New indexes for assessing aortic regurgitation with two-dimensional Doppler echocardiographic measurement of the regurgitant aortic valvular area

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ABSTRACT  Direct examination of the aortic orifice at the level of the aortic valves (aortic valvular orifice area, AVOA) in the short-axis plane was performed with a 3 MHz two-dimensional pulsed Doppler echocardiographic apparatus. The AVOA was mapped with the Doppler gate to detect or rule out the presence of a regurgitant aortic valvular area (RAVA) established by recording of abnormal diastolic Doppler signals on a "yes or no" basis. A group of 12 normal subjects and 83 patients, including 40 patients with aortic regurgitation proven by aortography, were investigated with this procedure. In the 38 patients with aortic regurgitation diagnosed by Doppler echocardiography (diagnostic sensitivity 95%, specificity 100%), planimetric measurements of the RAVA and AVOA were performed with calculation of two indexes: the RAVA/square meter of body surface area and the RAVA/AVOA ratio. These indexes correlated well with independently performed angiographic grading on a three-point scale (r = .87 for the RAVA, .88 for the RAVA/AVOA; p < .001), with highest significance of differences in mean values among each grade of severity found for the RAVA/AVOA (p < .001). In addition, Doppler echocardiography identified the anatomic valvular site of the lesion, and we confirmed the site during surgery.


PULSED DOPPLER echocardiographic techniques provide direct information about flow disturbances and are most appropriate for the noninvasive investigation of aortic regurgitation. However, some problems remain for the evaluation of severity in cases of associated lesions. In the literature, two pulsed Doppler echocardiographic approaches are usually proposed. They include a downstream investigation of the aorta and an upstream detection of the regurgitant jet in the left ventricular outflow tract, either isolated6–7 or associated.8,9 Our purpose is to examine the reliability of a completely new Doppler echocardiographic procedure. It consists of the direct Doppler echocardiographic examination of the aortic valvular orifice area to obtain calculated indexes of severity. Their reliability for grading the insufficiency will then be compared with aortography.

Methods

Subjects. The study population included 12 normal subjects (six women and six men, ranging from 15 to 78 years of age, mean 36) and 83 patients (39 women and 44 men, ranging from 13 to 74 years of age, mean 41), in whom the presence of an aortic regurgitation was confirmed or ruled out by aortopulmonary angiography performed within a week of the Doppler echocardiographic examination. Diagnoses mostly included valvular rheumatic diseases, with pure or associated lesions (48 aortic, 61 mitral, and 17 tricuspid), and also coronary heart diseases (n = 5), cardiomyopathies (n = 3), and congenital heart diseases (n = 4). Forty-five patients were in sinus rhythm, and 38 were in atrial fibrillation.

Diagnosis of aortic regurgitation. The diagnosis relied on angiographic data. Aortic root angiography was performed in a 45 degree left anterior projection with injection of 40 to 50 ml of meglumine diatrizoate (Renografin). The presence of an aortic regurgitation was demonstrated in 40 patients. The cause was rheumatic (n = 34), calcific (n = 3), postendocarditic (n = 2), and congenital (n = 1). Regurgitation was associated with stenosis in nine patients and with mitral lesions in 28 patients, and was proven by left heart catheterization. Diagnosis of regurgitation was further confirmed during surgery in 24 patients.

Classification of aortic regurgitation. The severity of aortic regurgitation was graded independently from the ultrasound findings on a three-point scale from angiography on the following findings10: (1) mild (15 lesions) — minimal jet of dye in the upper part of the left ventricular outflow tract cleared at the next systole, (2) moderate (nine lesions) — jet of dye not cleared at the next systole with slow and progressive opacification of the left ventricle, which remained fainter than that of the aorta, and
Doppler echocardiographic examination

Apparatus. We used an ATL 851 (ATL, Bellevue, WA) with a pulsed Doppler 3 MHz velocimeter and a two-dimensional 90 degree wide-angle mechanical sector scan with a single transducer for both techniques. The diameter of the transducer was 2.5 cm. According to the Doppler principle, the range-gating system makes it possible to record the velocity of a small blood sample (2 × 4 mm) at any given location along the ultrasound beam from 3 to 17 cm from the chest wall. The output consisted of an audiosignal of the Doppler shift and a graphic display of the frequency spectrum. In addition to the use of a time-interval histogram with a demodulated analog flow-velocity trace that used the zero-crossing detector method,11 the apparatus was connected to a fast Fourier transform device (Angioscan/Uniscan, Unigon, Mount Vernon, NY) to obtain a real-time spectral analysis. Analysis speed was 6.5 msec for a 128-point frequency spectrum. Other characteristics of this analyzer have been previously described.12

We also used two video monitors, one for the real-time scanning and the other for the Doppler display. Recordings were made on a Sony video tape recorder, and hard copies of real-time imaging were obtained on a 4633 Tektronix recorder. Doppler analog flow-velocity traces, TM echocardiographic tracings, Doppler spectral displays, simultaneous electrocardiogram lead II, and frequency-selecting phonocardiograms were recorded on a flex 1 (Irex, Mahwah, NJ) fiber-optics recording system.

