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Amplitude-Weighted Mean Velocity: Clinical Utilization for Quantitation of Mitral Regurgitation

MAURICE ENRIQUEZ-SARANO, MD, FACC, ALAN M. KANESHIGE, MD,
A. JAMIL TAJIK, MD, FACC, KENT R. BAILEY, PHD, JAMES B. SEWARD, MD, FACC
Rochester, Minnesota

Objectives. The purpose of this study was to determine the clinical usefulness of the amplitude-weighted mean velocity method for quantitation of mitral regurgitation.

Background. Amplitude-weighted mean velocity is a nonvolumetric method for calculating the mitral regurgitant fraction. Its previous validation at one center mandated an independent assessment of its usefulness and limitations.

Methods. In 56 patients with and 16 patients without mitral regurgitation, the regurgitant fraction was measured simultaneously by amplitude-weighted mean velocity, quantitative Doppler study and quantitative two-dimensional echocardiography. In 16 patients, multiple gain settings were used to determine the influence of this variable on amplitude-weighted mean velocity.

Results. In patients without regurgitation, amplitude-weighted mean velocity showed more scattering of regurgitant fraction (−18% to 23%) than Doppler ($p = 0.016$) or two-dimensional echocardiography ($p = 0.022$). The absolute value of regurgitant fraction was (mean ± SD) 8 ± 6%, 4 ± 2% and 4 ± 3%, respectively (p = NS). With increasing gain, the amplitude-weighted mean velocity mitral and aortic integrals increased, but the calculated regurgitant fraction remained unchanged. In patients with mitral regurgitation, significant correlation was found between amplitude-weighted mean velocity and Doppler study ($r = 0.79$, $p = 0.0001$) and between amplitude-weighted mean velocity and two-dimensional echocardiography ($r = 0.76$, $p = 0.0001$) for calculated regurgitant fraction, but the standard error of the estimate (12%) was large.

Conclusions. The amplitude-weighted mean velocity-calculated regurgitant fraction is gain independent, whereas the aortic and mitral integrals are gain dependent. Compared with Doppler and two-dimensional echocardiography, it shows more scattering of values in patients without regurgitation, but the methods correlate significantly in patients with mitral regurgitation. Amplitude-weighted mean velocity can be used as a simple adjunctive tool for comprehensive, noninvasive quantitation of mitral regurgitation.

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In patients with mitral regurgitation, surgical correction, repair (1) or replacement (2) is well established, but widely accepted quantitative criteria for severity of regurgitation are lacking (3). This void has led to uncertainty with regard to assessment of the severity of mitral regurgitation (4). Although noninvasive methods of quantitation of mitral regurgitation severity have been proposed (5,6), these have not been widely used clinically. In contrast to mitral stenosis, in which direct measurement of valve area (7) or pressure half-time (8) is possible, for mitral regurgitation, methods of quantitation are based on calculations incorporating several values, with an inherently higher range of error. It is essential in clinical practice to validate different methods that can be combined in an integrated approach to yield a higher degree of reliability in the quantitation of mitral regurgitation.

From the Division of Cardiovascular Diseases and Internal Medicine and the Section of Biostatistics, Mayo Clinic and Mayo Foundation, Rochester, Minnesota.

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Address for correspondence: Dr. Maurice Enriquez-Sarano, Mayo Clinic, 200 First Street SW, Rochester, Minnesota 55905.

Amplitude-weighted mean velocity is a nonvolumetric method for assessing ratios of flow in shunt lesions (9) and in valvular regurgitation (10,11). This method was developed at one institution, and validation was based on a small number of patients with mitral regurgitation (10). An independent validation of its clinical usefulness is therefore necessary. The regurgitant fraction measured by the amplitude-weighted mean velocity method was compared with the regurgitant fraction simultaneously measured by quantitative Doppler and quantitative two-dimensional echocardiography.

