Clinical Investigation of Aortic Insufficiency by Means of Pulsed Doppler Echocardiography

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SUMMARY

Pulsed Doppler echocardiography (PDE) was performed on 41 patients with aortic insufficiency (AI), isolated or associated with other cardiac diseases, using an ATL 500A pulsed Doppler system. The diagnosis was confirmed by angiocardiography in 25 cases. The purpose of the present study was to analyze the disturbed flow due to AI, to investigate the sensitivity of PDE to this lesion, and to compare with the angiographic severity of AI (Sellers). The transducer was placed on the left sternal border and the flow pattern was recorded at the aortic valve orifice and the proximal and distal left ventricular outflow tract (LVOT), using a strip chart recorder at a paper speed of 100 mm/sec.

The specific feature of AI was a widely dispersed dot pattern which began at the aortic valve closure and extended to late diastole. The severity of AI was graded by supravalvular aortogram in 25 patients. In grades I and II, the abnormal dot pattern due to AI was mostly detected at the aortic valve orifice and the distal LVOT, but it was rather difficult to detect the disturbed flow at the proximal LVOT. In contrast, in grades III and IV, the disturbed flow was recorded at all the sampling sites; with severe aortic regurgitation, it was detected at a wider range in the left ventricular cavity.

In grades I and II, the abnormal dot dispersion at the proximal LVOT was not so large at its onset in diastole but it tended to increase after the mitral valve opening, whereas in the majority of patients of grades III and IV, a large dot dispersion was recognized from its onset to late diastole.

The typical flow pattern due to AI was detected at the LVOT in 38 out of 41 patients (92.7%). Moreover, it was detected in all the patients with angiographically proved AI except for 1 case of grade I (96.0%).

Additional Indexing Words:

Time interval histogram Disturbed flow Regurgitant jet
Aortography Left ventricular outflow tract

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THE non-invasive diagnosis of aortic insufficiency (AI) has conventionally been made by phonocardiography[1)-3)] and echocardiography.[4)-10)] However, these methods demonstrate the indirect findings of AI by evaluating the abnormal cardiac movement and structures due to hemodynamic changes by this lesion. On the other hand, the definite diagnosis of AI has usually been made by invasive methods such as aortography,[11),12)] electromagnetic flowmetry[13)-15)] and intracardiac phonocardiography.[16)-18)]

Recently, various types of instrument for pulsed Doppler echocardiography (PDE) have been developed and come into clinical use. In 1970, Baker[19)] developed a non-invasive pulsed Doppler device for evaluating the flow pattern within a specified area in the great vessels and the heart chambers, by combining the conventional echocardiography with a pulsed Doppler flowmeter.

The purpose of this study was to analyze the abnormal flow pattern in AI using PDE, to investigate its sensitivity to this lesion, and to compare with the angiocardiographic severity of AI according to the classification of Sellers. We also evaluated the localization of the abnormal flow pattern due to AI.

Materials and Methods

The subjects of this study consisted of 41 patients with AI. There were 31 men and 10 women, ranging in age from 6 to 83 years with a mean of 39.3 years. In 25 cases, the diagnosis was confirmed by supravalvular aortography and was made by phonocardiography in 16 cases. Eleven patients had isolated AI. Twelve cases were associated with aortic stenosis, 20 with mitral stenosis, and 7 with mitral insufficiency. There were also 3 cases associated with ventricular septal defect, 2 of which had undergone surgical repair of the interventricular septum (Table I).

Table I. Case Materials

Aortic insufficiency	No. of patients	Sex		Age (mean)
		male	female	
Isolated	11	7	4	45.6
Associated*	30	24	6	36.9
Total	41	31	10	39.3
Asociated with				
AS	12	10	2	46.5
MS	20	14	6	41.9
MI	7	5	2	37.4
VSD	3	3	0	14.0

Abbreviations: AI=aortic insufficiency; AS=aortic stenosis; MS=mitral stenosis; MI=mitral insufficiency, VSD=ventricular septal defect. *=11 patients had overlapped associated lesions.

Aortography was performed prior to and/or after PDE examinations, and each aortogram was graded according to the degree of AI by Sellers' classification. There were 7 cases of grade I, 9 of grade II, 7 of grade III, and 2 of grade IV, respectively.