Recording method. Subjects were generally studied while in the supine left lateral position. The method used for two-dimensional Doppler echocardiographic examination of the heart has been already reported.13 In brief, it requires (1) dynamic visualization of the structure or chamber to be investigated, (2) location of the Doppler beam, seen as a continuous white line, to transect the area of interest, and (3) adjustment of the Doppler gate, seen as a bright spot, to control the depth of the sample volume along that beam. The image is then frozen while the apparatus is automatically switched to the Doppler system. When the characteristic Doppler sound is heard, the recording may be performed.

Pulsed Doppler echocardiographic positive diagnosis criteria. The criterion for pulsed Doppler echocardiographic assessment of a regurgitation at the aortic valve oriﬁce area was the finding of a signal in diastole on a “yes or no” basis established by the presence of an audiosignal, the graphic inscription of a spectral disturbance at least twice as wide as the base line, and a duration of the latter at least for 0.10 sec.

Examination of the aortic valve oriﬁce area (Figure 1). We used the parasternal short-axis approach. Once a satisfactory echocardiographic image of the aortic oriﬁce was obtained, the procedure sequentially was as follows:

1. Pulsed Doppler echocardiographic examination of the oriﬁce was performed to detect a diastolic anomaly. The entire oriﬁce was carefully checked along its vertical and horizontal axes. When an anomaly was found the abnormal area was mapped with concentric circles from its center, and its limits were defined by the Doppler gate. A sheet of transparent plastic was then applied over the video monitor and the contour of the abnormal area, labeled the regurgitant aortic valve oriﬁce (RAVA), was delineated; we carefully tried to avoid parallax errors.

2. In these patients and in normal subjects the aortic valve oriﬁce area (AVOA) was also delineated on a transparent sheet by outlining its inner circumferential edge seen on the video screen in diastole, which represents the aortic root area.

3. An index of magnitude of the aortic regurgitation was calculated from the values of both areas (determined by planimetry), as RAVA/AVOA and was labeled the valvular regurgitant index (VRI).

The measurements were repeated three times, and we retained the average values over the three measurements. All subjects were examined by two observers without interobserver or interobserver discrepancy interpretation as tested by over 30 random reviews of video tapes. Direct ultrasonic measurements performed at the aortic oriﬁce area were also corrected for body surface area.

Aortic areas were measured by planimetry with a Hewlett Packard integrator 98134 A with a 1% estimated error. Analysis of the ultrasonic findings was made without knowledge of the invasive procedure results obtained by separate teams. A statistical analysis of the results was made with a Hewlett Packard 4815. Values were expressed as mean ± 1 SD. The signiﬁcance of the differences found among the mean values was assessed with Student’s t test. Linear regression analyses were performed for the grading derived from pulsed Doppler echocardiographic indexes and aortographic data.

Results

Normal subjects (Figure 2, Table 1). No anomaly was found in diastole at the AVOA during the pulsed Doppler echocardiographic examination. Table 1 shows the values for the normal aortic valve area, age, and body surface area.

Diagnosis of aortic regurgitation (Figures 3 and 4). Doppler echocardiographic anomalies were detected at the aortic oriﬁce in 38 of the 40 patients with proven (3) severe (16 lesions) — jet of dye producing a rapid or imme-
diate opacification of the left ventricle equal to that of the aorta.
mean the of addition aortic regurgitation (sensitivity 95%). The Doppler signal was usually harsh and rough; however, in cases of large regurgitant areas, the signal could be smoother in the center with a to-and-fro character due to the addition of a systolic component.

Table 1 and figure 5 show a significant increase of the mean values for the AVOA in this group, with or without correction for body surface area. Linear regression analysis among the values of the RAVA and AVOA showed a significant correlation coefficient of \( r = .65 \) (\( p < .001 \)) with the following equation: \( \text{AVOA} = 1.12 \text{RAVA} + 7.62 \), SEE 2.15. No Doppler echocardiographic anomaly was detected in any of the subjects of the control group (specificity 100%).

