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METHODS

Observer Variability in the Quantitation of Doppler Color Flow Jet Areas for Mitral and Aortic Regurgitation

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Early studies using Doppler color flow imaging have suggested that measurement of the regurgitant jet area provides information regarding the severity of valvular insufficiency. This study was performed to assess the observer variability of mitral and aortic regurgitant jet area measurements using the Doppler color technique.

Color Doppler recordings from 45 patients were reviewed: 23 patients had aortic regurgitation and 22 had mitral regurgitation. To assess interobserver variability, the largest definable mitral regurgitant jets from three cardiac cycles were independently chosen and measured by planimetry by two observers who were unaware of other patient information. Measurements were repeated by both observers at a separate time to obtain intraobserver data. Videotapes from 23 patients with aortic regurgitation were similarly analyzed. Each observer measured the isovolumic aortic jet (before mitral valve opening) and the maximal aortic regurgitant jet (at any time during diastole) using computer-assisted planimetry.

Both intraobserver and interobserver correlations were excellent for mitral regurgitant jet areas (r = 0.97 and r = 0.93, respectively). The intraobserver correlation for isovolumic aortic regurgitant jet was r = 0.73; the interobserver correlation for this measurement was only fair (r = 0.57). For the maximal aortic regurgitant jet area, intraobserver correlation was good (r = 0.86) and interobserver correlation was fair (r = 0.72).

These findings suggest that intraobserver and interobserver reproducibility are acceptable for the measurement of mitral regurgitant jet area. However, the measurement of aortic regurgitant jet areas results in significant observer differences that appear to be related to problems with slow sampling rates for the measurement of isovolumic aortic regurgitation and to difficulties in separating mitral inflow from aortic regurgitation for the maximal jet.

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Real time color-encoded Doppler flow imaging is a new, noninvasive technique that allows the simultaneous visualization of pulsed Doppler flow velocity data superimposed on a two-dimensional echocardiogram. This technique provides information regarding not only the instantaneous direction and velocity of blood flow within the heart and great vessels, but also the spatial characteristics of the flow stream. Thus, disturbed flow velocity jets can be well visualized by color Doppler imaging in the presence of valvular stenosis or regurgitation as well as in the setting of intracardiac shunts (1–5).

Of the several proposed applications for Doppler color flow imaging, the quantitation of valvular regurgitation has received the greatest attention. Thus, early studies employing this technology (6–10) have suggested that measurement of the area of disturbed flow might be useful in the quantitation of valvular insufficiency. However, such quantitation would depend on the accuracy with which measurement of jet area could be performed from velocity imaging records. Few data currently exist regarding the reproducibility of measurements of disturbed flow area between observers or for a single observer at different times. Therefore, the purpose of this study was to define the intraobserver and interobsever variability of color flow Doppler measurements of regurgitant jet area in patients with mitral and aortic insufficiency.

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Methods

Study patients. Videotapes from all patients who underwent a Doppler color flow imaging study during a 6 month period were retrospectively reviewed for the presence of mitral or aortic regurgitation. Only patients in normal sinus rhythm with a heart rate <100 beats/min, with native valve lesions and technically adequate Doppler color studies performed using the same equipment (Aloka 880 or 860) were considered. Seven patients were excluded from the study including three patients with atrial fibrillation, two with prosthetic valves, one with sinus tachycardia and two with poor quality two-dimensional echographic and Doppler images. Forty-five patients with aortic or mitral regurgitation were identified, all of whom manifested the typical findings of the lesion by clinical examination or cardiac catheterization. A total of 23 patients with aortic regurgitation and 22 patients with mitral regurgitation were reviewed.

The group comprised 29 women and 16 men with a mean age of 52 ± 18 years. the mitral valve disease was of varied origin: rheumatic (n = 5), ischemic (n = 4), mitral prolapse (n = 4), cardiomyopathy (n = 3), calcified anulus (n = 2) and idiopathic (n = 4). Aortic valve disease was of degenerative (n = 6), rheumatic (n = 6), congenital (n = 5), dilated aorta (n = 2) and idiopathic (n = 4) origin.

