Quantifying Valvular Regurgitation
Limitations and Inherent Assumptions of Doppler Techniques

Ann F. Bolger, MD, Neal L. Eigler, MD, and Gerald Maurer, MD

The recognition, quantification, and follow-up of valvular regurgitation is a long-standing clinical problem. While many ways to evaluate the severity of valvular insufficiency have been tried, none allows precise quantification of regurgitant volume, much less of the severity of the lesion's effect on the cardiovascular system and the patient. Inv. Invasive angiography is the traditional and most widely accepted standard for the assessment of valvular regurgitation. Angiographic grading is recognized as only semiquantitative and subjective, however, and is affected by many variables, including catheter position, rhythm disturbances, amount of dye injected, chamber size, forward flow, and x-ray penetration. Calculation of regurgitant volume, derived by subtracting effective forward stroke volume (obtained by indicator dilution or Fick method) from total stroke volume (obtained by angiography), is limited by the problems of deriving left ventricular volume measurements from planar angiograms. While carefully done biplane angiograms may offer more reliable estimates than single-plane images, they are still unable to provide us with the needed accuracy. Further, this method is only valid in single valve regurgitation and in the absence of a shunt lesion. Therefore, angiography, albeit the accepted gold standard, falls short of providing a precise and truly quantitative measure of regurgitant volume.

Doppler techniques, especially color-flow velocity mapping, seem attractive alternatives for the clinician because of their noninvasive nature, relatively low cost, and consequent ability to provide convenient serial studies. Doppler regurgitant fractions can be obtained by comparing mitral and aortic stroke volumes (calculated as the forward flow velocity integrals multiplied by the respective valve's cross-sectional area). This method applies only to single valve regurgitation and is hampered by potential inaccuracies in stroke volume calculations. Approaches to Doppler evaluation of aortic regurgitation have included measurement of the rate of deceleration of regurgitant blood flow velocity. This reflects the decline in the diastolic pressure difference between aorta and left ventricle, which bears some correlation to regurgitant severity. The most widely used methods, however, use pulsed wave or color-encoded Doppler to map the dimensions of the regurgitant jet.

Pulsed wave Doppler samples the echocardiographic plane for blood flow velocity and direction point by point. Describing a three-dimensional jet with this method can be tedious and may lead to underestimation of jets, particularly if they are eccentric or cling to a wall or valve leaflet. Color flow mapping, which is derived from pulsed wave Doppler technology, determines the velocity at multiple sample sites and provides real-time, two-dimensional color-coded images of regurgitant jet velocity superimposed on two-dimensional echocardiographic images. The flow velocity signal is analyzed with the autocorrelation technique, which is more rapid than conventional pulsed wave Doppler spectral analysis with the Fast Fourier or Chirp-Z transform algorithms. The autocorrelation method provides information only about mean velocity ranges, however, and may be less sensitive than pulsed wave Doppler. Both pulsed wave and color Doppler are limited in the maximum velocity they can easily measure and are subject to "aliasing," an artifact of the sampling procedure. Both measure only the velocity of the vector component in the direction of sound transmission and will underestimate velocities that are not coaxial with the ultrasonic beam.

Current clinical color Doppler grading of mitral regurgitation is based on spatial criteria, using single still frames to measure the maximal two-dimensional area occupied by the regurgitant jet, or a ratio of jet area to the cross-sectional area of the receiving atrium. Aortic insufficiency has been graded according to the length and area of the jet and its width in the left ventricular outflow tract. Assessment of this lesion represents a more complex problem than atroventricular valve regurgitation: while mitral or tricuspid regurgitation occurs into the atria, which are relatively static and symmetrical cavities, the aortic insufficiency jet flows into the left ventricular outflow tract, which is a more dynamic structure delineated by the mobile anterior mitral leaflet and interventricular septum.

From the Cedars-Sinai Medical Center, Los Angeles, California.
Address for correspondence: Gerald Maurer, MD, Division of Cardiology, Room 5314, Cedars-Sinai Medical Center, 8700 Beverly Boulevard, Los Angeles, CA 90048.
Received November 18, 1987; revision accepted June 16, 1988.
Furthermore, beyond the tip of the mitral leaflets, the aortic regurgitant flow signal may be difficult to separate from the simultaneously occurring mitral inflow.

Current pulsed wave and color Doppler criteria for estimating regurgitation are based on the assumption that the spatial distribution of the regurgitant velocities reflects or at least is proportional in some way to the regurgitant volume. What does the spatial distribution of regurgitant flow velocities actually represent? The jet area mapped with pulsed wave or color Doppler reflects not only the velocities of the blood moving from one chamber to another but also the motion of the blood that is entrained and displaced in its path. Both routine pulsed wave and color Doppler grading of valvular regurgitation are based on the assumption that a larger regurgitant jet area indicates a larger regurgitant volume. However, in vitro studies have shown that color Doppler jet area is not linearly or easily related to measured flow volume. Furthermore, the measured jet area is markedly affected by changes in driving pressure, orifice area, chamber size, and gain setting.