**Assessment of the severity of aortic regurgitation (figure 6, table 2).** Except for one underestimated and two overestimated sizes of lesions, the assessment of severity was satisfactorily obtained in 92% of patients by use of the indexes. Table 2 shows a significant increase of the mean values among each grade of increasing severity for two parameters, the RAVA corrected for body surface area and the VRI. Figure 6 illustrates the results obtained with these Doppler parameters correlated with the angiographic grading (\( r = .87 \) for the former, \( r = .88 \) for the latter, \( p < .001 \)). The AVOA was also plotted against the angiographic grading, with a correlation coefficient of \( r = .43 \). Although the correlation was at a low level, it was significant (\( p < .05 \)).

**Surgical correlations.** Pulsed Doppler echocardiography predicted the site of the valvular lesions to be central in all patients who underwent surgery, with additional spreading of the sites to the right (two patients), left (one patient), and noncoronary cusp (one patient). We confirmed these predictions in all patients at surgery. One more right coronary cusp lesion was missed by Doppler echocardiography. Surgery further confirmed the presence of the regurgitation (mild-to-moderate grade) predicted by Doppler echocardiography in eight patients undergoing surgical repair for mitral lesions.

**Discussion**

At the present time, the pulsed Doppler echocardiographic technique may be considered as the most suitable noninvasive technique for investigation of valvular regurgitation. However, it suffers from well-known limitations. These mainly consist of the Nyquist limitation for the recording of high velocities at any depth, noisy receivers, and gain-dependent output displays. Recent technological improvements in measuring the variable size of the sample volume and the signal-to-noise ratio and in performing the real-time spectral analysis have already taken place and have made quantitative flow parameters available. In the present study, limitations are minimized because the aortic orifice is a rather superficial structure and the assessment of a disturbed spectrum only relied on a “yes or no” basis (since no signal is normally heard in diastole at the aortic orifice). The diagnostic value of

![FIGURE 2. Pulsed Doppler recording at the AVVA in a normal subject. Top, Two-dimensional echocardiographic short-axis scan plane. The Doppler beam transects this plane, and the Doppler gate is located at the AVVA. Bottom, Corresponding Doppler recording. The frequency spectrum (TIH) is displayed as a thin line of clustered dots, interrupted by deflections of short duration (inferior to 0.10 sec), related to the velocity of the closings and opening motion of the aortic valves (oblique arrows). Each vertical bar at the bottom trace equals 0.04 sec. DB = Doppler beam; G = Doppler gate; E = echographic trace (M mode); L2 = lead II of the electrocardiogram; TIH = time interval histogram; 0 = zero line of the frequency spectrum; PCG = phonocardiogram; 1 S = 1 sec; AO = aortic orifice; LA = left atrium.](https://circ.ahajournals.org/content/1/2/1000/f2.html)
TABLE 1

Values in age, body surface area, and measurement of the AVOA (mean±SD)

<table>
<thead>
<tr>
<th>Age (yr)</th>
<th>Normal subjects (n = 12)</th>
<th>Patients with aortic regurgitation (n = 38)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
<td>Grade 1 Mean ± SD</td>
</tr>
<tr>
<td>Range</td>
<td>36 ± 18</td>
<td>39 ± 17</td>
</tr>
<tr>
<td>Range</td>
<td>1.69 ± 0.14</td>
<td>1.59 ± 0.17</td>
</tr>
<tr>
<td>Range</td>
<td>6.12 ± 1.54</td>
<td>9.99 ± 2.82</td>
</tr>
<tr>
<td>Range</td>
<td>(1.42–1.85)</td>
<td>(1.26–1.96)</td>
</tr>
<tr>
<td>Range</td>
<td>3.71 ± 0.85</td>
<td>6.25 ± 1.74</td>
</tr>
<tr>
<td>Range</td>
<td>(2.46–4.99)</td>
<td>(2.56–9.52)</td>
</tr>
</tbody>
</table>

Grades = angiographic grade of increasing severity; BSA = body surface area.

*p < .01; **p < .001.

our procedure is therefore minimally affected by these existing technological drawbacks.