Doppler color flow imaging. In all cases, Doppler color studies were recorded as part of a clinical diagnostic echographic examination. Studies were performed with the patient in a slight left lateral decubitus position, from standard echographic imaging planes (parasternal long and short axes, apical views) using commercially available equipment operating with either a 2.5 or 3.5 MHz transducer. Gain and depth settings were optimized for image quality as previously described (6). Specifically, for each plane the system gain was increased to the maximal level possible before the introduction of background artifact. For the equipment used, maximal frame rate was determined by depth, sector arc and bursts per line, with a maximum of 30 frames/s at 12 cm depth and 15° sector arc, with 9 bursts per scan line. Frame rates were 12/s when using a 45° sector. In individual patients, the narrowest possible sector that enabled visualization of the entire regurgitant jet area was employed. The maximal discernible velocity recordable without aliasing with the equipment used was 64 cm/s at 12 cm depth. Velocity of flow traveling toward and away from the transducer was represented as 16 shades of red and blue, respectively (Fig. 1 and 2). On the basis of extent of variance in the velocity signal, green was added to each color to indicate the presence of nonlaminar flow.

Regurgitant jet area measurements. Color flow images were retrospectively analyzed from recordings made on 1/2 inch (1.27 cm) videotape. For the purposes of this study, only the apical views were evaluated. Two observers who were unaware of each other's results traced the outer border of the largest definable area of regurgitant flow as viewed from a still frame image. All jet area measurements were repeated by each observer at an interval of at least 5 days (mean interval 9 days) to evaluate intraobserver variability. Measurements of jet area were performed using a microprocessor with a digitizing pad and an electronic overlay system using a mouse-driven light pen for tracing.

A representative example of a systolic still frame from a patient with mitral regurgitation is shown in Figure 1A. For each patient, the outer border of the largest definable flow disturbance as seen from the apical two-, four- or five-chamber view was identified for two cardiac cycles and was traced three times with results reported as mean jet area (cm^2). Each observer selected individual frames that were believed to be the most appropriate by scanning the entire color flow examination on the videotape.

For aortic regurgitation, the outer border of the largest regurgitant jet present before mitral valve opening was traced and reported as the isovolumic jet (Fig. 1B). The largest area of regurgitant velocity occurring at any time during diastole was also traced and reported as the maximal aortic regurgitant jet (Fig. 1C). Maximal and isovolumic jets were measured by both observers in each patient with aortic insufficiency and the results are analyzed separately.

Statistical methods. Jet area measurements are reported in square centimeters ± standard error of the estimate (SEE). Interobserver and intraobserver correlations were analyzed using simple linear regression. Two intraobserver and interobserver correlations existed for each measurement; however, only the highest correlations are shown graphically because the other values were not significantly different.

Mitral regurgitation (Fig. 3). Regurgitant jet areas for patients with mitral insufficiency ranged from 0.93 to 13.24 cm^2 (mean 5.17 ± 0.67) for Observer 1 and from 0.74 to 14.39 (mean 5.36 ± 0.70) for Observer 2; the comparison of intraobserver measurements were made by linear regression. The correlation between measurements for the same observer was excellent (r = 0.97; SEE 0.76 cm^2). The intraobserver correlation for the other observer was similar (r = 0.90; not shown). An excellent correlation between observers (r = 0.93, SEE = 1.34 cm^2) was also observed for measurement of mitral regurgitant jet area.

Isovolumic aortic jet area (Fig. 4). Measurements of the largest aortic regurgitant jet occurring during isovolumic relaxation before mitral valve opening ranged from 1.08 to 9.31 cm^2 (mean 4.03 ± 0.46) for Observer 1 and from 0.92 to 11.85 (mean 4.50 ± 0.50) for Observer 2. Correlation between measurements made on two separate occasions was only fair (r = 0.73; SEE 1.2 cm^2). This represents the best correlation obtained for this measurement because intraobserver correlation for the other observer was only r = 0.66 (not shown). Only a general correlation was observed be-

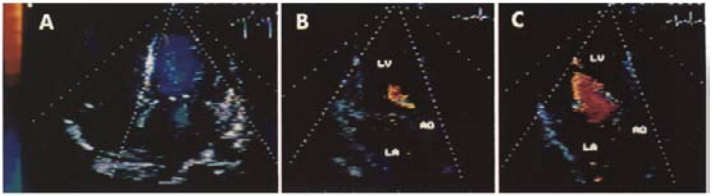


Figure 1. A, Systolic frame from the apical four-chamber view showing mitral regurgitation. The outer border of the largest definable flow disturbance **(blue)** within the left atrium was traced using computer-assisted planimetry. **B,** Diastolic frame from the apical long-axis view in a patient with aortic regurgitant flow **(red)**. The outer border of largest red-yellow area seen before mitral opening was traced by computer planimetry to measure the aortic isovolumic jet area. **C,** Same patient. In a later diastolic frame, the largest area of regurgitant velocity **(red-yellow)** occurring at any point during diastole was traced to determine the aortic maximal jet area. Ao = aortic root; LA = left atrium; LV = left ventricle.