The ATL 500A pulsed Doppler system was used for tracing of intracardiac flow patterns. This device is a combination of the pulsed Doppler flowmeter and conventional pulsed echo system. The transmitted ultrasound frequency of 3 MHz is used with a pulse repetition rate of 5.5 KHz. The sample volume is of a tear drop shape with an effective size of 2 by 4 mm. The position of a sample volume is continuously selected between the depth of 5 mm and 12 cm, and displayed on A- and M-mode echocardiogram. Moreover, the flow pattern within the sample volume is displayed by time interval histogram. Above the zero flow line the flow is toward the transducer and below it the flow is away from the transducer. The distance from the base line is proportional to the blood flow velocity within the sample volume. If the angle between the incident ultrasound beam and the blood flow vector is smaller, a more rapid flow is recorded. When laminar flow exists, the time interval histogram produced by this flow shows a narrowly dispersed dot pattern. When turbulent flow exists, it shows a widely dispersed dot pattern.

The patients were examined in a supine or left lateral position. The transducer was applied to the third to fifth intercostal space near the left sternal edge in order to record the flow pattern in the left ventricular outflow tract (LVOT). As illustrated in Fig. 1, points A, O, and M are selected for sampling sites. That is to say, point A is positioned at the aortic valve orifice and point M is located in the LVOT where the anterior mitral leaflet is maximally recorded by M mode echocardiography. Moreover, point 0 is placed between the points A and M. In addition, the normal flow patterns in the same points were evaluated in 14 healthy controls.

All recordings of the flow patterns were made by a strip chart recorder (Honeywell 1856 ultraviolet recorder) at a paper speed of 100 mm/sec.

Results

Flow patterns by PDE in normal subjects

First, the typical flow patterns in a normal subject at the sampling points shown in Fig. 1 are displayed to compare with those in patients with AI. As shown in Fig. 2A, at the aortic valve orifice (point A), the systolic flow displayed by time interval histogram shows a narrowly dispersed dot pattern, indicative of flow toward the transducer and terminated by the aortic valve click. In diastole, the flow also indicates a narrowly dispersed dot pattern near the base line except for the spike-like pattern. At the point 0 in the distal LVOT (Fig. 2B), the systolic flow shows a narrowly dispersed dot pattern and is terminated by an aortic valve click. The flow in diastole shows a narrow band pattern and slightly fluctuates around the base line. At the point M in the proximal LVOT (Fig. 2C), systolic flow shows a narrow band pattern oriented away from the transducer, whereas in early diastole there is

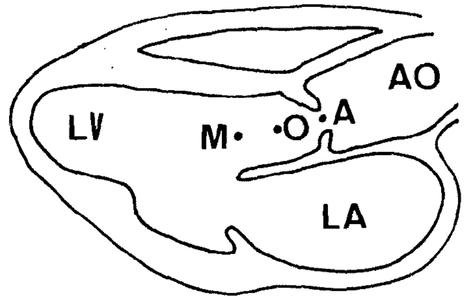

Fig. 1. Schematic illustration of sampling sites. Point A indicates the sampling site at the aortic valve orifice and point M is located in the proximal left ventricular outflow tract (LVOT) where the anterior mitral leaflet is maximally recorded in M-mode echocardiogram. Moreover, point O is located in the distal LVOT between the points A and M. Abbreviations: LV = left ventricle; LA = left atrium; AO = aorta.

a slightly dispersed dot pattern that begins at the mitral valve opening and is compatible with the rapid flow into the left ventricle. Soon after P wave of electrocardiogram, a small bidirectional flow is seen, which is probably produced by left atrial contraction. As is stated above, in 14 normal subjects, the flow in the LVOT indicated a somewhat narrowly dispersed dot pattern.

Flow patterns by PDE in patients with AI

Fig. 3 shows a flow pattern in the proximal LVOT (point M) from a 83-year-old patient with isolated AI caused by syphilitic aortitis. In systole, the flow shows a narrow band pattern away from the transducer, whereas the diastolic flow indicates a widely dispersed dot pattern mainly toward the transducer, which begins at the aortic valve closure and extends to late diastole.

Fig. 4 is an another example of isolated AI with a musical diastolic murmur. The flow pattern at the point 0 in the distal LVOT was taken from a 49-year-old male. Aortic regurgitation of grade III was recognized by angiography (Sellers). In systole, the flow shows a slightly fluctuating narrow dot pattern near the base line, whereas the diastolic flow indicates a bidirectional, widely dispersed dot pattern that begins at the aortic valve closure and continues to late diastole.

