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Editorial Comment

Doppler Assessment of Left Ventricular Diastolic Function: The Refinements Continue*

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Use of mitral flow velocity recordings to assess left ventricular filling and diastolic function. Mitral flow velocity recordings obtained with pulsed wave Doppler technique have been used to assess left ventricular filling and diastolic function for approximately a decade (1). During this time it has been established that mitral flow velocity accurately reflects left ventricular filling as measured by radionuclide (2) and angiographic (3) techniques and that mitral flow velocity patterns change throughout life in normal persons (4) and are dynamic, shifting with alterations in left ventricular diastolic properties (5–8) or loading conditions that alter the transmitral pressure gradient (9–11).

Three general abnormal left ventricular filling patterns are recognized in patients with heart disease (8). These can be independent of left ventricular systolic function. In the most common abnormal pattern, mitral flow velocity is reduced in early diastole (E wave) with an increased velocity at atrial contraction (A wave). The reduced early filling is caused by slower than normal left ventricular relaxation, which decreases the early diastolic transmitral pressure gradient (5,6,8). The second abnormal mitral flow velocity pattern is called "pseudonormal," to indicate that although the ratio of mitral E and A wave velocities appears normal, abnormalities of left ventricular diastolic properties are present (8). In these cases an elevated left atrial pressure normalizes the early diastolic transmitral pressure gradient and velocity despite impaired left ventricular relaxation (6). In the third and most abnormal left ventricular filling pattern, the proportion of filling in early diastole is increased with an abrupt, premature cessation of flow caused by an abnormally rapid increase in early diastolic left ventricular pressure (12). This "restricted" left ventricular filling pattern is the result of a severe decrease in left ventricular compliance and an increase in filling pressures; it is usually seen in patients who have advanced heart disease, markedly reduced functional capacity and atrial systolic failure (8,12).

Mitral flow velocity patterns and related variables have been shown to have diagnostic and prognostic value in several disease states such as acute myocardial infarction (13) and restrictive (14) and dilated (15) cardiomyopathies. Individual mitral flow velocity variables have also been used to estimate left ventricular filling pressures in patients with heart disease (8,15,16) and equations utilizing Doppler variables to predict left ventricular end-diastolic pressure have been proposed (16).

The problem. Despite these encouraging results, the similarities of normal and "pseudonormal" mitral patterns, the age and load dependency of left ventricular filling and the variable results linking mitral flow velocity variables and individual left ventricular diastolic properties have led to caution, or even skepticism, about using mitral flow velocity recordings to evaluate diastolic function in a general population of patients with heart disease (17,18).

In an attempt to refine these techniques, more recent studies have analyzed pulmonary venous flow velocity in conjunction with mitral flow velocity. Pulmonary venous flow is phasic, with anterograde peaks during ventricular systole and diastole and retrograde flow during atrial contraction (19,20). Early diastolic pulmonary venous and mitral flow are closely related (11,20), whereas pulmonary venous systolic flow appears to be most influenced by atrial systolic function (21–23). Although recorded most clearly with transesophageal technique (11), adequate transthoracic recordings can be obtained in most patients (22), and normal ranges have been established for different age groups (24,25). In selected patient groups, left ventricular filling pressures have been related to the proportion of pulmonary venous flow in systole (the systolic fraction) (22,26) or peak reverse flow velocity at atrial contraction (11). However, pulmonary venous flow velocities are also influenced by age (24,25) and loading conditions (11,26) and, as with mitral flow velocities, similar patterns can sometimes be seen in normal persons and patients with heart disease (27). Therefore, additional two-dimensional and Doppler variables are still needed to improve the specificity of echocardiographic techniques for the assessment of left ventricular diastolic function and filling pressures.

The present study. In this issue, Rossvoll and Hatle (28) describe a new Doppler variable, the difference in duration between pulmonary venous and mitral A wave flow velocity, which may represent a significant advance in these techniques for detecting abnormal hemodynamics. In 50 patients undergoing cardiac catheterization, these investigators related mitral and pulmonary venous flow velocity variables obtained with transthoracic echocardiography to three left ventricular filling pressures: left ventricular pressure before atrial contraction (pre-A wave), left ventricular pressure increase during atrial contraction and left ventricular end-diastolic pressure. Strengths of the study include the authors' experience in obtaining high quality pulmonary venous recordings and the size of the study group. Relative

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weaknesses include a study group limited to older persons (mean age 60 ± 11 years) and composed mainly of patients with coronary artery disease (80%), and the use of fluid-filled rather than micromanometer catheters for measuring pressures. The results show that a pulmonary venous A wave flow reversal that exceeds the duration of mitral A wave velocity predicted a left ventricular end-diastolic pressure >15 mm Hg with a sensitivity of 85% and a specificity of 79%. The difference in flow duration also showed the strongest relation of any mitral or pulmonary venous variable to the increase in left ventricular pressure at atrial contraction ($r = 0.70$), and left ventricular end-diastolic pressure ($r = 0.68$). Left ventricular pre-A wave pressure was most strongly correlated with the pulmonary venous systolic velocity time integral ($r = -0.69$) and systolic fraction ($r = -0.70$), although the scatterplot for the latter correlation (their Fig. 6) shows that the relation is strongly influenced by three patients with markedly elevated pressures.

