Impaired Function of Cloth-Covered
Starr-Edwards Mitral Valve Prosthesis

Detection by Phonocardiography

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SUMMARY
Malfunction of a cloth-covered Starr-Edwards mitral valve prosthesis (6300 series) was suspected because of phonocardiographic abnormalities. A prolonged interval from aortic closure to opening of the mitral ball suggested an impediment to movement of the ball. This was confirmed by catheterization and cinefluorography. At autopsy the impaired ball movement was found to be due to thrombus buildup on the outflow face of the mitral valve orifice. It is suggested that frequent postoperative phonocardiographic observations may be useful in detecting malfunction of valvular prostheses.

Additional Indexing Words:
Phonocardiography Surgery Mitral valve surgery Prosthesis

IN THE EVOLUTION of improved versions of valvular prostheses for the treatment of heart disease, a cloth-covered Starr-Edwards valve has been developed in hopes of reducing the incidence of thrombus formation and arterial embolism.1 Recent studies have shown that the effective orifice size provided by these devices is less than that of the comparable series of prosthetic valves which are not cloth-covered2 resulting in appreciable pressure gradients across the valve.1,3 The present report deals with another complication related to the formation of pseudo-intima on the valve ring resulting in greatly delayed opening of a prosthetic mitral valve. The impaired function of the mitral valve prosthesis after operation was first detected by phonocardiography and verified by cinefluorography. Hemodynamic correlations were made at cardiac catheterization and the mechanical difficulty was identified at autopsy.

Report of Case
The patient, a 29-year-old female, had had acute rheumatic fever at age 10, which was associated with murmurs and congestive failure, and treatment with digitalis and diuretics was started. There was subsequent progressive deterioration in her condition until her admission to North Carolina Memorial Hospital when she was dyspneic on mild exertion, orthopneic, and having attacks of paroxysmal nocturnal dyspnea. On examination she was in atrial fibrillation with a ventricular rate of 88/min. Blood pressure was 110/40 mm Hg, and venous pressure was not elevated although small v waves could be seen in her neck veins. Her liver was slightly enlarged but not tender or pulsatile, and she was not edematous. There were moist rales at both lung bases. Her heart was enlarged to the anterior axillary line and both right and left ventricles felt hypertrophied. On auscultation in the mitral area, a grade IV/VI, pansystolic murmur extending to the axilla was heard with a third heart sound followed by a II/IV mid-diastolic rumble. At the left sternal edge, a II/VI ejection murmur was heard and a II/IV early diastolic murmur. No opening snap was detected. The electrocardiogram showed atrial fibrillation and left ventricular hypertrophy. Chest x-rays and fluoroscopy
Figure 1

A record of phonocardiograms in pulmonary area (PCG PA) and mitral area (PCG MA) with indirect carotid tracing and lead II of the electrocardiogram. There is a loud closure sound of the mitral ball (Mo) 0.12 sec after the onset of the QRS. Aortic ball opening (Ao) is followed by an ejection systolic murmur (SM) which is terminated by aortic ball closure (Ac). A greatly delayed mitral ball opening (Mo) is seen 0.20 sec after Ac. An early to mid-diastolic, low frequency murmur (MDM) is recorded at the mitral area. The ejection time is 0.24 sec, and time from Q to aortic closure is 0.42 sec. In the second or shorter of the two cardiac cycles, the time from mitral ball opening click to the next mitral ball closure sound is only 0.17 sec, resulting in a greatly abbreviated filling period for the left ventricle. Interval between time lines equals 0.10 sec.

showed gross cardiomegaly with huge left atrium and left ventricle, with no valve calcification. The clinical diagnosis was aortic regurgitation, mitral stenosis and regurgitation, and insignificant tricuspid regurgitation. Cardiac catheterization showed a mitral valve gradient of 15 mm Hg. Cardiac output was measured at 3.7 L/min by the Fick principle with an index of 2.6 L/min/m². Pulmonary vascular resistance was 361 dynes sec cm⁻⁵ with pulmonary artery pressure of 62/32 (mean, 38 mm Hg). There was an 11 mm Hg right atrial v wave with a mean of 4 mm Hg. Aortic root and left ventricular cineangiograms showed marked aortic and mitral regurgitation.