Fig. 5 is the flow pattern at the point A in the same patient as in Fig. 4. Similarly, a bidirectional, widely scattered dot pattern starting from the aortic valve closure is seen in diastole. The flow pattern recorded in middle to late diastole is obtained only by placing the sample volume of point A at the aortic valve orifice.

Fig. 6 is the flow pattern from a 24-year-old male with AI and ventric-

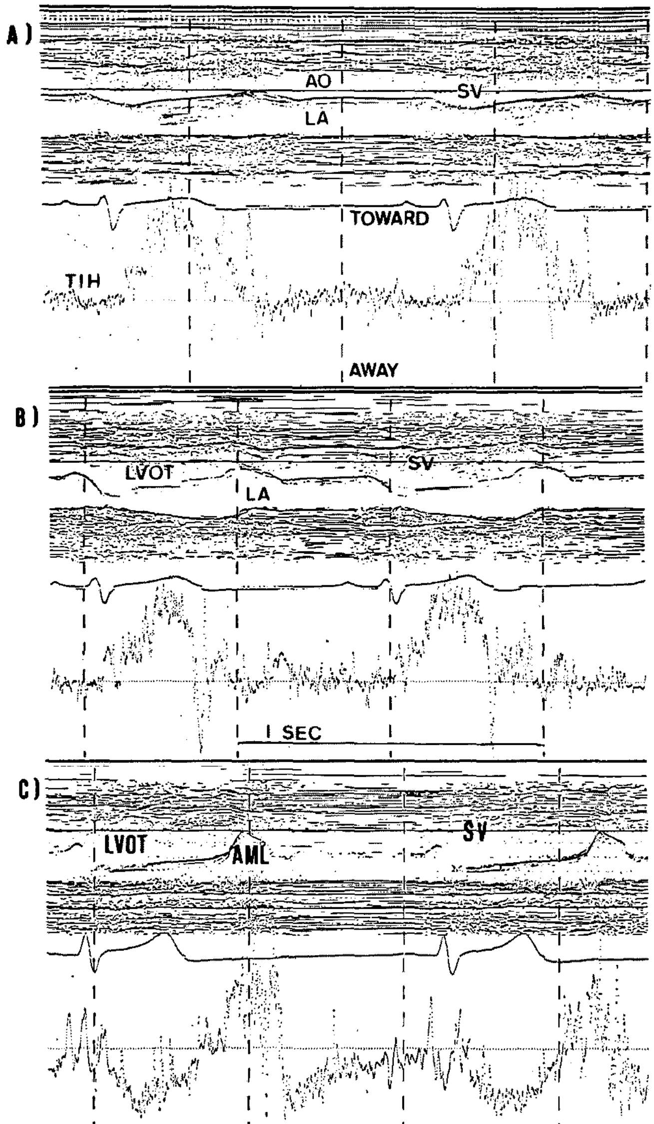

Fig. 2. Flow patterns by PDE in a normal subject. A) The sample volume is located at the aortic valve orifice (point A). The systolic flow shows a narrow band pattern, indicative of flow toward the transducer, and is terminated by the aortic valve click. The diastolic flow also indicates a narrow band pattern near the base line. B) The flow pattern in the distal LVOT (point O) is similar to that at the point A. C) The sample volume is located in the proximal LVOT (point M). The systolic flow shows a narrow band pattern oriented away from the transducer. In early diastole there is a slightly dispersed dot pattern that begins at the mitral valve opening, and is compatible with the rapid flow into the left ventricle. Abbreviations: AO=aorta; SV=sample volume; LA=left atrium; LVOT=left ventricular outflow tract; AML=anterior mitral leaflet; TIH=time interval histogram.