Methods

Study patients. Patients were included prospectively, examined by one of us and represented a consecutive experience. Inclusion criteria were 1) the presence of pure, isolated mitral regurgitation of at least mild degree, as determined by standard two-dimensional Doppler color flow imaging; 2) complete two-dimensional echocardiography and Doppler measurement, allowing quantitation of mitral regurgitation; and 3) satisfactory amplitude-weighted mean velocity signal of the aortic and mitral valves. The 57 patients meeting

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criterion 1 were screened. One patient did not meet criterion 3 and was excluded, leaving a study group of 56 patients with mitral regurgitation (mean age 66 ± 12 years; 31 men, 25 women). Forty-two had sinus rhythm, and 14 had atrial fibrillation.

In addition, 16 patients without mitral or aortic regurgitation were studied as a control group. They all had a complete set of measurements to determine the reliability of quantitative Doppler and two-dimensional echocardiography and amplitude-weighted mean velocity. Their mean age was 57 ± 16 years; nine were men and seven were women.

Quantitative Doppler study. Quantitative Doppler measurements were made, as previously described (5,14). The diameters of the mitral and aortic annuli were measured at maximal opening, at the point of insertion of the leaflets (inner edge). The pulsed wave Doppler signals were recorded at the mitral and aortic annuli and digitized, and the time-velocity integral was computed. At least three measurements of each variable were averaged (six for patients with atrial fibrillation).

The cross-sectional areas of the mitral and aortic annuli were calculated using the πr^2 formula. The mitral and aortic

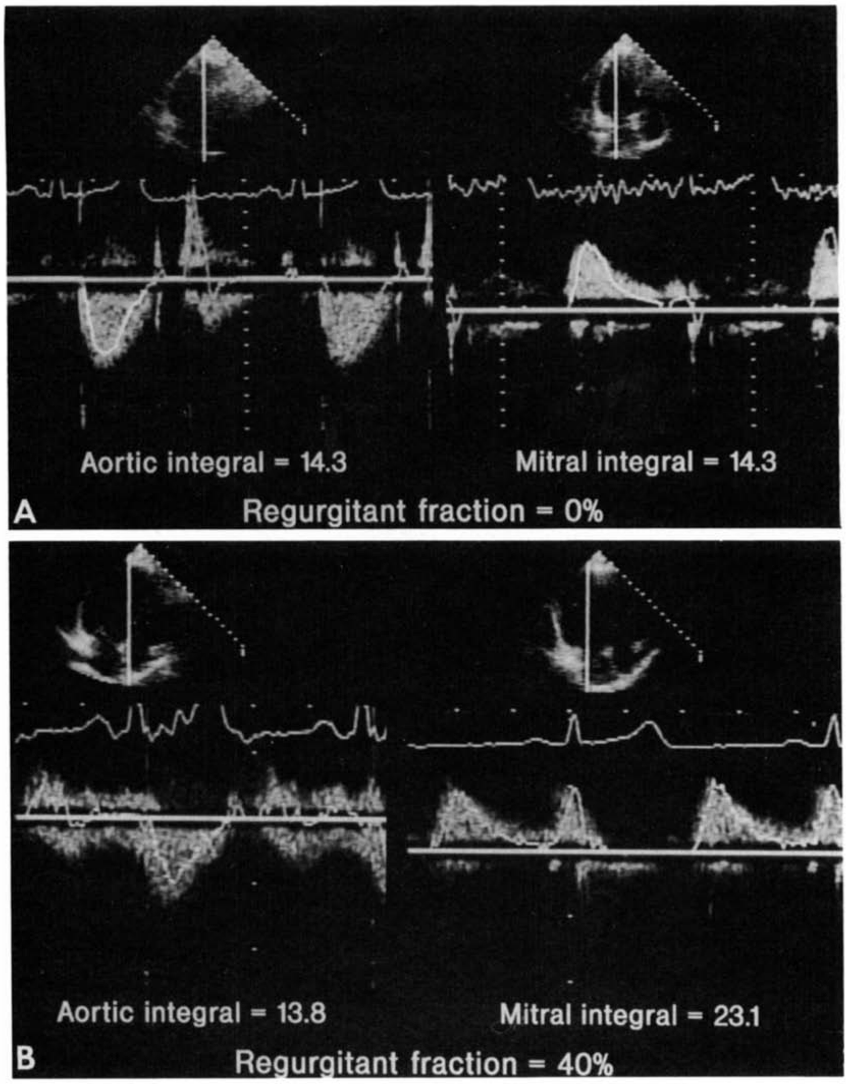
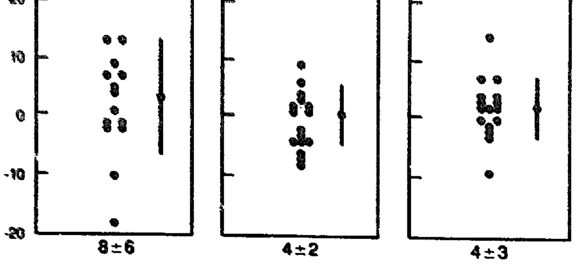