Following cardiac catheterization the aortic and mitral valves were replaced by cloth-covered Starr-Edwards prostheses (6300 series). The immediate postoperative course was satisfactory. Anticoagulation with warfarin (Coumadin) was begun on the fifth postoperative day, and the prothrombin time was maintained subsequently between two and two and a half times the control value. On the ninth postoperative day, signs of congestive failure were noted; these increased rapidly, and the heart became larger in successive x-rays. Although vigorous diuretic therapy controlled edema, tricuspid regurgitation, hypotension, and drowsiness persisted. Phonocardiographic investigations suggested dysfunction of the mitral prosthesis (figs. 1 and 2), and as her condition failed to improve, she was recatheterized. Right atrial mean pressure was 18 mm Hg with a v wave of 30 mm Hg. The right ventricular angiogram confirmed gross tricuspid regurgitation. An 8-mm mean gradient across the mitral valve in diastole was obtained from direct left ventricular puncture and transseptal left atrial puncture. Left atrial and left ventricular pressures equalized in end diastole only when diastolic filling time exceeded 0.30 sec. Left atrial mean pressure was 20 mm Hg with a v wave of 26 mm Hg. Left ventricular end-diastolic pressure was 14 mm Hg. A left atrial angiogram showed delayed mitral opening and poor left ventricular function manifest by a dilated left ventricular chamber with small ejection fraction. Further surgery was not recommended in view of the poor myocardial
function, and the patient died in congestive heart failure on the thirty-eighth postoperative day.

**Autopsy Findings**

The heart weighed 1,000 g. The tricuspid valve was 9.5 cm in circumference. The leaflets were generally opaque and thickened, and the leaflet edges were somewhat rounded. The chordae tendineae were shortened and thickened. The pulmonic valve was normal. Marked right atrial dilatation was present such that the atrial appendage was continuous with this chamber. The right ventricle was markedly hypertrophied, and the myocardial thickness was 11 mm.

The mitral valve area contained a Starr-Edwards prosthetic valve which was remarkable in that small amounts of thrombotic material were adherent to both the superior and the inferior surfaces of the annulus. When the ball portion of the valve was introduced against this material, the ball remained briefly adherent to the annular ring, even against gravity.

The aortic valvular area contained a Starr-Edwards prosthetic valve which had small amounts of adherent thrombus on its superior surface. The left atrium was moderately dilated and hypertrophied and its myocardium was 4 mm thick. No mural thrombi were present. The left ventricle was moderately dilated and its myocardial thickness was 15 mm at the annulus and 10 mm at the apex. Papillary muscles were hypertrophied, and the endocardial surface was normal.

Microscopic examination of the thrombotic material from the prosthetic mitral valve indicated that it had been deposited recently (fig. 3). It consisted only of cellular blood elements, primarily polymorphonuclear leukocytes and platelets in a fibrin meshwork. There was an early breakdown of the cellular elements, but no evidence of organization of the thrombus. The thrombotic material from the aortic valve, in contrast, showed early organization.

No structural defect in the valvular prosthesis was found by the manufacturer.

**Discussion**

The cloth-covered modification of the Starr-Edwards valve prosthesis (6300 series) was introduced with the objective of reducing the incidence of thrombus formation and arterial embolism which frequently complicates the course of patients with artificial heart valves. By completely covering the sewing ring and the cage of the prosthesis with a porous cloth, encapsulation of the valve with autogenous tissue is made possible. Although the incidence of thromboembolism may have been decreased in this way and has been demonstrated by Spencer and associates to be reduced to 1% in 1 year of follow-up, excessive deposition of tissue in the valve orifice may produce a significant stenosis to flow across the valve. Anticoagulation with coumarin type of drugs has been shown to decrease the ultimate thickness of the autogenous tissue layers without impairing the basic mechanism involved in the deposition of fibrin thrombus on the fabric and its subsequent organization. In the present case, early postoperative buildup of thrombus occurred predominantly on the outflow face of the mitral valve orifice despite adequate anticoagulation. As a result, there was delayed opening of the mitral valve in diastole.

Phonocardiographic technics have been employed previously to detect malfunction of prosthetic valves by the sounds created by the impact of the ball as it seats itself in the ring on closing or strikes the cage on opening. The mitral ball produces a sound on closure which is analogous to the mitral component of the first heart sound, and on opening another sound which corresponds to the opening snap in mitral stenosis.

A certain delay in opening and closing of the mitral valve prosthesis can be attributed to the inertia of the ball.

In reported series (table 1) as well as in 10 of our own patients with prosthetic mitral Starr-Edwards valves whose clinical courses have been satisfactory, this inertia is demonstrated in a delay of Q-mitral closure (Q-Mc). In the present case, the Q-Mc time had an average duration of 0.10 sec which is similar to that of the patients with a more favorable course. Since the patient was in atrial fibrillation, these figures represent the average of measurements from 10 cardiac cycles.

