Mitral Prosthesis Malfunction

Comparative Doppler Echocardiographic Studies of Mitral Prostheses Before and After Replacement

Ulrich Nellessen, MD, Tohru Masuyama, MD, Christopher P. Appleton, MD, Terrence Tye, RDMS, and Richard L. Popp, MD

To assess the influence of mitral prosthesis malfunction on various Doppler echocardiographic indexes, we studied the changes in the peak mitral flow velocity during early diastolic filling phase ($V_{max}$), the mean transprosthesis pressure drop from the simplified Bernoulli equation, the mitral valve area by the pressure half-time method, and the left ventricular isovolumic relaxation time in 15 patients before and after replacement of the malfunctioning mitral prosthesis using continuous wave Doppler echocardiography. Examination of the 15 replaced prostheses revealed a torn or perforated leaflet in 12 valves and a sewing ring dehiscence in one valve. Additional restricted leaflet motion (classified as mild obstruction) was seen in three of these 13 valves. In the remaining two valves, severe prosthesis obstruction was noted. Changes in the Doppler indexes between the preoperative and postoperative study were present in all patients regarding $V_{max}$ (mean, 2.2±0.3 versus 1.6±0.2 m/sec; $p<0.001$), mean gradient (mean, 9±5 versus 5±0.8 mm Hg; $p<0.001$), and isovolumic relaxation time (mean, 47±12 msec versus 80±13 msec; $p<0.001$). The mean mitral valve area remained virtually unchanged (2.3±0.9 versus 2.6±0.3 cm²; $p=NS$) but increased postoperatively in each patient with preoperative mild or severe prosthesis obstruction without concomitant aortic regurgitation. Our conclusion is that the peak mitral flow velocity, the mean gradient, and the isovolumic relaxation time are useful parameters in the differentiation of normal and abnormal mitral prosthesis function but may not define the underlying lesion. The determination of the mitral valve area facilitates detection of even mild mitral prosthesis obstruction, but, contrary to theoretical considerations, these data suggest this parameter is not significantly influenced by mitral regurgitation. (Circulation 1989;79:330–336)

Doppler echocardiography now plays an important role in the evaluation of cardiac valve prostheses. Recently, several studies have reported Doppler echocardiographic features of apparently normal prostheses and compared these with a patient group with malfunctioning biologic or mechanical prostheses or both.1-5 These studies suggest that measurements of the peak mitral flow velocity, the peak and mean gradient, and the valve area are useful in differentiating a normal from a malfunctioning prosthesis. In the majority of patients with presumably normal prosthesis function, this assumption was made on the basis of an unremarkable history and a normal physical examination. Many patients were studied months or even years after cardiac valve replacement, so some impairment of prosthesis function may have occurred in some patients during the follow-up period. Furthermore, these Doppler indexes were obtained by comparing groups of patients separated only on the basis of the presence or absence of prosthesis malfunction. Doppler indexes, however, are influenced by many factors, some of which may not be matched between the groups and the individual patients. The purpose of this study is to assess Doppler echocardiographic features of mitral prosthesis malfunction. In contrast to previous studies, the present study exclusively focuses on serial changes of Doppler indexes analyzing patients before and after replacement of the malfunctioning mitral prosthesis, thus using each patient as his or her own control.
TABLE 1. Patient Characteristics

<table>
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<tr>
<th>Patient</th>
<th>Age (yr)/sex</th>
<th>Prosthesis type and size (mm)</th>
<th>Heart rate (beats/min)</th>
<th>Rhythm</th>
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Mean ± SD 60±10 82±15 86±13 (NS)

MR, mitral regurgitation; pre, preoperative; post, postoperative; F, female; M, male; Carp-Edw, Carpentier-Edwards; Med-Hall, Medtronic-Hall; SR, sinus rhythm; AF, atrial fibrillation; DDD, dual chamber pacing.
*Additional aortic valve replacement.