The area measured in any two-dimensional view represents only a single tomographic slice of the three-dimensional jet. Color Doppler has expanded our understanding of jet morphology, which is often complicated and dynamic. The direction and expansion of a regurgitant jet is not readily predictable and may vary markedly between imaging planes. Therefore, the ability of a single echocardiographic section to describe overall jet volume or shape is limited and decreases further with less-symmetrical jets. In addition, jets are dynamic three-dimensional structures that can change shape and direction throughout the cardiac cycle. The instantaneous hemodynamic state, including heart rate, afterload, and preload, appears to have important effects on the spatial extent of the measured regurgitation.

Regurgitant color Doppler jet area is markedly affected by changes in afterload, but the extent of that effect is highly variable from patient to patient. When quantifying regurgitation according to the maximal jet area in a single frame, we may lose sight of the complex shape, hemodynamic influences, and intrinsic temporal variation of the regurgitation.

How easy and reproducible are the jet area measurements that are the basis of Doppler quantification? Delineation of jet boundaries can be difficult, particularly when there is mixing with flow from another source or when there is substantial swirling from the regurgitant jet itself. The jet area visualized with color Doppler is influenced by axial and lateral target resolution that may vary significantly from machine to machine, depending on differences in beam focus, scan converter algorithm, pixel distribution, and spatial filtering. Even for a given machine, significant differences in jet size can occur with changes in the pulse repetition frequency, gain setting, transducer frequency, and variance algorithm. Awareness of these factors may avoid misinterpretation due to changes in machine settings. Other current limitations of color Doppler velocity mapping include a suboptimal signal: noise ratio, especially at greater depth ranges; frame rates that are slow relative to cardiac events; narrow imaging sector angles; and poor representation of lower velocity ranges. We can expect that many, but probably not all, of these shortcomings will be improved in future generations of color Doppler equipment.

Doppler-derived measurements must, therefore, be recognized as valid only for a specific combination of physiological and technical variables. For these reasons, current estimates may not be comparable from machine to machine, from patient to patient, or in a given patient over time.

If we could reliably measure regurgitant volume or fraction, would we then have an adequate parameter of clinical severity? It is clear that neither regurgitant volume nor regurgitant fraction is the sole determinant of the pathophysiological impact of an insufficient valve. Relatively large regurgitant volumes that develop gradually are well tolerated for long periods of time when compensatory changes in chamber size, compliance, and mass occur. This contrasts with acute valvular insufficiency in which much smaller volumes have overwhelming hemodynamic effects in the face of normal chamber size and compliance. Clearly the functional reserve of the ventricle and the pressure-volume characteristics of the receiving chamber have tremendous influence on the sequelae of regurgitation of any volume. We doubt that pulsed wave or color Doppler estimates of regurgitation can fully characterize the presence or absence of these compensatory factors.

Quantification of valvular regurgitation may be improved in the future by more sophisticated analysis of Doppler information and by other noninvasive modalities. Present clinical approaches extract only a fraction of the information offered by color Doppler instrumentation because they do not use the temporal and velocity information provided. The detailed spatial and temporal pattern of color Doppler velocity maps of regurgitant jets may provide new quantitative parameters of valvular insufficiency by allowing calculation of the amount of work done by the jet. It is conceivable that this measure of the regurgitant jet's kinetic energy transfer, calculated from color Doppler information, could be a relevant descriptor of its physiological impact. Both nuclear magnetic resonance and cine computed tomography may improve the accuracy of regurgitant volume measurements, which can be calculated from differences between left and right ventricular stroke volumes. As with angiographic regurgitant fractions, however, these measurements would only be valid in single valve regurgitation and in the absence of shunt lesions. Finally, cine nuclear magnetic resonance flow imaging also allows visualization of regurgitant jets but appears
to be subject to rules and limitations similar to those of color Doppler.  

Empiric data lead many centers, including our own, to use Doppler color flow mapping in the assessment of mitral and aortic regurgitation because good correlation with the imperfect but clinically accepted angiographic grading has been demonstrated. We should remember, however, that at present we can at best obtain only semiquantitative grading rather than true measures of regurgitant severity and that this grading may be adversely influenced by simplistic analysis methods, equipment limitations, and hemodynamic variability. Thus, the relation between Doppler measurements and the physiological impact of valvular regurgitation is complex and poorly defined currently. The challenge we will face in the future lies in defining better gold standards; extracting more of the spatial, temporal, and velocity information offered by color Doppler velocity mapping; and searching for truly quantitative parameters of valvular insufficiency.

References


The opinions expressed in this editorial are not necessarily those of the editors or of the American Heart Association.
Quantifying valvular regurgitation. Limitations and inherent assumptions of Doppler techniques.
A F Bolger, N L Eigler and G Maurer

Circulation. 1988;78:1316-1318
doi: 10.1161/01.CIR.78.5.1316

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