Relevancy of the new indexes. The magnitude of the regurgitation depends on three factors: the size of the defect, the diastolic pressure gradient across the defect, and the duration of diastole. Of these, the first two are by far the most determinant. Our procedure makes possible, for the first time, the direct assessment of the RAVA. Since it has been demonstrated that the regurgitation increases with the regurgitant area, it is therefore no surprise that we found a high level of correlation for this parameter. On the other hand, the pertinency of relating the RAVA to the AVOA needs two comments: First, one would think that no relationship would be expected between the size of the aortic orifice and the severity of the regurgitation. However, our findings indicate that they are not independent variables because a significant correlation was found between them. Moreover, analysis of the correlation between the RAVA and the AVOA shows that these two parameters are also significantly related. They tend to move in the same direction, but the increase in RAVA overcompensates that of the AVOA, particularly in severe grades. Our findings show that a more refined differentiation among the three grades is obtained when these parameters are introduced in a ratio. In physiologic terms it does suggest that the percentage

FIGURE 3. Pulsed Doppler echocardiographic detection of the aortic regurgitation at the AVOA. The Doppler gate is located at the center of the aortic orifice as proven by the two-dimensional echocardiographic image of the short-axis plane shown at the top and also by the M mode recording shown at the bottom. There is a conspicuous diastolic spectral broadening on both sides of the zero line, and both on the TIH and on the real-time spectral analysis (black and white arrows). These diastolic anomalies are characteristic of aortic regurgitation and may present a slightly variable pattern from one diastole to another; here they exhibit two successive peaks — one in early diastole and one in mid-diastole (black and white arrows) or a single disturbance (second diastole). FFT = real-time spectral analysis with the fast Fourier transform; Hz = hertz; + and − = positive and negative Doppler shifts; t = time axis; DB = Doppler beam; AO = aortic orifice; G = Doppler gate; LA = left atrium; TIH = time interval histogram.
of the leaking area versus the entire aortic anulus is likely to be the most sensitive index to grade the regurgitation. Second, this ratio relates to the methodology in that an ideal measurement of these two parameters should be simultaneous and requires optimal lateral resolution. With the present available equipment some causes of errors were thus unavoidable. Other pitfalls might have come from incomplete visualization of the aortic orifice edge, requiring some points to be extrapolated. Possible differences among the planes of the regurgitant area and aortic orifice might also affect the value of the ratio. Another factor of inaccuracy could stem from the occurrence of exceptionally marked aortic enlargement such as in Marfan’s disease, in which case the single RAVA would be preferable. But in practice all these causes of errors should have minimal effect on the results.

Validity of the new procedure

Diagnostic reliability. The reliability of this new approach remained high even in cases of mild regurgitation, present in 39% of the patients investigated. This represents a clear-cut advantage of the procedure over the previously described procedures. Pulsed Doppler echocardiography picks up the disturbance at the very site of the lesion, just as an internal phonocardiogram would. Moreover, it is the most appropriate method to differentiate a pulmonic from an aortic diastolic murmur. The two false-negative diagnoses were due to weak Doppler signals and subvalvular stenosis. On the other hand, our timing criteria provided excellent specificity and avoided confusion with physiologic disturbances.

Reliability of the assessment of the severity. The main advantage of the pulsed Doppler echocardiographic technique is to provide reliable information on the severity of the lesion. Clearly, with our procedure, errors might stem from ignorance of the other predominant factor of regurgitation, the diastolic pressure gradient. It has been shown that small defects may entail large regurgitant flows with an appropriate gradient. Discrepancies noted between preoperative and operative findings are likely to be explained in part by changes in this parameter. However, the effect of the size of the defect and that of the pressure gradient on the clinical significance of the regurgitation are somehow conflicting; with an increasing grade of severity, the pressure gradient between the aorta and left ventricle tends to be lower, which suggests that the size of the defect is of primary importance.

In our study we used, as previously reported, an
aortographic qualitative grading. It relied on a three-grade classification that minimized the discrepancies and is convenient for clinical needs. A poor Doppler signal obviously entailed underestimation in one of the discrepant cases. Future technological improvements in measuring signal-to-noise ratio and permitting lateral resolution should lead to even better results.

Comparison with other Doppler procedures

Investigation of the aortic arch. We previously proposed to assess the severity of the regurgitation by examination of the aortic arch; the assessment relied on the finding of a diastolic reversal wave at various levels downstream from the aortic arch. Good correlations were found for pure lesions with a decreased success rate for associated lesions. Planimetric analysis of the aortic flow velocity traces, reported by Quinones et al., did not solve remaining problems probably for two reasons: the Nyquist limit led to inaccurate recording of the systolic high velocities present in aortic regurgitation, and of the changes in the angle θ and in the aortic diameter observed in those patients. Additional complexity of blood flow in cases of associated stenosis probably explains most of the discrepancies.

In our opinion, this procedure remains the most reliable for pure lesions when one-dimensional Doppler echocardiography is used. It should always be considered with caution to assess mixed lesions.