tween measurements of isovolumic aortic regurgitant jet performed by two observers (r = 0.57; SEE = 2.39 cm^2).

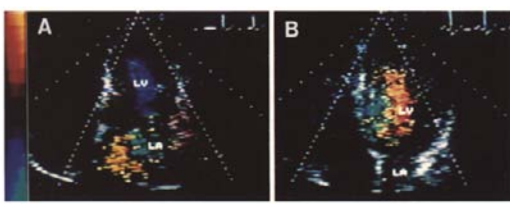
Maximal aortic jet area (Fig. 5). Measurements ranged from 1.45 to 12.67 cm^2 (mean 5.69 ± 0.60) for Observer 1 and 1.03 to 19.47 cm^2 for Observer 2. Intraobserver correlation for maximal aortic regurgitant jet was good (r = 0.86; SEE = 1.45 cm^2). The correlation for the other observer (not shown) was similar (r = 0.81; SEE = 1.85 cm^2). The data for interobserver variability also exhibited a fair correlation (r = 0.72; SEE = 3.18 cm^2).

Discussion

Both pulsed and continuous wave Doppler techniques are now used to noninvasively assess the severity of aortic and mitral insufficiency. Quantitative estimates of the degree of aortic regurgitation have been obtained by means of pulsed wave Doppler mapping of the disturbed flow in the left ventricular outflow tract on two-dimensional echocardiograms (11,12), by quantitation of the amount of flow reversal in the descending aorta (13,14) and by obtaining a ratio of aortic to pulmonary or mitral volumetric flows to compute the regurgitant fraction (15). Mapping techniques have also been employed to semiquantitate severity of mitral regurgitation (16,17). The pulsed wave technique is particularly suited to estimating the size of the regurgitant jet because its range-gating properties allow detection of abnormal flow velocity within a small sample volume. However, this method is tedious and time-consuming and requires a mental reconstruction of the three-dimensional jet detected in multiple orthogonal imaging planes. Techniques employing continuous wave Doppler imaging have also been utilized to estimate the severity of aortic regurgitation. The decay slope of the diastolic velocity curve and a pressure half-time index have been proposed as noninvasive indicators of severity of aortic insufficiency (18–21).

Previous studies in Doppler color flow imaging. One of the initial quantitative applications of the two-dimensional color flow Doppler mapping technique was to estimate the severity of mitral and aortic regurgitation (6–10). Miyatake et al. (6)

Figure 2. A, Systolic frame, apical four chamber view, in a patient with a mitral regurgitation jet in the left atrium (LA). The regurgitant jet **(blue-yellow)** is irregular in shape, heterogeneous in color and dispersed throughout the atrium. Differences in interpretation of this flow disturbance may account for interobserver variability. **B,** Mid-diastolic frame from the apical five-chamber view in a patient with aortic regurgitation. The left ventricle (LV) is filled with a vortex of many colors representing flow in many directions and at a wide range of velocities. Separation of the aortic regurgitant jet from mitral inflow may not be possible in this case.



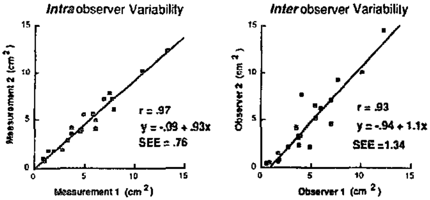


Figure 3. Linear regression plots of mitral regurgitant jet areas, comparing intraobserver (**left**) with interobserver (**right**) variability. Excellent correlations were seen both for a single observer (r = 0.97) and between two observers (r = 0.93).

studied the relation of mitral regurgitant jet area to severity by angiography and found an excellent overall correlation. These investigators employed the solitary measurement of the length of the jet in the left atrium to semiquantitatively classify patients into mild, moderate and severe categories. They (6) referred to difficulties encountered because of temporal variability in jet size and duration, but no observer variability data were provided. Helmcke et al. (7) assessed mitral regurgitant color jet length, width, height and area in multiple orthogonal projections and found a fair correlation with angiographic grade, although there was significant overlap among the groups. Better correlations were obtained when left atrial size was also measured to determine the percent of left atrial area filled by the regurgitant jet. These investigators (7) provided data on the interobserver variability of mitral regurgitant jet area measurements and found an excellent correlation of r = 0.99 between two observers unaware of other data. However, no intraobserver data were provided, and aortic regurgitant jets were not part of their study.