Figure 1. Examples of amplitude-weighted mean velocity recordings. In each frame the amplitude-weighted mean velocity tracing is superimposed on the continuous wave Doppler spectral display simultaneously obtained. **A,** Example of a patient without regurgitation. The integrals on the mitral and aortic valves are identical, and the calculated regurgitant fraction is 0%. **B,** Example of a patient with mitral regurgitation. The mitral and aortic integrals and the calculated regurgitant fraction are indicated at the bottom.

Figure 2. Results of the three techniques used in patients without regurgitation. **Solid circles** indicate the regurgitant fraction for the individual patients. **Vertical bars** indicate the mean value ± SD for the uncorrected regurgitant fraction. The mean value ± SD of the absolute value of the regurgitant fraction is indicated at the bottom of each panel. There is a wider scattering of values in patients without regurgitation for amplitude-weighted mean velocity (AWMV) than for quantitative Doppler or quantitative two-dimensional (2 DE) echocardiography.



fraction in the 16 patients without regurgitation were 3.4 ± 10% and 8 ± 6%, respectively, by amplitude-weighted mean velocity, not significantly different from Doppler study (−0.6 ± 5% and 4 ± 2%, respectively) or two-dimensional echocardiography (2.1 ± 5% and 4 ± 3%, respectively). However, the variance (i.e., the scattering of values) was larger for amplitude-weighted mean velocity than for Doppler ($p = 0.016$) or two-dimensional ($p = 0.022$) echocardiography.

Effect of incremental gain. At least two different levels of Doppler gain were recorded for the amplitude-weighted mean velocity in a total of 16 patients, of whom 9 had a third level of gain recorded. In these 16 patients, with increasing gain the amplitude-weighted mean velocity integrals increased for the mitral valve (14.4 ± 4 vs. 10 ± 4, $p < 0.0001$) and the aortic valve (10 ± 3 vs. 6.7 ± 2.5, $p < 0.0001$), but the regurgitant fraction (calculated using the same gain for the mitral and aortic integrals) was unchanged (27 ± 20% vs. 28 ± 23%, p = NS) (Fig. 3). For the nine patients with a third level of gain recorded, with further increase in gain the

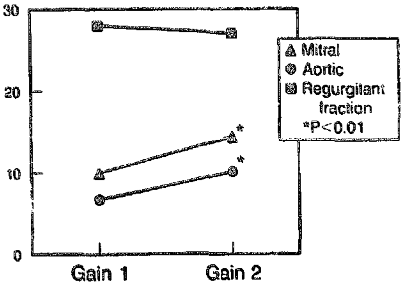


Figure 3. Influence of increased gain on the mitral (triangles) and aortic (circles) integrals and the regurgitant fraction (squares) calculated by amplitude-weighted mean velocity in 16 patients with at least two levels of gain recorded (Gain 2 > Gain 1). $P < 0.01$ applies to comparison between gain levels. With increasing gain, the mitral and aortic integrals increase, but the regurgitant fraction is unchanged.

amplitude-weighted mean velocity integrals continued to increase for the mitral valve (17 ± 4 vs. 14 ± 4, $p < 0.001$) and the aortic valve (13 ± 3 vs. 10 ± 3, $p < 0.0001$), but the regurgitant fraction calculated using the same gain was unchanged ($22 \pm 22\%$ vs. $24 \pm 22\%$, p = NS).