The importance of the study results. The description of these new variables and their hemodynamic relations may have important implications for using Doppler technique for the assessment of left ventricular diastolic function. Previous studies have been unable to identify a Doppler variable that correlated with an abnormal increase in left ventricular pressure at atrial contraction (8), a distinction that would help identify the subset of patients with low mitral E to A wave ratios who are developing higher filling pressures (27). The results also suggest that different left ventricular pressures (pre-A, end-diastolic, and so forth) can have different physiologic significance and, therefore, different Doppler correlates. Finally, the analysis of pulmonary venous and mitral flow dynamics at atrial contraction represents a new approach to identify hemodynamic and diastolic abnormalities that should be less influenced by age than by current Doppler variables. Reliable identification of abnormal hemodynamics would be a major advance in interpreting mitral and pulmonary venous flow velocity recordings, especially in cases with unremarkable anatomic findings and "normal"-appearing flow velocities.

Mitral and pulmonary venous flow dynamics at atrial contraction. With atrial contraction, blood is ejected from the atrium into the left ventricle and also backward into the pulmonary veins. The amount and duration of flow each way are determined by the transmitral and atriovenous pressure gradients, which are likely influenced by left atrial systolic function and left atrial and left ventricular compliance. Under normal circumstances the pressure increases in the left atrium and left ventricle at atrial contraction are approximately equal, and the amount and duration of transmitral flow exceeds reverse flow into the pulmonary veins. However, with a decrease in left ventricular compliance and elevated filling pressures, the pressure increase in the left ventricle is larger and more rapid in the ventricle than in the left atrium (29). This shortens the duration of the positive transmitral pressure gradient and transmitral flow. At the same time the increased pressure rise in the atrium results in a larger velocity and longer duration of flow backward into the pulmonary veins.

The results of Rossvoll and Hatle (28) provide further insight into these relations. For instance, as shown in their Figure 4, patients with elevated left ventricular pre-A pressures show a larger difference from normal subjects in mitral than in pulmonary venous A-wave duration; the reverse is true when patients are subgrouped by A-wave pressure increase. Although not specifically studied, these data may indicate that patients with elevated left ventricular pre-A wave pressures have reduced atrial systolic function compared with that of patients whose exaggerated A wave pressure increase is the reason for an elevated left ventricular end-diastolic pressure. As discussed by Rossvoll and Hatle, the former group probably represents a more advanced stage of diastolic dysfunction, which may also be identified by a reduced proportion (<40%) of pulmonary venous systolic flow.

The relations between mitral and pulmonary venous flow described should be relatively age independent. Although the speed of left ventricular relaxation slows with aging (5), there is no evidence that normal older persons have a significant decrease in left ventricular compliance or a marked increase in left ventricular end-diastolic pressure. This implies that mitral flow duration at atrial contraction may exceed reverse pulmonary venous flow throughout life, irrespective of the age-related changes observed in mitral and pulmonary venous flow velocities. The duration of mitral and pulmonary venous A wave flow can also be correlated with pulmonary venous A wave velocity, because age-related values have been established and do not exceed 35 cm/s in healthy adults (24,25). Although the additive value of correlating both duration and peak velocity variables was not examined in the current study, it deserves attention in future investigations.

Limitations of the study. Further work is needed to better establish the sensitivity and specificity of the current findings in patients with other heart diseases, in younger age groups and under different loading conditions. A reduced specificity would diminish the value of the results by misdiagnosing patients as having significant diastolic dysfunction or elevated filling pressures. Arrhythmias, such as atrial fibrillation, make most of the variables described unmeasurable or more difficult to interpret. Similarly, a short PR interval would result in an abrupt termination of mitral A wave flow, which may not reflect the altered left atrial and left ventricular compliance relation associated with this finding and described above.

Recording and analyzing mitral and pulmonary venous flow velocities. The variables studied by Rossvoll and Hatle require high quality Doppler recordings obtained with attention to detail and a commitment to go through a considerable learning curve. A mitral sample volume location that is too

medial may give a spuriously short mitral A wave duration, and this signal is usually best obtained slightly more toward the anulus than the "between the tips" location commonly used for recording early mitral flow velocity. Pulmonary venous flow is recorded from an apical transducer position with the sample volume placed in the right upper pulmonary vein. Because of the large distance from the transducer, this signal can be difficult to record clearly with some types of ultrasound equipment or in patients who are obese or have an enlarged heart. In these cases a modified precordial or suprasternal transducer location can be tried. The recording of the pulmonary venous A wave reversal is the most difficult velocity to record clearly because of wall motion artifacts associated with atrial contraction. The sample volume must be placed 1 to 2 cm into the pulmonary vein to record peak velocity, and in some cases the best anterograde and retrograde signals are obtained with a slightly different transducer angulation.

Rossvoll and Hatle mention three ways to measure pulmonary venous A wave duration. Direct measurement is best, but it can also be approximated in some cases by measuring the discontinuation between pulmonary venous diastolic and systolic antegrade flow. If this method is used the end of diastolic flow should be checked with the end of the P wave on the electrocardiogram to make sure it is coincident with mechanical atrial systole. Finally, because the beginning of mitral and pulmonary venous A waves is simultaneous, the termination of both A wave flows can be referenced to the QRS complex as a rapid means of determining which flow has a longer duration.

Conclusions. Rossvoll and Hatle have shown that a duration of pulmonary venous flow reversal at atrial contraction that exceeds mitral A wave duration indicates an exaggerated increase in late diastolic left ventricular pressure. However, in broader terms they have introduced two important ideas: 1) The study of mitral and pulmonary venous flow dynamics at atrial contraction may aid the Doppler evaluation of left ventricular diastolic function, and 2) alterations in different Doppler variables may indicate abnormalities in different left ventricular filling pressures. Although the ultimate place of these new ideas and variables awaits further study, the potential that these relations may be more independent of age than previously used variables ushers in a new and exciting era of investigation. After a decade of study, the refinements continue.

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