Preliminary data by Yock et al. (9) suggested that the measurement of aortic regurgitant jet area by two-dimensional Doppler color flow mapping is more difficult because of merging of the signal with mitral inflow. More recently, Perry et al. (22) proposed that jet height, as compared with width of the left ventricular outflow tract, is a better predictor of the angiographic severity of aortic regurgitation. However, all these methods involve the quantitation of areas of disturbed or abnormal flow as measured from a still frame color map.

Observer variability in quantitation of significant jet areas. The purpose of our study was to assess the observer variability in the quantitation of regurgitant jet areas by the Dopper color flow imaging technique. To simplify the analysis, only the jets obtained from the apical long-axis, apical four- or apical five-chamber views were measured. These views were selected because it was reasoned that they would allow for the most parallel beam alignment to regurgitant flow. However, the individual observers were responsible for selecting the still frame demonstrating the largest clearly defined area of disturbed flow. Observers were unaware of all other clinical, angiographic or conventional Doppler data in these patients. Because the intent of this study was to assess the interobserver and intraobserver variability, no attempt was made to correlate the Doppler-measured jet areas with catheterization or clinical estimates of severity of regurgitation.

Mitral regurgitation. Interobserver and intraobserver variability were both quite acceptable for measurement of mitral regurgitant jet area. Identification of the jet was not impeded by a second source of blood flow with this lesion because the left atrium is normally devoid of high velocity flow during systole. Therefore, any blue or green color appearing during this portion of the cardiac cycle was considered most likely due to mitral regurgitation alone. In addition, because mitral regurgitation is often holosystolic,

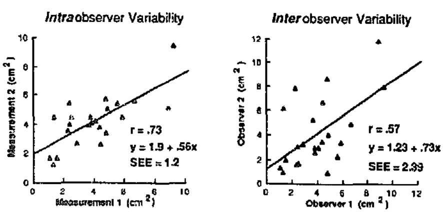


Figure 4. Linear regression plots of aortic isovolumic jet areas, comparing intraobserver (**left**) with interobserver (**right**) variability. Correlation between measurements made by a single observer was only fair (r = 0.73). The correlation between two observers was poor (r = 0.57 and SEE = 2.39).

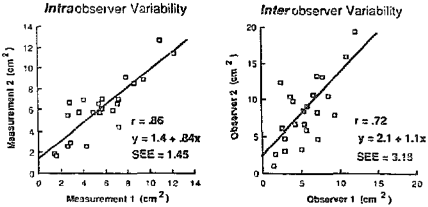


Figure 5. Linear regression plots of maximal aortic jet areas, comparing intraobserver (left) with interobserver (right) variability. The intraobserver correlation was good (r = 0.86) while the interobserver correlation was only fair (r = 0.72 with a large standard error).

the regurgitant jet persisted for numerous frames of each cardiac cycle, which provided an additional reference for identification and measurement.

Occasionally, significant differences existed between observers in performing measurements of mitral regurgitant jet areas. Figure 2A shows an example of a still frame from a patient with rheumatic mitral insufficiency. The regurgitant jet seen in the left atrium is irregular in shape, heterogeneous in color and quite dispersed. The yellow-green portion of this jet may represent turbulent flow, a reversal of direction (swirling) within the left atrial cavity or possibly pulmonary venous inflow. Thus, individual observers may choose to include or exclude the yellow portions of the jet, which would result in a large discrepancy in jet area measurements. At present, it is not known whether such signals should be regarded as part of the flow disturbance and incorporated into measurements of jet area. However, such flow recordings may result in interobserver variability in measurement of mitral regurgitant jet areas in patients with this type of flow.

