak pressure gradient, 64 mm Hg).

In mitral bioprostheses the calculated valve area (MVA) at rest was 46 ± 14 percent of the manufacturer's nominal valve area at a mean of 3.8 years after implantation and 45 ± 12 percent one year later (NS) (Fig 5). In eight patients, MVA was also calculated during exercise and increased to 68 ± 18 percent (Table 2). Regurgitation was detected in two of 13 patients with mitral bioprostheses.

**DISCUSSION**

This study casts some light on the time course of degenerative changes in tissue cardiac valve prostheses. In aortic bioprostheses a gradual decrease of the functional opening area could be demonstrated with increasing time from implantation by Doppler ultrasonography. The functional impairment was subclinical in all but one patient, who had to undergo repeat surgery because of symptomatic deterioration when a pressure gradient of 64 mm Hg and a reduction of the AVA to 18 percent of the manufacturer's nominal value was reached.

The calculation of the functional valve area was performed using the suture ring diameter, rather than an actually measured internal diameter in the echocardiogram. This method has the advantage of being free from the methodologic problems of echo measurements which are thought to be greater than the possible inaccuracy resulting from subvalvular pannus formation.

Most of the prostheses in our series were bovine pericardial xenografts. Porcine valves, which were implanted earlier at our hospital, were no longer available for study, as these patients had either died or undergone repeat surgery before the advent of Doppler echocardiography; however, bovine grafts seem to yield essentially similar long-term results as the porcine valves. According to the functional deterioration observed in our patients, clinically relevant obstruction must be anticipated after about eight to ten years.

Our results are in accordance with data from recent studies which have shown satisfactory clinical failure-free rates of bioprostheses up to five years, but accelerated failure rates thereafter. Moreover, in a series of surgically removed bovine pericardial prostheses, valves with degenerative dysfunction had

**Table 2—Mitral Valve Area and Heart Rate in Eight Patients with Mitral Bioprostheses Studied at Rest and during Bicycle Exercise**

<table>
<thead>
<tr>
<th>Data</th>
<th>Rest</th>
<th>Exercise†</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR, beats per min</td>
<td>84 ± 13</td>
<td>99 ± 13</td>
</tr>
<tr>
<td>MVA, cm²</td>
<td>1.9 ± 0.5</td>
<td>2.9 ± 0.9</td>
</tr>
<tr>
<td>Percent of nominal valve area</td>
<td>45 ± 12</td>
<td>68 ± 18</td>
</tr>
</tbody>
</table>

*Table values are means ± SD. HR, heart rate.
†Five minutes at 50 W.
functioned a mean of 68 months prior to removal, whereas valves that were removed for other reasons (eg, infectious endocarditis) had been in situ a mean of seven months.

Mitral valves seem to be less prone to structural failure, which has been shown in the same pathologic series where calcific degeneration was found in five of 15 aortic prostheses but in only one of seven mitral prostheses.\(^2\)\(^,\)\(^3\) This may in part be due to less mechanical stress at the low-pressure mitral orifice, although calcification has also been shown to occur regardless of anatomic site, and failure-free rates are roughly equal in the aortic and mitral positions in major surgical series of bioprostheses.\(^4\)\(^,\)\(^5\) However, mitral prostheses seem to have a considerable functional reserve, as the calculated valve area increases with accelerated heart rate and increased flow through the valve orifice,\(^6\)\(^,\)\(^7\) which was also substantiated by our own data.\(^8\) Whether functional impairment of mitral values can be detected by a progressive reduction of the increase in valve area during exercise remains to be determined. Mitral valve areas in this study were calculated from the pressure half-time. These values are, to some extent, dependent on flow and recently have been found to be somewhat inaccurate for assessing valve function of bioprostheses.\(^9\)

**Limitations of the Study**

The number of patients with prostheses of the same type and size is rather small. Efforts were made therefore to enable data analysis in a size-independent way by expressing valve area as a percentage of nominal values and by studying the same patients repeatedly up to four times, thereby emphasizing intraindividual changes over time.

Ideally, baseline values should be obtained in each patient shortly after implantation of the prosthesis. Since only a very limited number of patients received bioprostheses after Doppler ultrasonography because became available, we had to include all patients in order to form a meaningful study group, and we had to use nominal values as a baseline reference to enable size-independent analysis of data.

In conclusion, with Doppler echocardiography, we were able to demonstrate a progressive functional deterioration of aortic tissue prostheses over time. In mitral tissue prostheses such a deterioration could not readily be detected, probably due to their considerable functional reserve.

**REFERENCES**

2. Gallo I, Nistor F, Artinano E. Six year to 10 year follow-up of patients with the Hancock cardiac bioprostheses. J Thorac Cardiovasc Surg 1982; 92:14-20