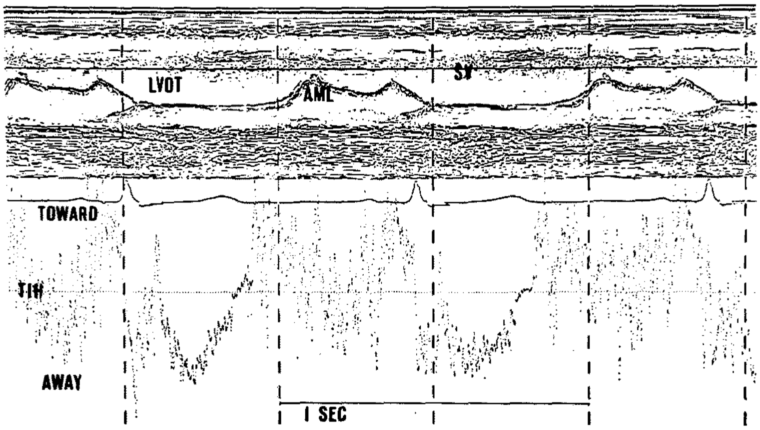

Fig. 3. Flow pattern in the proximal LVOT (point M) from a 83-year-old male with isolated aortic insufficiency. The systolic flow shows a narrow band pattern away from the transducer, whereas the diastolic flow indicates a widely dispersed dot pattern that begins at the aortic valve closure and extends to late diastole. Abbreviations: LVOT=left ventricular outflow tract; AML=anterior mitral leaflet; SV=sample volume; TIH=time interval histogram.

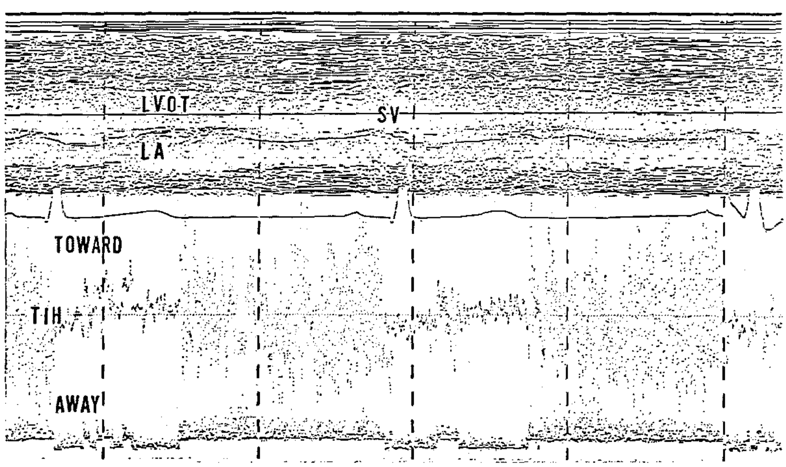

Fig. 4. Flow pattern in the distal LVOT (point O) from a 49-year-old male with isolated aortic insufficiency. In this case, a musical diastolic murmur was audible and aortic regurgitation of third degree was recognized by angiography (Sellers). A narrow band pattern is recognized near the base line in systole, whereas the diastolic flow is widely dispersed bidirectionally, starting from the aortic valve closure. Abbreviations: LVOT=left ventricular outflow tract; SV=sample volume; LA=left atrium; TIH=time interval histogram.

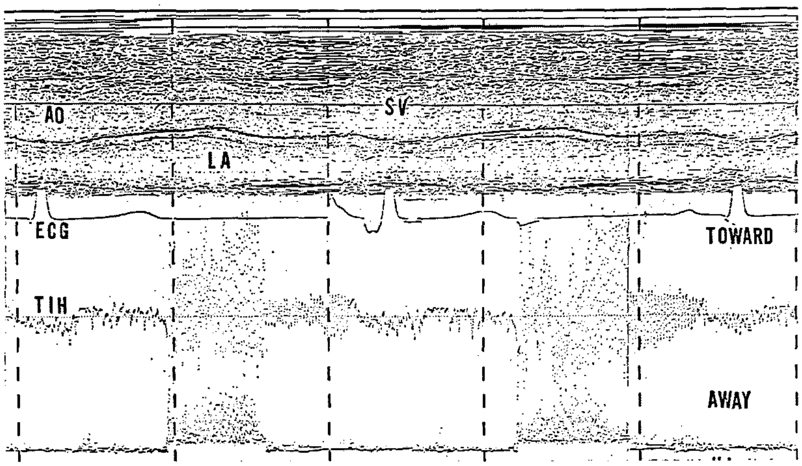

Fig. 5. Flow pattern from same patient as in Fig. 4. The sample volume is positioned at point A. Similarly, the typical diastolic flow pattern of AI is recorded. The late diastolic dot pattern is thought to be produced by the vibration of the aortic valve. Abbreviations: AO=aorta; SV=sample volume; LA=left atrium; ECG=electrocardiogram; TIH=time interval histogram.