Patients with mitral regurgitation. In the 56 patients with mitral regurgitation, the amplitude-weighted mean velocity regurgitant fraction was $35 \pm 18\%$; the Doppler regurgitant fraction was $32 \pm 17\%$ ($p = 0.05$ compared with amplitude-weighted mean velocity), and the two-dimensional echocardiography regurgitant fraction was $31 \pm 18\%$ ($p = 0.02$ compared with amplitude-weighted mean velocity, p = NS compared with Doppler study).

The correlation between the amplitude-weighted mean velocity regurgitant fraction and Doppler regurgitant fraction was significant ($r = 0.79$, $p = 0.0001$, SEE = 12%) (Fig. 4A). The correlation between the amplitude-weighted mean velocity regurgitant fraction and two-dimensional echocardiography regurgitant fraction was also significant ($r = 0.76$, $p = 0.0001$, SEE = 12%) (Fig. 4B).

The scatter plots of the method difference ([Amplitude-weighted mean velocity regurgitant fraction] − [Doppler regurgitant fraction]) regressed against the Doppler regurgitant fraction (Fig. 5A) and of the difference ([Amplitude-weighted mean velocity regurgitant fraction] − [Two-dimensional echocardiography regurgitant fraction]) regressed against the two-dimensional echocardiography regurgitant fraction (Fig. 5B) showed no specific trend of overestimation or underestimation according to the regurgitant fraction level, but there was a large 95% confidence interval. No significant trends in overestimation were found when the differences ([Amplitude-weighted mean velocity regurgitant fraction] − [Doppler regurgitant fraction]) and ([Amplitude-weighted mean velocity regurgitant fraction] − [Two-dimensional echocardiography regurgitant fraction]) were regressed against the diameter of the mitral annulus or the cardiac index.

In seven patients the measure of amplitude-weighted mean velocity regurgitant fraction was performed in duplicate by two observers, and the correlation between the regurgitant fraction calculated by the two observers was satisfactory ($r = 0.77$, $p = 0.04$, SEE = 11%).

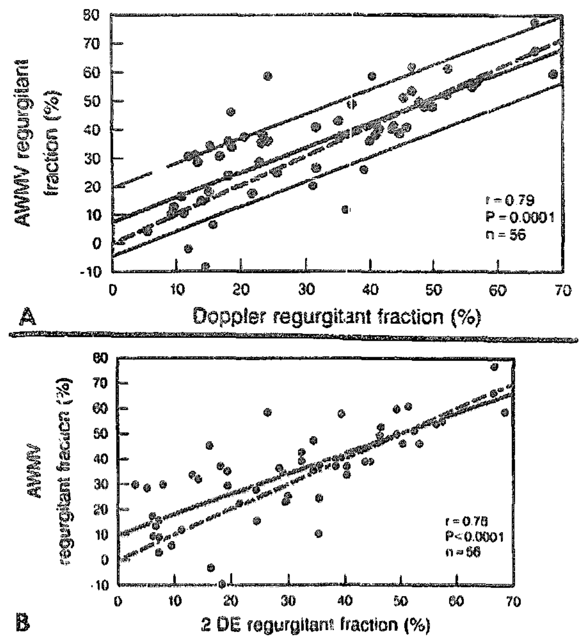


Figure 4. Correlations between amplitude-weighted mean velocity (AWMV)-calculated regurgitant fraction and that obtained by quantitative Doppler echocardiography (**A**) and quantitative two-dimensional echocardiography (2 DE) (**B**). The **solid line** indicates the regression line. The **gray zone** indicates ± 1 SEE. The **dashed line** indicates the identity line. **A**, There is a significant correlation, but the SEE is large. **B**, There is a significant correlation with quantitative Doppler echocardiography, but the SEE is large (12%).

Discussion

The process of clinical decision making with regard to mitral regurgitation inevitably includes assessment of the degree of regurgitation. Surgical correction is reserved for patients with severe regurgitation (3). Existing methods of semiquantitation of regurgitation have important pitfalls. For example, selective angiography has been shown (17) to produce significant misclassification of patients. Color flow Doppler study has similar limitations, the most significant of which is caused by the eccentricity of the jet (18,19). These limitations are the impetus for ongoing research on new methods of quantitation of mitral regurgitation.