Aortic regurgitation. Two measurements of aortic regurgitant jet area were performed by both observers. To avoid contamination with mitral inflow, jet area was measured during isovolumic diastole. However, intraobserver and interobserver variability were substantial for this measurement. These data are likely related to the fact that the sampling rates obtainable with most currently available systems are too low to adequately sample isovolumic diastole, a temporally brief event. Thus, the aortic regurgitant jet during isovolumic diastole was frequently imaged in only a single frame and showed considerable variability in size from cycle to cycle.

In comparison with isovolumic values, measurements of maximal aortic regurgitant jet area yielded superior reproducibility. The analysis of intraobserver and interobserver variability for maximal aortic regurgitant jet size yielded correlation coefficients (r) of 0.86 and 0.72, respectively. However, measurement of maximal jet area introduced other problems in the assessment of aortic regurgitation. As diastole progressed, the left ventricle contained not only the aortic regurgitant stream but also transmitral flow velocity signals from large intraventricular swirling vortices (Fig. 5B). It thereby became difficult, if not impossible, to determine the exact extent of disturbed flow. In addition, the correlation coefficients for interobserver and intraobserver measurements of maximal aortic jet area were significantly influenced by the presence of a few large lesions. If only jet areas <15 cm^2 are considered (n = 21), the interobserver correlation becomes r = 0.52. The standard error for this measurement was also substantial at 3.2 cm^2, which reflects the difficulty in making individual measurements in these complex flow disturbances. The intraobserver correlation is also reduced to r = 0.78 when the large jets (>15 cm^2) are excluded.

Limitations of the study. Several factors are worthy of consideration in interpreting our results. Our data address the selection and measurement of jets, only two of many important variables in the sequential process of noninvasive grading of regurgitant valve lesions by the Doppler color flow technique. Because first generation Doppler flow imaging equipment was used in this study, technical advances in the ability to acquire information at faster frame rates could lessen the problems encountered with inadequate sampling. Gain settings were not standardized among patients, and previous studies have shown that the size of the regurgitant jet is quite sensitive to alterations in gain (1). However, in our study no changes were made in gain settings once the echographic recording was begun.

The problem of merging of the aortic regurgitant jet with mitral inflow might have been lessened if parasternal views had been included in the analysis. To further consider this limitation, we retrospectively analyzed the parasternal long-axis and modified low parasternal views from 18 patients in the current study with aortic regurgitation. The jet areas for both isovolumic and maximal jets were traced on separate occasions by the same two observers, at least 2 weeks apart, as in the methods used to evaluate the apical views. Intraobserver correlation using linear regression analysis was r = 0.59 and SEE = 1.5 cm^2 for the isovolumic jet area and r = 0.72 and SEE = 1.53 cm^2 for the maximal jet area. The interobserver agreement was also only fair (r = 0.54 and SEE = 1.59 cm^2 for the isovolumic period and r = 0.71 and SEE = 2.13 cm^2 for the maximal jet areas). Thus, the observer variability was substantial for the measurement of both isovolumic and maximal aortic regurgitant jet areas, even when views were chosen that should theoretically minimize the problem of merging flows.

The measurement of jet areas from the parasternal views is limited by a different set of technical difficulties. When the beam is nearly perpendicular to direction of flow, as with aortic regurgitation imaged from the parasternal long-axis view, small changes in jet direction may result in complete color reversal from red to blue within the same jet. In addition, the maximal area of flow disturbance may not be adequately recorded unless the widest sectors are used to visualize long jets extending from the outflow tract toward the apex. Such wide sector angles further reduce the frame acquisition rate. Theoretically, significant signal "dropout" of the jet may occur because of failure to record lower velocities as a result of the large angle of incidence between Doppler beam and direction of aortic regurgitant flow from the parasternal views.

Conclusions. Intraobserver and interobserver reproducibility are acceptable for the measurement of mitral regurgitant jet area. Thus, difficulty with measurement techniques should not present a problem to the quantitation of mitral regurgitation by Doppler color flow imaging. However, the interobserver variability is substantial for measurements of aortic regurgitant jet areas, whether performed in the isovolumic period or at maximal size. Furthermore, even when a flow signal is reproducibly identified by an individual observer in a patient with aortic regurgitation, it may not be possible to determine the relative contribution of the aortic regurgitant jet, transmitral filling and vortices within the signal. These results may have an important bearing on future attempts to quantify regurgitation using Doppler color flow imaging techniques.

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