The pre-ejection period (PEP) determined by subtracting the systolic ejection time (0.24 sec) from the period Q to aortic ball closure (0.405 sec)17 is prolonged to 0.165 sec in comparison with our other 10 patients whose mean duration of PEP was 0.14 sec (0.12 to 0.20 sec). The prolongation of the PEP in the
Figure 2

Two tracings which are not simultaneous showing precordial movement at left sternal edge (above) and at the apex of the heart (below). The phonocardiogram at mitral area shows a prominent systolic ejection murmur and a mid-diastolic murmur of lower frequency believed to arise at the tricuspid valve. The tracing made at left sternal edge shows a prominent inward movement (IM) during systole indicating loss of volume of the right ventricle. A nadir is reached at point To at the time of tricuspid opening at which point an upward-moving filling wave (FW) is recorded reflecting filling of the right ventricle. This period of right ventricular filling is synchronous with the flow murmur (MDM) described above and precedes mitral ball opening which is greatly delayed at point MO.

The lower tracing shows that the outward movement (OM) at the apex is exaggerated in amplitude and abnormal in its dome-shaped or sustained configuration. A change in shape...
present case was entirely due to a long isovolumic contraction time (0.065) compared with a mean value of 0.04 sec of the others. The isovolumic contraction time is obtained by subtracting the Q-Mc from the PEP.

The period from the aortic ball closure to the opening click of the mitral ball (Ac-Mo) was measured in 22 cardiac cycles and was found to be 0.16 to 0.22 sec with an average of 0.20 sec. These measurements agreed well with those obtained from frame-by-frame analysis of the cinefluorograms (fig. 4). By this method, representative sequences showed a delay of 0.18 to 0.21 sec between closure of the aortic ball and subsequent opening click of the mitral ball. The traverse time of each ball was estimated both on opening and closing. It was apparent that these movements were accomplished in less than 0.033 sec (less than two frames at 1/60 sec/frame). Thus it is evident that the delay in mitral opening is due to retarded onset of movement of the ball rather than sluggish traverse time.

Although the duration of the preceding P-R interval varied widely owing to the rhythm of atrial fibrillation, there was no correlation between cycle length and degree of prolongation of the interval from aortic ball closure to mitral ball opening. In this respect, the present patient differed from patients with mitral stenosis\textsuperscript{16} or some patients with pros-

\begin{table}
\centering
\caption{Times from Onset of Q Wave to Mitral Valve Closure in Normal Subjects, Patients with Mitral Stenosis, and with Mitral Valve Prostheses}
\begin{tabular}{ll}
\hline
Author & Time from onset of Q wave to closure of mitral valve or mitral ball valve (sec) \\
\hline
Craige\textsuperscript{16} & 0.04 - 0.09 (0.06) Normal subjects \\
Hultgren and Hubis\textsuperscript{14} & 0.06 - 0.11 (0.085) Mitral stenosis \\
Najmi and Segal\textsuperscript{13} & 0.06 - 0.08 (0.073) \\
Present case & 0.055 - 0.09 (0.075) \\
N. C. Memorial Hospital patients & 0.08 - 0.13 (0.10) Prosthetic ball valves \\
\hline
\end{tabular}
\end{table}

is noted at the point marked by the arrow when mitral ball closure occurs. Following aortic ball closure (Ac), the curve falls rapidly, but then a gentler fall is noted to a nadir at point 0 corresponding to mitral ball opening click (Mo). A slow filling wave (SFW) occurs after this point. Interval between the time lines equals 0.10 sec.
Figure 4

Selected frames from cinefluorography showing the delayed movement of the mitral ball. In the first enlarged pair of consecutive frames, above left, the aortic ball is moving to a closed position and the mitral ball is closed at the end of systole. In the next frame, below left, the aortic valve has closed. In the first frame of the second pair, above right, after the passage of 11 frames or 0.18 sec, both ball valves are still in the closed position. In the next frame, below right, after a further 0.016 sec, the mitral ball is beginning to move to its open position. Film speed is 60 frames/sec.

Table 2

<table>
<thead>
<tr>
<th>Author</th>
<th>Time from aortic closure to mitral ball opening (sec)</th>
<th>Average time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Najmi and Segal⁹³</td>
<td>0.09 - 0.15</td>
<td>0.12</td>
</tr>
<tr>
<td>Hultgren and Hubis¹⁴</td>
<td>0.07 - 0.15</td>
<td>0.11</td>
</tr>
<tr>
<td>Pichard et al¹⁴</td>
<td>0.09 - 0.14</td>
<td>0.116</td>
</tr>
<tr>
<td>Boicourt et al¹¹</td>
<td>0.059 - 0.99*</td>
<td>0.777</td>
</tr>
<tr>
<td>N. C. Memorial Hospital patients</td>
<td>0.08 - 0.13</td>
<td>0.11</td>
</tr>
</tbody>
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*Patients with multiple prosthetic valves.
thetic mitral valves who are doing well postoperatively.8,14

In previously reported series (table 2), a range of 0.07 to 0.15 sec for the interval from Ac to mitral ball opening click was found with average figures of 0.11 to 0.12 sec. A shorter interval (0.777 sec) between aortic ball closure and mitral ball opening click was noted by Boicourt and associates11 in cases of multiple prosthetic valves.

