The Assessment of Mitral Stenosis and Prosthetic Mitral Valve Obstruction, Using the Posterior Aortic Wall Echocardiogram

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SUMMARY The echocardiographic motion of the aortic root reflects, in part, left atrial filling and emptying. Patients with mitral valve obstruction were studied to determine whether clinically important alterations in patterns of left atrial emptying would alter motion of the posterior aortic wall. Patients with mitral stenosis had a characteristic pattern of slowing of left atrial emptying in early diastole, with loss of the conduit phase in mid-diastole. The atrial emptying index, defined as the fraction of passive posterior aortic wall motion occurring in the first third of diastole, was significantly related to the mitral valve area index ($r = 0.86$), and thus provides a noninvasive quantitation of the degree of mitral stenosis. Determination of the atrial emptying index also proved useful in the evaluation of patients with prosthetic mitral valve obstruction and in documenting improvement in left atrial emptying after mitral valve surgery.

ONE OF THE EARLIEST CLINICAL APPLICATIONS OF ECHOCARDIOGRAPHY was the diagnosis of rheumatic mitral valve stenosis by the detection of specific abnormalities of mitral valve motion. However, attempts to quantitate the degree of mitral stenosis by measuring the initial velocity of closure of the anterior mitral leaflet, the E-to-F slope, have been disappointing. Many echocardiographers agree with the view that although the echocardiogram is qualitatively accurate, it is unreliable in quantitating the degree of mitral stenosis. Obstruction to flow of blood from the left atrium into the left ventricle due to a stenotic mitral valve or an obstructed prosthetic mitral valve should alter the pattern of left atrial emptying. We have recently reported that the posterior aortic wall echocardiogram approximates the left atrial volume curve. Here we report the use of the posterior aortic wall echocardiogram to grade the severity of rheumatic mitral stenosis and prosthetic mitral valve obstruction.

Methods

Echocardiographic Studies

All echocardiograms were performed using a Smith-Kline Ekoline 20A ultrasonoscope, with a 0.50 inch, 2.25 MHz transducer collimated to 5 cm and an Irex 101, Cambridge, or Honeywell strip chart recorder. All examinations were conducted with the patient in a $30^\circ$ left lateral decubitus position. The transducer was placed along the left sternal border at the interspace where the mitral valve echo is well seen when the transducer is perpendicular to the chest wall. To obtain the left atrial echocardiogram, the transducer was tilted cephalad and medially to record the aorta (at the level of the aortic valve) and left atrium.

Patients

The patients in this study were identified from the echocardiographic, catheterization, and surgical files of Stanford University Hospital and the Palo Alto Veterans Administration Hospital from 1973 to 1976, and most, but not all, were analyzed retrospectively. All echocardiograms had to be of good quality and recorded within 24 hours of cardiac catheterization or cardiac surgery. No patients were included who had more than trivial mitral regurgitation. Mitral valve gradients were approximated using simultaneous pulmonary capillary wedge and left ventricular pressures. The mitral valve areas were calculated using the Gorlin formula.* A total of 25 patients with mitral stenosis were studied, eight of whom later had mitral valve replacement with postoperative echocardiograms. In addition, seven patients with nonobstructed prosthetic mitral valves and normal left ventricular function, 13 patients with nonobstructed mitral prosthetic valves and abnormal left ventricular function, and three patients with obstructed prosthetic mitral valves, were studied. For establishment of "normal" values, echocardiograms were recorded in ten adult subjects with no evidence of cardiac abnormalities.

Echocardiographic Quantitation of Mitral Stenosis

It was necessary to devise an echocardiographic measurement of the pattern of left atrial emptying based on the motion of the posterior aortic wall echocardiogram. Normal left atrial emptying occurs in three distinct phases: early rapid emptying phase, middle conduit phase, and late atrial systolic phase (fig. 1). To quantitate the early rapid phase of left atrial emptying, we calculated an echocardiographically measured atrial emptying index from the posterior aortic wall echocardiogram. The following guidelines were used in calculating the atrial emptying index:

1) The aortic echocardiogram is obtained in the usual manner, as previously described. An aortic echocardiogram obtained from nonstandard transducer locations is not used for calculating the atrial emptying index.

2) The scale should be expanded so that only the anterior and posterior aortic walls are included in the recording, to

$$MVA = \frac{CO}{DFP \times 44.5 \sqrt{MV \text{ grad}_a}}$$

where $MVA = $ mitral valve area; $CO = $ cardiac output; $DFP = $ diastolic filling period; $MV \text{ grad}_a = $ mean diastolic mitral valve gradient.