Amplitude-weighted mean velocity: quantitation of mitral regurgitation. The velocity of blood flow is only partly related to the volume of blood flowing through a valvular orifice. However, the amplitude of the continuous wave Doppler signal is related to the number of erythrocytes backscattering the ultrasonic wave. The basis of amplitude-weighted mean velocity is to weight each velocity according to the amplitude (i.e., strength) of its signal. The mean of these weighted velocities should be proportional to the volume flow through the examined orifice if the hematocrit is

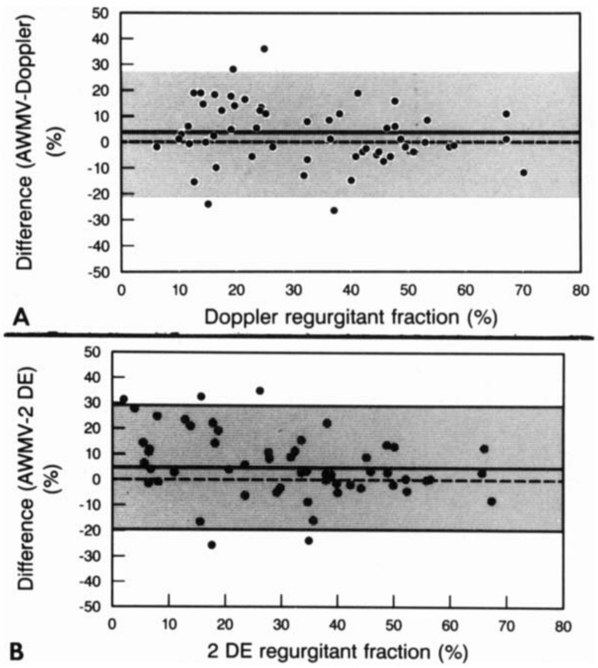


Figure 5. Regression of the difference between the amplitude-weighted mean velocity and the reference method (y-axis) versus the regurgitant fraction measured by the reference method (x-axis). The **solid line** indicates the mean difference. The **gray zone** indicates the 95% confidence interval. The **dashed line** indicates the zero ideal difference. Note that with both reference methods, there is no specific trend of more overestimation or underestimation according to the level of the regurgitant fraction. Abbreviations as in Figure 4.

normal and if there is no valvular stenosis (10,20). Although it is dimensionless, the integral of this amplitude-weighted mean velocity reflects the bolus of energy along the interrogating line and when measured in diastole through the mitral orifice and in systole through the aortic orifice it should be proportional to the stroke volume. Thus, if the attenuation is identical, and the insonation of the annuli is complete and is not overriding other flows, these integrals should be equal in patients without regurgitation. The important advantage of the amplitude-weighted mean velocity is that it allows the calculation of ratios of stroke volumes (without measuring them and independently of flow profiles) in shunt lesions (9) and in valvular regurgitation (10,11) and thus provides a simple method for quantitation of the volume overload. This method has been validated compared with quantitative angiography in mitral regurgitation (10). This validation study was performed at one institution and included only 25 patients with few regurgitant fractions in the range of 20% to 40%. In the present study of 56 patients with mitral regurgitation of all degrees, the significant correlation between the regurgitant fraction calculated by the amplitude-weighted mean velocity method and that calculated by either quantitative Doppler or quantitative two-dimensional echocardiography confirmed the previous observations (10). This finding should promote the use of this technique as an adjunct for the quantitation of mitral regurgitation.

Limitations of the method. However, the limitations of the method in clinical practice deserve special discussion. In our experience, the regurgitant fraction calculated by amplitude-weighted mean velocity in patients without regurgitation showed more scattering of values (−18% to 23%) than that obtained with quantitative Doppler or quantitative two-dimensional echocardiography. Also, the correlations in patients with mitral regurgitation were weaker than expected (10), and the SEE was large. In some patients there were significant discrepancies with the reference methods.