Methods

Patients

Twenty consecutive patients with prosthetic mitral valve malfunction were considered for inclusion. All patients had a Doppler echocardiographic study before valve replacement and a repeat study after the operation. Five patients with a complicated postoperative course were later excluded (sepsis, n = 3; kidney failure, n = 1; severe congestive heart failure, n = 1); thus, the study population was 15 patients. There were five men and 10 women; the mean age was 60±10 years. Symptoms of heart failure had progressively increased over a few months before admission in all patients. At the time of hospitalization, no patient had clinical evidence of active endocarditis. The preoperative Doppler ultrasound examination was done within 3 days of valve replacement, and the postoperative study was performed 6–16 days after surgery. At the time of the second study, all patients were fully ambulatory. In 11 patients, the original malfunctioning mitral bioprosthesis was replaced by a bioprosthesis of the same sewing ring size; in two patients, a smaller bioprosthesis was used for valve replacement; and in another two patients, the size of replacement was unchanged, but a prosthesis of a different type was used (Table 1).

Mitrail regurgitation judged by left ventricular angiography was severe in seven patients and absent in two patients. Valve replacement was done without left ventricular angiography in the remaining six patients. In these six patients, pulsed and continuous wave Doppler echocardiography suggested severe mitral regurgitation defined as detection of the regurgitant jet in the distal one third of the left atrium and an intense regurgitant spectral signal relative to the antegrade flow signal intensity.

The surgical and pathologic examination of the 15 malfunctioning mitral prostheses revealed a torn or perforated leaflet(s) in 12 valves and a sewing ring dehiscence from the anulus in one valve. Additional restricted leaflet motion (classified as mild prosthesis obstruction) due to marked leaflet calcifications was seen in three of these 13 valves. In the remaining two valves, the mitral valve orifice area was estimated to be less than 0.5 cm² (classified as severe prosthesis obstruction) due to tissue ingrowth or obstruction by a large clot.

Doppler Echocardiography

All Doppler echocardiographic studies were performed with either an Irex Exemplar (Upper Saddle River, New Jersey) or a Hewlett-Packard (Model 77020 AC, Andover, Massachusetts) ultrasound system. The interrogation of the mitral prosthesis was done by continuous wave Doppler with a 2.5-MHz transducer. The patient was in a left lateral position and breathed normally during the study. The transducer was placed near the cardiac apex and angled slightly medially to detect flow across the mitral prosthesis. The Doppler beam was placed perpendicular to the valve ring with real-time imaging for
initial orientation. Doppler signals were obtained from neighboring transducer positions and angulations while monitoring the audio output to ensure recording of the highest flow velocities, which were then recorded by a strip chart recorder at 50 and 100 cm/sec paper speed. A high-pass filter of 400 Hz was used to minimize Doppler signals from cardiac structures.

Peak mitral flow velocity during the early diastolic filling phase ($V_{max}$) was measured in meters per second and was taken as the maximum recorded velocity that showed a continuous envelope and a well-defined peak (Figure 1). The peak mitral valve gradient was obtained from the maximal recorded transmitral flow velocity ($V_{max}$) by the simplified Bernoulli equation: \( \text{gradient} = 4(V_{max})^2 \). The calculation of the mean transmitral gradient was performed with the Hewlett-Packard Doppler measurement package by averaging the instantaneous calculated pressure drop, from the user-designated tracing of the spectral envelope, at intervals of each pixel column (480 pixel columns/screen) or by averaging the instantaneous pressure drops calculated every 0.04 seconds throughout the diastolic flow period. A "deceleration" time was measured by drawing a perpendicular from the baseline to the peak velocity and a second line along the upper edge of the spectral envelope of the early diastolic filling wave from the peak velocity to the baseline (Figure 1). The time between the points at which these two lines intersect the baseline was defined as the deceleration time. Conversion to pressure half-time was done by multiplying the deceleration time by 0.29. The mitral valve area was calculated by dividing the constant 220 by the pressure half-time. The left ventricular isovolumic relaxation time was measured from the time of aortic closure on the phonocardiogram to the start of mitral flow on the