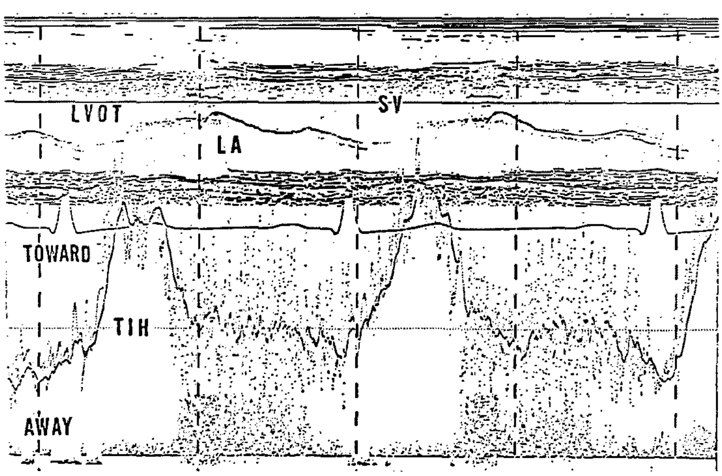

Fig. 6. Flow pattern in a 24-year-old male with aortic insufficiency and ventricular septal defect. This case showed aortic regurgitation of the third degree (Sellers). The sample volume is positioned near the point M. The systolic flow shows a narrow band pattern toward the transducer, whereas the diastolic flow is widely dispersed throughout diastole and independent of the mitral valve opening. Abbreviations: LVOT=left ventricular outflow tract; SV=sample volume; LA=left atrium; TIH=time interval histogram.

ular septal defect. The angiographic severity of aortic regurgitation was of grade III in this case (Sellers). The systolic flow shows a narrow band pattern toward the transducer, whereas the diastolic flow displays a greatly scattered dot pattern throughout diastole independent of the mitral valve opening. This type of diastolic flow pattern at point M was demonstrated in 5 out of 6 patients of AI of grades III and IV.

Fig. 7 indicates a flow pattern in the proximal LVOT (point M) of a 11-year-old male with AI and aortic stenosis. In this case, aortic regurgitation of grade I was recognized by angiography. The flow in this point shows a coherent flow pattern toward the transducer in systole. In contrast, the diastolic flow indicates a non-coherent dispersed dot pattern mainly away from the transducer. Moreover, the flow is a mildly dispersed dot pattern before the mitral valve opening but a widely dispersed one after the opening. This flow pattern was recorded in all 4 AI patients of grades I and II.

Localization of the abnormal flow pattern due to AI by means of PDE

Table II demonstrates the localization of the specific flow pattern of AI in the points A, O, and M by PDE, comparing with the angiographic severity of regurgitation. In most patients of grades I and II, the specific flow pattern of AI was detected at points A and O, but not always at point M. In contrast, in all the patients with grades III and IV, the flow pattern of AI

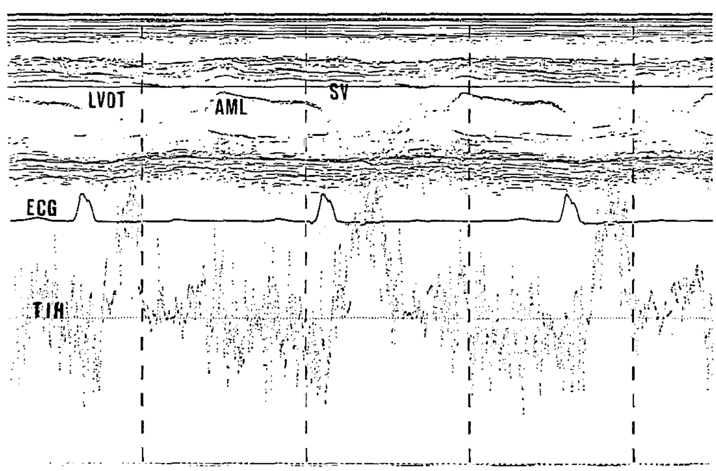

Fig. 7. Flow pattern in a 11-year-old male with aortic insufficiency and stenosis. The sample volume is located at point M. In systole, there is a narrowly dispersed dot pattern. In contrast, the diastolic flow showed a mildly dispersed dot pattern before the mitral valve opening. However, a widely dispersed dot pattern is recorded after the mitral valve opening. Abbreviations: LVOT=left ventricular outflow tract; SV=sample volume; AML=anterior mitral leaflet; ECG=electrocardiogram; TIH=time interval histogram.