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increase the ease of measurement of the excursion of the posterior aortic wall.

3) The patient's heart rate should not be greater than 85 beats/min, because of the influence of increased heart rate on left atrial emptying pattern. Carotid massage or other measures may be used to reduce the heart rate.

4) For patients in normal sinus rhythm, the total excursion of the posterior aortic wall is measured from point O to A (fig. 2, left). O is defined as that point where the posterior aortic wall begins to move posteriorly following the opening of the mitral valve. A is defined as an abrupt posterior movement of the posterior aortic wall following the P wave on the electrocardiogram. The time from point O to point A is the period of passive left atrial emptying during ventricular diastole. The distance X is the posterior aortic wall motion that occurs during the first third of this passive diastolic emptying period, and approximates the amount of left atrial emptying that occurs during the first third of passive left atrial emptying. The left atrial emptying index is the ratio of X/OA and approximates that fraction of total passive left atrial emptying that occurs during the first third of the O-A period.

For patients in atrial fibrillation, the posterior aortic wall excursion during atrial emptying is described from point O to point V (fig. 2b). O is defined as above. V occurs at the onset of ventricular systole as the mitral valve closes to end left atrial emptying. Point V on the posterior aortic wall echocardiogram is taken either at the end of the QRS complex on the electrocardiogram or at the abrupt posterior motion of the posterior aortic wall echocardiogram, whichever occurs first. The abrupt posterior motion of the posterior
ECHO ASSESSMENT OF MV STENOSIS/Strunk et al.

an aortic wall echo is assumed to be related to contraction of the heart, as it coincides with the onset of ventricular systole. Passive left atrial emptying time is defined as the time from O to V. The posterior aortic wall moves a distance X posteriorly during the first third of this emptying phase. The atrial emptying index is X/OV or that portion of the total posterior aortic wall motion that occurs during the first third of passive left atrial emptying.

Results

An aortic echocardiogram from a patient with moderate mitral stenosis and a mitral valve area index of 0.7 cm²/m² is shown in figure 3. The posterior aortic wall begins to move posteriorly, indicating left atrial emptying, as the mitral valve opens at the onset of ventricular diastole. Since this patient is in atrial fibrillation, the passive atrial emptying period ends with the onset of ventricular systole. Note the slow initial posterior motion of the posterior aortic wall, and the lack of a diastasis period in diastole, as compared with the echocardiogram in a normal subject (fig. 1). Figure 4 is a postoperative left atrial echogram from the same patient after aortic and mitral valve replacements with porcine heterograft valves. Preoperatively the posterior aortic wall motion at the onset of passive atrial emptying was slow and gradual; postoperatively the posterior aortic wall motion at the onset of left atrial emptying is rapid, with an average

FIGURE 2. Left) Calculation of the atrial emptying index (AEI) from the posterior aortic wall echogram in patients in sinus rhythm. Time of passive atrial emptying (tPAE) occurs between points O and A. O is where the posterior aortic wall begins to move posteriorly reflecting the onset of left atrial emptying. A is where the posterior aortic wall begins to move posteriorly following the P wave on the electrocardiogram, corresponding to atrial systolic emptying. Right) Calculation of the atrial emptying index (AEI) in patients in atrial fibrillation. Time of passive atrial emptying (tPAE) occurs between O and V. V occurs at the end of the QRS complex of the electrocardiogram, or where the posterior aortic wall moves abruptly posteriorly, whichever occurs first. Other abbreviations as in figure 1.

FIGURE 3. Aortic echocardiogram from a patient with a mitral valve area index (MVAI) of 0.7 cm²/m² and no mitral regurgitation. The aortic echocardiogram was recorded with expanded depth scale for accuracy in calculating the atrial emptying index. (See figure 2 (right) for calculations and abbreviations.)
emptying index of 0.9. This set of posterior aortic wall echocardiograms illustrates that with relief of mitral stenosis, early passive left atrial emptying once again becomes rapid, and a conduit stage of left atrial flow (with presumed equilibration of left atrial and left ventricular pressures) reappears.

Figure 5 shows a plot of the atrial emptying index versus the mitral valve area index. There is a direct correlation between these calculated values with an r value of 0.86. As the severity of mitral stenosis increased, the fraction of the passive atrial emptying occurring during the first third of passive atrial emptying decreased. While there is a good correlation between the atrial emptying index and the mitral valve area index, there is a range of error, and an atrial emptying index of 0.4 corresponds to a mitral valve area index ranging from 0.4 to 0.6 cm²/m². It appears that an atrial emptying index of 0.4 or less indicates severe mitral stenosis, an atrial emptying index of 0.5 or 0.6 indicates moderate mitral stenosis, and an atrial emptying index of 0.7 or greater indicates mild mitral stenosis. In this same group of patients, there was not a significant correlation between mitral valve E-F slope and the mitral valve area index.