Figure 1. Doppler flow velocity signals recorded with the transducer at the cardiac apex in patient 5 with pure mitral prosthesis regurgitation. Preoperative recording obtained in the presence of mitral prosthesis malfunction (upper panel) and after mitral prosthesis replacement (lower panel) at a 100 mm/sec paper speed. In each panel, the electrocardiogram (ECG) and phonocardiogram (PHONO) are recorded for timing. The long vertical line marks the time of aortic valve closure (defined by the phonocardiogram, with previous confirmation by Doppler signals from the aortic valve). The onset of the mitral flow signal is marked by the short vertical line. The isovolumic relaxation time (IVRT) is the interval between these two points. The peak mitral flow velocity during early diastolic filling phase ($V_{max}$) is indicated by the apex of the triangle made by the baseline (thick horizontal line), vertical line to the peak velocity, and the line approximating the decrement in velocity with time. The deceleration interval (DC) multiplied by the constant 0.29 gives the pressure half-time used in this study. Mitral valve area is calculated by dividing 220 by the pressure half-time. Values in the upper and lower panel are, respectively, IVRT, 60 and 80 msec; $V_{max}$, 1.9 and 1.5 m/sec; pressure half-time, 95 and 92 msec; and mitral valve area, 2.3 and 2.4 cm$^2$. 
TABLE 2. Doppler Echocardiographic Values in Prosthetic Mitral Valves

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<th>Patient</th>
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<th>Mean gr (mm Hg)</th>
<th>Pressure half-time (msec)</th>
<th>M-valve area (cm&lt;sup&gt;2&lt;/sup&gt;)</th>
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</table>

Mean±SD: 2.2±0.3 1.6±0.2* 21±6 10±3* 9±5 5±0.8* 122±80 85±9 2.3±0.9 2.6±0.3 47±12 80±13*

V<sub>max</sub>, peak mitral flow velocity during early diastolic filling phase; gr, gradient; M-valve, mitral valve; IVRT, isovolumic relaxation period; pre, preoperative; post, postoperative.

*p<0.001 vs. preoperative values.

continuous wave Doppler recording (Figure 1). Values from five cardiac cycles were averaged for patients in sinus rhythm, and values from 10 cardiac cycles were measured and averaged for patients in atrial fibrillation.

Statistics

Values are presented as mean±SD. The comparison between the preoperative and postoperative data was performed with the paired t test.

Results

The mean heart rate did not change significantly between the two ultrasound studies; the rhythm changed in one patient in whom there was atrial fibrillation before the operation and sinus rhythm afterward (Table 1). The Doppler echocardiographic results before and after prosthesis replacement are summarized in Table 2. The mean preoperative value for peak mitral flow velocity for the group decreased from 2.2±0.3 to 1.6±0.2 m/sec after valve replacement (p<0.001). The peak and mean gradient decreased from 21±6 to 10±0.3 mm Hg (p<0.001) and from 9±5 to 5±8 mm Hg (p<0.001), respectively. The pressure half-time and the mitral valve area were unchanged, whereas the mean left ventricular isovolumic relaxation time increased significantly from 47±12 before to 80±13 msec after operation (p<0.001). A typical example of a preoperative and postoperative Doppler recording is shown in Figure 1.

Figure 2 shows the changes in the Doppler indexes. In the presence of prosthesis malfunction, peak mitral flow velocity was 1.9 m/sec or more in all patients. After valve replacement, the velocity was less than 1.9 m/sec in 13 of the 15 patients. The patients with severe prosthesis obstruction showed the highest flow velocities preoperatively, but the patients with mild prosthesis obstruction did not differ from patients with pure regurgitation. The mean gradient preoperatively exceeded 6 mm Hg in all patients. The highest mean mitral gradients obviously were obtained in the two patients with severe prosthesis obstruction, but gradients in mixed mitral prosthesis regurgitation and obstruction did not differ from the patients with pure regurgitation. Postoperatively, no patient showed a mean gradient of more than 6 mm Hg.