Table II. Localization of the Abnormal Disturbed Flow Due to Aortic Insufficiency in the Left Ventricular Outflow Tract

Case	Diagnosis	Aortography (Sellers)	PDE (Sampling site)		
			point A.	point O.	point M.
A. W.	AI+VSD	I°	−	−	−
N. I.	AI+MS	I°	+	+	−
M. H.	AI+MS	I°	+	+	+
H. S.	AIS	I°	+	+	+
R. S.	AI+MS	I°	+	+	+
M. A.	AIS+MS	I°	+	+	+
S. M.	AI+MSI	I°	+	+	+
T. T.	AIS+MS	II°	+	−	−
T. O.	AI	II°	−	+	+
N. Y.	AI+MSI	II°	+	+	+
J. H.	AI+MS	II°	+	+	+
S. I.	AIS+MS	II°	+	+	+
Y. A.	AIS+MS	II°	+	+	+
S. N.	AIS+MS	II°	+	+	+
H. Y.	AI+VSD	II°	+	+	+
K. O.	AIS	II°	+	+	+
H. S.	AI+VSD	III°	+	+	+
K. N.	AI	III°	+	*	+
N. Y.	AI+MSI	III°	+	+	+
H. I.	AI	III°	+	+	+
M. O.	AI	III°	+	+	+
G. D.	AIS+MS	III°	+	+	+
K. Y.	AI	IV°	+	+	*
K. T.	AI	IV°	+	+	+

A+means that the abnormal disturbed flow due to AI was detected and a −means that it was not detected. Points A, O, and M are explained in Fig. 1. *=not examined; PDE=pulsed Doppler echocardiography; AI=aortic insufficiency; AIS=aortic insufficiency with stenosis; MS=mitral stenosis; MSI=mitral stenosis with insufficiency; VSD=ventricular septal defect.

was recorded at all points, namely A, O, and M.

The sensitivity of PDE to aortic insufficiency (Table III)

The 25 cases of the angiographically documented AI were grouped according to the severity of regurgitation (Sellers), and the sensitivity of PDE to each group was then evaluated. In grade I, the diastolic abnormal flow pattern in the LVOT due to AI was detected in 6 of 7 patients; in all 9 of the grade II patients; in all 7 of the grade III patients; and in both of the grade IV patients. In total, it was recorded in 24 of the 25 patients with angiographically proved AI (96.0%).

Table III. Sensitivity of PDE to Aortic Insufficiency

	No. of patients	Disturbed flow	Sensitivity (%)
1) Angiographically proved AI Grade (Sellers)			
I°	7	6	85.7
II°	9	9	100
III°	7	7	100
IV°	2	2	100
Total	25	24	96.0
2) All the patients	41	38	92.7

Abbreviations: PDE = pulsed Doppler echocardiography; AI = aortic insufficiency.

AI was recognized in 38 out of 41 patients diagnosed by phonocardiography or angiocardiography (92.7%).

Discussion

Since its advent, pulsed Doppler echocardiography has enabled us to non-invasively evaluate the blood flow pattern in a specific area of the great vessels and the heart chambers.[20] Many authors have reported that this method is very useful for diagnosis of cardiac shunt and valvular regurgitation and for evaluating the cardiac function in the normal and the diseased hearts.[21-30]

In this study, we used an ATL 500A pulsed Doppler system which displayed the flow pattern as a series of points of the time interval histogram. When the blood flow within the sample volume is laminar, a narrowly dispersed dot pattern is printed on the strip chart recorder. However, when the Doppler gain control is fully advanced or the threshold control is improperly decreased, noise is easily produced and the base line is broadened, so that the flow pattern is displayed as a scattered dot pattern, eventually leading to misdiagnosis.

Thus, as recommended by the manufacturer, the Doppler gain control and the threshold control were suitably adjusted, using the signal amplitude indicator. The Doppler gain was set at the point where its amplitude trace left the baseline at the time of flow and the threshold control was set at the point where its amplitude trace jumped from the base line. In every patient, these controls were invariably performed at all sampling sites.