Investigation of the left ventricular outflow tract. Since Johnson et al. first described the procedure, it has been the one most frequently used. All studies confirm its high diagnostic reliability. Reliability of results of the evaluation of severity in correlated studies range from insufficient to satisfactory, the discrepancy probably being due to differences in the study material. Recently, two technological improvements have been made: the use of two-dimensional echography and the availability of quantitative parameters drawn from real-time spectral analysis. Nevertheless, the accuracy of results obtained with this procedure suffers due to errors inherent when associated pathology is present. Despite the presence of hypokinetic dilated left ventricle and low cardiac output, we believe that it is associated mitral lesions that produce error. Theoretically, disturbances due to aortic regurgitation have a different timing, location, and tone from those due to mitral stenosis. In fact, these characteristics may be less obvious if there is a bulging of the anterior mitral leaflet or low cardiac output. Associated mitral regurgitation raises an even more embarrassing problem with its well-known increased left ventricular inflow. Conditions such as tachycardia and arrhythmia may increase the difficulties by reducing the diastolic interval free of mitral velocity deflection.

A large amount of associated valvular disease was observed in our study. Clearly, the direct examination of the aortic orifice made it possible to avoid many causes of error. This advantage of the new procedure over the previous ones cannot be disputed.

Anatomic-pathologic implications

Doppler information. Anatomic identification of the valvular site of the regurgitation by Doppler echocardiography appeared quite reliable. The finding of a central regurgitation is a common finding in rheumatic disease. The ability to predict a predominant involvement of a particular leaflet shows the accuracy of the Doppler technique. Moreover, its practical application will grow with further developments in reconstructive surgery.

Echographic information. Our study also delved into
the determination of echographic values for the aortic root (AVOA). A previous report had shown decreased values in patients with cardiomyopathy.24 Our finding of increased values for the aortic root in patients with aortic regurgitation is clinically pertinent. It needs to be validated against the values of other groups of patients. Again, the prediction of the size of the aortic anulus has a preoperative interest. Two patients with the lowest values required the insertion of an annular patch before valve replacement. Conversely, ten patients for whom a dilated anulus was found at operation had an aortic orifice equal to or over 10 cm².

**TABLE 2**

**Measurement of RAVA and VRI (mean ± SD)**

<table>
<thead>
<tr>
<th>Patients with aortic regurgitation</th>
<th>Grade 1 (n = 15)</th>
<th>Grade 2 (n = 7)</th>
<th>Grade 3 (n = 16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAVA (cm²)</td>
<td>0.59 ± 0.38</td>
<td>2.02 ± 0.83 ²</td>
<td>3.46 ± 1.23 ³</td>
</tr>
<tr>
<td>Range</td>
<td>(0.19–1.48)</td>
<td>(1.21–3.69)</td>
<td>(1.11–5.22)</td>
</tr>
<tr>
<td>RAVA (cm²/m² BSA)</td>
<td>0.37 ± 0.25</td>
<td>1.18 ± 0.42 ²</td>
<td>2.34 ± 0.83 ³</td>
</tr>
<tr>
<td>Range</td>
<td>(0.11–1.01)</td>
<td>(0.69–1.94)</td>
<td>(0.77–3.72)</td>
</tr>
<tr>
<td>RAVA/AVOA (VRI)</td>
<td>0.07 ± 0.03</td>
<td>0.16 ± 0.06 ²</td>
<td>0.31 ± 0.07 ³</td>
</tr>
<tr>
<td>Range</td>
<td>(0.02–0.12)</td>
<td>(0.08–0.26)</td>
<td>(0.17–0.42)</td>
</tr>
</tbody>
</table>

Grade = angiographic grade of increasing severity; BSA = body surface area.

²p < .02; ³p < .01; ⁴p < .001.

**FIGURE 6.** Values of the VRI (RAVA/AVOA) and the regurgitant valvular aortic area. A. This diagram illustrates the significant increase of the mean values found for the VRI among each angiographic grade of increasing severity, with a correlation coefficient between angiographic and Doppler grading at .88, p < .001. B, Values found for the RAVA corrected for the body surface area; these results are almost as satisfactory as in A (correlation coefficient between the angiographic and Doppler grading at .87). M²BSA = square meter of body surface area; I, II, III = angiographic grading of severity of the aortic regurgitation; P = p values; AR = aortic regurgitation.

**Limitations of the method.** Limitations of our method remain minimal compared with those encountered in other procedures. Any attempt for measurements should be considered with caution in case of imperfect echographic visualization. Doppler echocardiographic detection of the regurgitation may be difficult in cases of associated subvalvular stenosis and aneurysmal aorta. Low cardiac output might generate weak Doppler signals. Extreme tachycardia makes the detection of diastolic disturbance more difficult. Free silent aortic regurgitation due to acute infective destruction of the aortic valvular apparatus might theoretically constitute a limitation to the method.

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**References**


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