In all patients with pure mitral regurgitation, the mitral valve area was more than 2.1 cm<sup>2</sup> before, as well as after, valve replacement. In contrast, four of the five patients with prosthesis obstruction showed a Doppler-derived valve area of less than 1.9 cm<sup>2</sup>, ranging from 1.8 to 0.7 cm<sup>2</sup>. The remaining patient with prosthesis obstruction showed a Doppler-derived valve area of 4.2 cm<sup>2</sup> before and 2.7 cm<sup>2</sup> after valve replacement. In this patient (patient 11, Table 1), an aortic valve replacement was also done due to moderate aortic regurgitation.

All patients showed an increase in the isovolumic relaxation time after valve replacement.

Discussion

Features of mitral prosthesis malfunction were established by serial Doppler echocardiographic studies of mitral prostheses before and after replacement. Our data indicate pressure half-time is not significantly influenced by mitral regurgitation, whereas it is prolonged in the presence of only mild prosthesis obstruction. From a theoretical stand-
point, with physical and mathematical models, the pressure half-time will be affected by functional valve orifice area, initial left atrial pressure, atrioventricular pressure difference, and diastolic flow volume. Clinical experience in native valves shows orifice area per se is the most significant of these factors, within the limits of comparison with other measures of valve orifice area such as heart catheterization or surgery or both. Data in our patients with pure regurgitation suggest other hemodynamic factors mask the effect of an increase in initial transmitral pressure and diastolic flow volume on the pressure half-time.

The short pressure half-time (52 msec) and large calculated valve area (4.2 cm²) of patient 11 with mild mitral prosthesis stenosis seems an anomaly; however, this patient also had aortic regurgitation sufficient to require aortic valve replacement. The effects of aortic regurgitation on the mitral pressure half-time previously have been reported to markedly shorten the pressure half-time due to the rapid increase in left ventricular diastolic pressure. A rapid rise in left ventricular pressure may also occur in patients with restrictive ventricular physiology or acute mitral regurgitation; however, such critically diseased patients were not included in this study.

All patients showed an increase in the peak mitral flow velocity, as well as in the peak and mean pressure gradient, before operation. These are typical findings reported in patients with mitral prosthesis malfunction and may be due to either an increase in transmitral flow because of mitral regurgitation giving relative stenosis or a real decrease in mitral valve area representing true mitral prosthesis obstruction. Before valve replacement, all patients showed a peak mitral pressure gradient of more than 14 mm Hg and a mean mitral pressure gradient of more than 6 mm Hg. After valve replacement, there was a decrease in the peak and mean mitral pressure gradient in each patient. The peak mitral pressure gradient dropped below 14 mm Hg in 13 of 15 patients, whereas the mean pressure gradient was 6 mm Hg or less in all patients. Thus, this limited study implies a peak transmitral gradient of more than 14 mm Hg or a mean transmitral gradient of more than 6 mm Hg as suggestive of mitral prosthesis malfunction.

Three patients who had both prosthesis regurgitation and stenosis did not differ from the 10 patients...
with pure mitral regurgitation. This might be because all three patients had only a mild degree of stenosis as judged by the surgical and pathologic examination. The remaining two patients with severe pure mitral prosthesis obstruction had the highest trans-mitral pressure gradients, corresponding to the marked decrease in orifice area seen at surgical and pathologic examination. Thus, the peak and mean mitral gradient may be useful indicators of severe mitral prosthesis obstruction as opposed to the detection of mild mitral prosthesis obstruction in the presence of regurgitation.

The overlap of measured gradients among these patients, and especially between the preoperative and postoperative studies, indicates such values obtained in a single ultrasound examination may not allow accurate judgment of the prosthesis function. An early postoperative baseline study should be helpful for follow-up of individual patients.