According to Goldberg and associates,[27] frequency dispersion in normals did not exceed 1 cm with ATL 500A pulsed Doppler system. Thus, a frequency dispersion was considered abnormal if it exceeded 1 cm in vertical

amplitude for any complex of less than 3 cm or one-third of the amplitude in any complex of greater than 3 cm. Nevertheless, there are today no acceptable standards of disturbed flow with this device. Our criteria for the disturbed flow pattern in diastole are that the degree of dot dispersion is apparently more intense than in systole. Besides the time interval histogram, an audio signal is available as a display format, which corresponds to spectrum of Doppler shifts produced by normal or disturbed flow. By this output, smooth blood flow produces a tonal " music-like " sound, whereas disturbed or turbulent flow produces a harsh, scratchy sound. We also determined as to whether the flow was smooth or disturbed with the use of this output. Kalmanson and associates[28] reported that the blood flow patterns by pulsed Doppler technique were remarkably similar to those obtained by electromagnetic flowmeter in normal and diseased hearts except for some small discrepancies. Although quantitative measurements by a pulsed Doppler technique are impossible in the present state of the art, this method provides useful information on the blood flow pattern in clinical applications.

In this study, the systolic flow pattern in the LVOT was narrowly dispersed, similar to normal flow patterns, whereas in diastole, a widely dispersed dot pattern was seen to start from the aortic valve closure and run in the direction opposite to the systolic flow or scatter bidirectionally. These flow patterns in diastole were thought to be caused by aortic regurgitant jet, since they were detected at the LVOT with the direction opposite to the systolic flow or bidirectional dot pattern and started from the aortic valve closure.

In AI without mitral valve diseases, the characteristic of the abnormal flow pattern at the point M was that it began at the aortic valve closure and extended to late diastole. Moreover, the dot dispersion was minimal before mitral valve opening in grades I and II patients, but high throughout diastole in grades III and IV patients. These findings are consistent with the following hemodynamic events: In mild regurgitation, the turbulence is small before the mitral valve opening because of the small amount of regurgitation; but after the opening, the regurgitant blood from the aorta collides with blood flowing in from the left atrium, thus causing a large turbulence. On the other hand, in severe regurgitation, the jet may produce a large turbulence and is not nearly affected by the inflow blood, since the regurgitant volume is very large. Different types of abnormal flow pattern in diastole were observed in mild to severe AI without mitral valve diseases.

However, in the majority of patients associated with mitral valve diseases, the abnormal dot scattering in diastole was increased after the mitral valve opening, irrespective of the degree of aortic regurgitation. This was

due to the hemodynamic changes by the deformed LVOT in diastole and the abnormality of the inflow pattern from the left atrium into the left ventricle.

The degree of dispersion at the point A tended to be less than that at the points O and M. This is considered to be due to the considerable uniformity of regurgitant jet velocity and directions just below the aortic valve orifice. In the point A, the localization of the abnormal flow pattern was limited, and the abnormal flow pattern was easily recorded around the jet stream rather than in the center of the jet as might be expected from cineangiocardiography, because the area of the regurgitant jet was small, resulting in little turbulence, and the various components of blood flow velocity and directions may be easily generated around the regurgitant jet.

Ward and associates[30] reported that, with minimal regurgitation, a localized jet might be detected within or just below the aortic valve orifice, whereas with moderate to severe regurgitation, the jet could be often detected all the way to the left ventricular apex. In our study, the abnormal flow pattern of AI was detected in most of the LVOT even in mild regurgitation.

According to Ward and associates,[30] the sensitivity of PDE to AI was 86%; Kalmanson and co-worker[28] reported that the sensitivity of PDE was 95% to isolated AI and 80% to AI with aortic stenosis. Our result with respect to all 41 AI patients revealed a sensitivity of 92.7%, a finding quite similar to those of Ward et al and Kalmanson et al. As for angiographically proved AI, the abnormal flow pattern of AI was recorded in all patients except for 1 case of grade I. Ward et al[30] indicated a specificity of 94% in detecting AI.

There were 3 cases in which a typical abnormal AI flow pattern could not be detected. One was a 6-year-old male showing the first degree of regurgitation by cineangiography who, nonetheless, was not diagnosed as having AI by phonocardiography. In another case, there was a widely dispersed dot pattern in the LVOT which we did not regard as AI flow pattern, since it began at the point of mitral valve opening. However, we could not rule out latent AI, because it was also detected just below the aortic valve orifice. And another case had a blowing diastolic murmur only in sitting position by auscultation. In this case, a widely dispersed dot pattern that began after the mitral valve opening was recorded only at the point M. Therefore, it was thought to be due to turbulence from the inflow blood from the left atrium.

In conclusion, pulsed Doppler echocardiography is thought to be a useful, non-invasive method of localizing the abnormal flow pattern and of estimating the severity of AI.

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