Figure 6 shows a plot of the atrial emptying index versus the mitral valve area index calculated before and after mitral valve replacement with a porcine heterograft valve. In every case the atrial emptying index increased in the postoperative study, suggesting that rapid early left atrial emptying increased. Postoperatively, the atrial emptying index ranged from 0.7 to 1.0, with an average of 0.9. This index value is slightly lower than the atrial emptying index in normals, and reflects the hemodynamic limitations of the prosthetic mitral valve replacement as compared to the normal mitral valve.

**Prosthetic Mitral Valve Obstruction**

Three groups of patients with prosthetic mitral valves were studied. Group A consisted of seven patients who were found to have normal prosthetic mitral valves with "normal" left ventricular function, as defined by a left ventricular end-diastolic pressure (LVEDP) ≤ 12 mm Hg and a cardiac index ≥ 2.0 L/min/m², or with normal fractional shortening by echo, if no hemodynamic data were available.
Figure 6. Plot of mitral valve area index (MVAI) versus atrial emptying index (AEI) preoperatively (O) and after mitral valve replacement (Δ). The AEI increased in each instance, with relief of the mitral stenosis.

Figure 7 is an echocardiogram from one patient who had a mean pulmonary artery wedge-left ventricular diastolic pressure gradient of 5 mm Hg and a calculated mitral valve area index of 0.8 cm²/m². Because of this small gradient, the patient was discharged with a diagnosis of mild to moderate prosthetic mitral valve stenosis. However, even though the posterior aortic wall echocardiogram was not of optimal quality, it clearly showed rapid posterior aortic wall motion during the first third of passive left atrial emptying. The patient died one week postcatheterization from a cerebral embolus, and postmortem examination revealed a normal nonobstructed porcine heterograft valve in the mitral valve position. This case illustrates the value of the posterior aortic wall echocardiogram and calculated atrial emptying index in assessing prosthetic mitral valve obstruction. In group A, the atrial emptying index ranged from 0.6 to 1.0, with a mean of 0.8, and a conduit phase was present in each case. The presence of the conduit phase suggested that any obstruction across the mitral valve, if present, was not severe enough to prevent equilibration of atrial and ventricular diastolic pressures and mid-diastolic stabilization of left atrial size.

Group B consisted of 13 patients with normal prosthetic mitral valve function, but with left ventricular dysfunction (cardiac index < 2.0 L/min/m² and/or LVEDP > 12 mm Hg). These patients had atrial emptying indices which ranged from 0.5 to 1.0, with a mean of 0.7, and a conduit phase was present in each case. Of the 20 patients without prosthetic valve obstruction (groups A and B), 12 had artificial valves (11 Starr-Edwards, 1 Smeloff-Cutter) and eight had tissue valves (all porcine heterografts). The atrial emptying index averaged 7.9 for the artificial valve groups and 8.3 for the porcine heterograft group.

Group C consisted of three patients with prosthetic mitral valve obstruction, documented at cardiac catheterization or at surgery. Two patients, both with homograft tissue valves, had diastolic mean gradients of 35 and 20 mm Hg between pulmonary capillary wedge pressures and the left ventricular pressures. The atrial emptying index was 0.3 in each of these two cases, indicating severe impairment of left atrial emptying according to our data in figure 5. The third patient had a Starr-Edwards prosthetic mitral valve. Figures 8a and 8b show the pre- and postoperative posterior aortic wall echocardiograms, and figure 8c shows a large occluding thrombus found at the time of surgery in this patient. The preoperative posterior aortic wall echocardiogram showed no rapid passive atrial emptying at the onset of diastole and no conduit phase. Instead, there was a slow gradual posterior motion of the posterior aortic wall which was accelerated with atrial systole. The preoperative atrial emptying index was 0.4. Postoperatively there was an initial rapid posterior aortic wall motion corresponding to early rapid passive atrial emptying, with an atrial emptying index

Figure 7. Aortic-left atrial echocardiogram in a patient with a heterograft mitral valve replacement and a mean mitral valve gradient of 5 mm Hg and a calculated mitral valve area index of 0.8 cm²/m². The atrial emptying index (AEI) calculated from the posterior aortic wall echo was 0.8, suggesting minimal stenosis of the heterograft valve. Abbreviations as in figure 2. (This figure has been retouched for ease of reproduction.)
of 1.0, followed by flat posterior aortic wall motion corresponding to the conduit phase.