The effects of surgery on the isovolumic relaxation time were very consistent. The prolongation of this interval after valve replacement is most likely due to a decrease in the atrial pressure. Although our results show that mitral prosthesis malfunction is associated with a short isovolumic relaxation time, we do not think this interval alone is a reliable indicator of prosthesis malfunction. The isovolumic relaxation time may be defined as the interval between aortic valve closure and mitral valve opening and is, therefore, alterable by several factors. Among these are aortic pressure (related to timing of aortic valve closure), left ventricular relaxation (governing the rate of decline in ventricular pressure), and intravascular volume (affecting atrial pressure level and therefore the timing of mitral opening). Thus, the isovolumic relaxation time may change due to alterations in these factors even in the absence of mitral prosthesis malfunction.

**Doppler Variables of Normal Prosthesis Function: Comparison With Other Studies**

The verification of truly normal prosthesis function is difficult at any significant time after valve replacement because biologic processes may affect each individual differently. Thus, analyzing patients with presumably normal prostheses many months to many years after valve replacement may be an inadequate approach to establish Doppler indexes of truly normal prosthesis function. Such data may be a suboptimal standard for comparison with another group or individual suspected of prosthesis malfunction. Several studies have recently reported on values of mitral bioprostheses in asymptomatic patients with putatively normal prosthesis function.1-5 A comparison of these data with our postoperative values reveals a smaller range of individual variations, a tendency toward a lower peak and mean mitral gradients and especially a higher mitral orifice area in our study. Alam et al8 recently published their findings in patients with normal functioning biologic prostheses. The mean mitral valve area was 2.0±0.5 cm², ranging from 1.3 to 4.5 cm². In the present study, we found a mean mitral orifice area of 2.6±0.3 cm², ranging from 2.3 to 3.1 cm². In all current patients with a preoperative valve area less than 2.0 cm², the surgical and pathologic examination of the replaced prosthesis revealed some degree of mitral stenosis, thus suggesting a valve area less than 2 cm² as suspect for mitral prosthesis stenosis.

**Limitations of the Study**

In this study, the postoperative ultrasound examination was done within 3 weeks of valve replacement. Although all patients included in the study were fully ambulatory and in excellent physical condition at the time of the postoperative ultrasound study, their hemodynamic parameters and their cardiac function may not have been fully normalized. Thus, further slight changes in the Doppler indexes during the late postoperative period cannot be excluded.

In two of our patients, valve replacement was done implanting a prosthesis of a slightly smaller sewing ring size: in two other patients, a different type was used. The two (patients 10 and 11) with smaller valve replacements could potentially mask the effect of prosthetic malfunction, but at least the trends from preoperative to postoperative parameters seen in the other patients (Table 2) were also present in these cases. In patient 6, a mechanical prosthesis with dehiscence was replaced with a tissue valve although the sewing rings on both were 31 mm. Patient 15 had an obstructed tissue valve replaced with a mechanical prosthesis although the sewing rings on both were 29 mm. Direct comparison of Doppler parameters in these two cases is reasonable only in the context that postoperative values are in the range of the rest of the series.

Hemodynamic data were not uniformly available for comparison with preoperative Doppler data, and no patient had postoperative catheterization; however, lack of such data does not invalidate this study focused on serial changes in Doppler parameters. The excellent relation between Doppler calculation of pressure drop across such valves and catheter measured pressure drops is now well established.

**Value of Repeat Studies and Clinical Implications**

There are many factors that are reported to influence Doppler indexes of blood flow across cardiac valves. The transmitral flow pattern in native valves is affected by age, heart rate,16,17 previous myocardial infarction,18 loading conditions,19,20 aortic regurgitation,11,12 and left ventricular wall thickness.21 With an approach in which each patient serves as his or her own control, many of the aforementioned factors can be neglected. Therefore, we conclude that changes in the Doppler indexes presented in this study reflect the influence of mitral prosthesis malfunction. Values obtained by a single ultrasound examination may be useful
for confirmation of clinically suspected mitral prosthesis malfunction in many patients; however, comparative studies will facilitate an accurate judgment of the prosthesis function.

References

KEY WORDS • transmural flow • mitral prosthesis regurgitation • mitral prosthesis obstruction • pressure half-time • mitral valve area
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