Theoretically, the beam width/annulus size ratio or the actual volume flow may influence the signal, but the observed discrepancies could not be ascribed to the size of the mitral annulus or to the cardiac index. This study avoided the known potential pitfalls of the method. The hematocrit was normal in all patients; the transducer was maintained in the same position to avoid changes in attenuation; the direction of the interrogating beam was controlled by using two-dimensional and spectral display to avoid overriding other flows (i.e., pulmonary artery); and there was no associated mitral or aortic stenosis. The main potential pitfall of the method (i.e., the gain dependency of mitral and aortic amplitude-weighted mean velocity integrals) was clearly demonstrated in our study but was also taken into account throughout the study (integrals at the same gain were used for the calculation of regurgitant fraction) and did not interfere with our results. The observed discrepancies may be related to limited experience (learning curve). However, the problem may be inherent in the nature of the technique: 1) The proportionality between the bolus of energy as measured by the amplitude-weighted mean velocity integrals and the volume flow was not demonstrated formally, and in normal subjects the mitral/aortic ratio is often not equal to 1. 2) The values of the integrals measured on the mitral and aortic orifices do not reflect the absolute values of the stroke volumes and cannot be corroborated by any other physiologic variable. The only guide in the selection of the cardiac beats to be measured is the satisfactory shape of the signal, which represents a useful but limited indication.

Another limitation of the technique is that it provides only the regurgitant fraction and, as such, does not allow the calculation of the regurgitant volume or the effective regurgitant orifice, both of which provide important information and should be calculated in a comprehensive approach (19,21).

Clinical use of amplitude-weighted mean velocity. Because all of the methods of quantitation of regurgitation, including quantitative angiography, are based on calculations combining various measurements, their range of error is inherently larger than any simple measurement alone (22,23). It is desirable to combine different methods to ascertain reliably the degree of the regurgitation. Doppler echocardiography has the unique capability and flexibility to incorporate complementary methods in the same examination. Amplitude-weighted mean velocity is not timeconsuming and can easily be combined with quantitative Doppler or quantitative two-dimensional echocardiography, or both, to confirm the degree of regurgitation.

Limitation of the study. In this study, the conventional reference (i.e., quantitative invasive angiography) was not used because 1) quantitative angiography has been shown to have considerable variability and, thus, sources of error (22) that cannot be addressed during the procedure because ventricular volumes are calculated off-line; and 2) mitral regurgitation may vary (24) with changes in loading conditions, and the nonsimultaneity of the two techniques is an additional important source of error.

Conversely, amplitude-weighted mean velocity and quantitative Doppler and quantitative two-dimensional echocardiography were performed during the same examination without any significant hemodynamic changes. Quantitative Doppler and quantitative two-dimensional echocardiography have been validated elsewhere (5,6) but have been controversial. The measurement of the aortic stroke volume using pulsed wave Doppler echocardiography is now widely accepted (14,23,25,26), but mitral stroke volume calculation (27) and Doppler quantitation of mitral regurgitation (28) have been criticized on the basis of the results of small series of patients. In our clinical echocardiographic practice, calculation of regurgitant volume and regurgitant fraction is performed on a regular basis, and this experience has shown that quantitative Doppler echocardiography consistently used in a large number of patients is highly reliable and reproducible (23).

Measurement of ventricular volumes by two-dimensional echocardiography has also been criticized by one group (29), but the same workers (30) used the current high resolution imaging method and reversed their opinion, and other groups have reported its reliability (31,32) and reproducibility (33). In our experience, quantitative two-dimensional echocardiography has provided excellent results (23).

Finally, the consistency of the two comparisons (amplitude-weighted mean velocity vs. quantitative Doppler study and amplitude-weighted mean velocity vs. quantitative two-dimensional echocardiography) is additional evidence that the reference methods are not a limitation of this study.

Conclusions. Amplitude-weighted mean velocity is a nonvolumetric method that allows calculation of ratios of flow. Amplitude-weighted mean velocity integrals are gain dependent, but the mitral regurgitant fraction, calculated with the same gain levels, is gain independent. Amplitude-weighted mean velocity regurgitant fraction in patients with mitral regurgitation shows a significant positive correlation with both quantitative Doppler and quantitative two-dimensional echocardiographic regurgitant fraction, but with a large SEE. Thus, it can be used in combination with the standard two-dimensional Doppler quantitative techniques as an adjunctive tool for comprehensive, noninvasive quantitation of mitral regurgitation.

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