Although a lengthening of the time interval from aortic closure to the opening snap of the mitral valve following relief of mitral stenosis has long been recognized as a sign of a good surgical result, the usual postoperative 2-OS time is in the range of 0.09 to 0.10 sec.16 The interval from aortic ball closure to mitral ball opening click in the present case is double this figure (fig. 1) and almost double the average Ac-Mo time in reported cases of prosthetic mitral valve surgery and in the cases from our own files as shown in table 2.

A longer delay (0.14 to 0.17 sec) in the opening click of a prosthetic mitral ball was noted in one of the cases of Najmi and Segal18 and was attributed to left ventricular failure with suspected elevation of left ventricular pressure. In our case the mean gradient across the ball was measured and was found to be 8 mm Hg in diastole. Equalization of left atrial and left ventricular pressures occurred when the diastolic filling time exceeded 0.30 sec. Since, as stated above, the average time from aortic closure to mitral ball opening click was 0.20 sec, there remained an average period of 0.10 sec during which the mitral valve was fully open and a gradient persisted. Thus, the fully open valve continued to present some obstruction to forward flow as has been shown in patients with satisfactory postoperative courses by Kloster and co-workers.8 Therefore, the delay in ball opening could not be attributed to pressure changes in left-sided chambers of the heart that would impede its movement. A physical impediment to movement by thrombus deposit on the outflow face of the mitral prosthesis proved to be the explanation for the sluggish ball action at autopsy.

While the fabric covering of the cloth-covered valves permits ultimately a complete covering of the cage with autogenous tissue, it may make the valve structures more thrombogenic initially. The tissue layer which forms arises from a preceding thrombus deposit rather than from ingrowth of adjacent endothelium and connective tissue.19 The length of time necessary for complete organization of the thrombus and development of an endothelial covering has not been determined in man. In the growing calf it requires on the average 1 to 3 months.10 Adequate anticoagulation during this time decreases the amount of the initial thrombotic deposit and accelerates the rate of organization of the thrombus.5 Similarly, Chidoni and co-workers8 have shown experimentally that implanted tissue fragments may accelerate the formation of a pseudointima and reduce the thickness of the organized cellular lining. If organization is for some reason delayed, as in the case reported, continued buildup of thrombus and interference with proper function of the prosthesis may occur. The earlier organization of the thrombotic material on the aortic prosthesis may be related to faster blood flow across the aortic valve causing a thinner thrombotic deposit and thus rendering it less likely to this complication.

The extraordinary delay in mitral ball opening provided an opportunity to separate it from tricuspid opening in the phonocardiogram to a degree not usually possible. In figure 2, for instance, the record of precordial movement at the left sternal edge, presumably over the right ventricle, demonstrates a trough (To) followed by an outward movement FW believed to reflect tricuspid opening and right ventricular filling, respectively. The early portion of this filling wave is synchronous with a flow murmur (MDM) which clearly precedes mitral ball opening and therefore must be of tricuspid origin. In contrast to this, the lower tracing in figure 2 demonstrates precardial movement at the apex, over the left ventricle, where the nadir of the movement in diastole (o) is achieved at the time of mitral ball opening and is followed by a slow filling.
wave (SFW) which is clearly delayed with respect to the right ventricular filling. The encroachment on diastolic filling time by the late opening of the mitral ball is manifest in the very short interval between mitral ball opening and its closure with the next cardiac cycle, as illustrated in figure 1. Here in the second cycle only 0.17 sec is available for flow across the mitral ball during diastole. The stasis in the pulmonary circuit occasioned by this obstruction to flow led to pulmonary hypertension and right ventricular failure with dilatation of the tricuspid valve and massive tricuspid regurgitation.

The phonocardiogram was most useful in this case to establish that malfunction of the mitral valve prosthesis was present. The cause of the delayed opening and closure of the mitral valve was clearly related to buildup of recent thrombotic material on the outflow face of the mitral valve ring. Thus, periodic observations by phonocardiogram in the postoperative period are suggested. It is possible that an early appreciation of the mechanical problem may lead to corrective surgery with replacement of the malfunctioning valve in some cases. It is also possible, however, that the malfunction may correct itself when the endothelial covering of the ring is complete.

Acknowledgment

We wish to thank Dr. Kathleen Kagan for the pathologic studies, Dr. Orlando Gabriele for the radiologic studies, and Drs. William P. Hood, Jr., and Daniel T. Young for the cardiac catheterizations.

References

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Circulation. 1970;41:141-148
doi: 10.1161/01.CIR.41.1.141
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
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