Discussion

In normal hearts, most of passive atrial emptying is completed by the first third of the passive emptying time, defined as from the onset of the opening of the mitral valve to the onset of atrial systole, or ventricular systole in the presence of atrial fibrillation. It is this early phase of emptying that is most noticeably altered in mitral stenosis. There are other factors that might affect the rapid left atrial emptying phase in addition to mitral valve stenosis. Conditions which stiffen the left ventricle such as coronary artery disease and hypertrophic cardiomyopathies may reduce the rate of blood flow from the atrium to the ventricle in early diastole. Such conditions can usually be differentiated from mitral stenosis by clinical and other echocardiographic features.

The atrial emptying index seems to provide a more physiologically sound basis for grading the severity of mitral valve narrowing than prior echocardiographic methods. The more severe the stenosis, the longer it takes for the left atrium to empty, and the smaller the fraction of left atrial emptying occurring during the first third of diastole. Our data in figure 6, comparing the atrial emptying index to the mitral valve area index, show that the atrial emptying index is a good predictor of the severity of mitral stenosis. Also, the increase in the atrial emptying index after mitral valve replacement further supports this concept.

Since the posterior aortic wall is one of the easier intracardiac structures to record, the atrial emptying index should be obtainable in a high percentage of patients. Errors
in measurement of the small absolute changes in posterior aortic wall motion are reduced by using an expanded scale setting for recording motion amplitude and using a fine continuous echo for measurement. Valve area was not confirmed by pathological measurements in our study. For this reason our correlation of the atrial emptying index with the mitral valve area index suffers from the limitations inherent in the Gorlin formula.

Cope et al. concluded that the mitral valve E-F slope was a poor predictor of the severity of mitral stenosis. This finding may be explained in part by the general lack of definition of the various factors which affect mitral valve motion. The mitral valve E-F slope is related to the early diastolic posterior aortic wall motion since the base of the aorta and mitral valve ring are continuous structures. However, the atrial emptying index may better quantitate the severity of mitral stenosis than the mitral valve E-F slope because the diastolic posterior aortic wall motion depends mainly on the left atrial volume curve. Also, the early diastolic motion is measured in relation to the total posterior aortic wall motion during passive emptying, and thus variation in slope due to differences in atrial size are partially compensated.

Assessing the functional status of a prosthetic mitral valve is a difficult clinical problem. Each type of valve has peculiar characteristics — resting gradients, presence or absence of opening and closing sounds, and flow murmurs. Numerous criteria for evaluating prosthetic mitral valve dysfunction have been published, such as the duration and variation of the S2 opening sound interval, and the echocardiographic measurements of the amplitude and diastolic slopes of the prosthetic anulus. Previous authors have commented on the difficulty in separating prosthetic mitral valve stenosis from ventricular dysfunction using noninvasive techniques such as the second heart sound to prosthetic opening sound interval.

The advantage of the atrial emptying index is that it is calculated from the echogram of the posterior aortic wall, which is not directly altered by surgery, and the motion of which reflects the left atrial volume curve — a parameter affected by all types of prosthetic valves. An atrial emptying index less than 0.5 suggested significant prosthetic mitral valve stenosis, a value in close agreement with the data from our patient with rheumatic mitral stenosis. In our patients without prosthetic valve stenosis, but with left ventricular dysfunction, the atrial emptying index was greater than 0.4 and a conduit phase reflecting equilibration of left atrial and left ventricular diastolic pressures was present. This separated them from our three patients with significant stenosis. Thus, the use of the AEI may help in the assessment of prosthetic mitral valve dysfunction as well as in the evaluation of the severity of rheumatic mitral stenosis.

In summary, we would like to emphasize the following points:

1) We previously postulated that the posterior aortic wall motion on the echocardiogram describes a left atrial volume curve — a physiological parameter which should be of use in quantitating mitral stenosis. Our results further support this concept.

2) The atrial emptying index calculated from the posterior aortic wall echocardiogram is related to the mitral valve area index, with an atrial emptying index $\leq 0.4$ suggestive of severe mitral stenosis, an atrial emptying index of 0.5 to 0.6 suggestive of moderate stenosis, and an atrial emptying index $\geq 0.7$ suggestive of mild stenosis.

3) The atrial emptying index may be a useful adjunct in evaluating prosthetic mitral valve dysfunction, and an atrial emptying index $\leq 0.4$ is suggestive of significant prosthetic mitral valve stenosis.

4) The atrial emptying index may be altered in other disease processes and should not be used in isolation from clinical examination and other noninvasive measurements, including aspects of the echocardiogram such as mitral valve motion.

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