Detection of severe left anterior descending coronary artery stenosis by transthoracic evaluation of resting coronary flow velocity dynamics

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Abstract

In the presence of severe stenosis, coronary artery flow may be reduced at rest. Recent advances in echocardiography have made non-invasive sampling of velocities in the left anterior descending coronary artery (LAD) possible. The aim of our study was to evaluate feasibility and capability of transthoracic Doppler to detect severe stenosis of the LAD. The study population consisted of 42 subjects with suspected coronary artery disease scheduled for coronary angiography. All had complete transthoracic echocardiography and Doppler sampling of LAD velocities. Quantitative coronary angiography was performed within 24 hours of the echocardiogram. Correlations between LAD velocity profile, measurements and calculations, and the angiographic results were performed. Six subjects had LAD occlusion, 10 had severe (>80% diameter) LAD stenosis, and 26 had normal or non-occlusive LAD disease. In all six subjects with LAD occlusion, distal LAD velocities were not detectable, while in the other 36 subjects, LAD velocities were recorded indicating the vessels were patent. In the 10 subjects with severe LAD stenosis, the diastolic/systolic velocity ratio was <1.5, while in those with non-significant LAD disease, the diastolic/systolic velocity ratio was >1.5 (P<0.005). Diastolic LAD flow was 21.8±13 mL/min in the presence of severe stenosis as compared to 48.5±20 mL/min in subjects without severe stenosis (P<0.0013). LAD velocities had high sensitivity and specificity for the prediction of severe angiographic stenosis. Thus transthoracic Doppler measurement of LAD velocities is feasible and can predict the presence of severe LAD stenosis or occlusion.

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Introduction

Recent technological advances in transthoracic echocardiography have made Doppler sampling of coronary artery velocities possible.[1-6] Because coronary artery flow may be reduced at rest in the presence of severe stenosis, our study was conducted to evaluate the feasibility and capability of transthoracic Doppler to detect severe (>80% diameter) left anterior descending coronary artery (LAD) stenosis.

Materials and Methods

Population

Doppler recordings of LAD velocities using the transthoracic approach are performed routinely in our echocardiography laboratory where the success rate exceeds 97%. In our study subjects with suspected coronary artery disease, having coronary angiography within 24 hours of the echocardiographic study, were considered for inclusion. In order to test the hypothesis of the study, only those with severe LAD (>80% diameter) stenosis and those with normal or non-occlusive disease (<50% diameter) stenosis were included.

Echocardiography

A Siemens Acuson Sequoia echocardiographic system equipped with a 3.5- 7 MHz transducer was used. In order to obtain LAD velocities, the color Doppler Nyquist limit was set at 17 cm/sec. Systematic attempts to record LAD color flow were performed. From the low parasternal short axis view, a search for diastolic color velocity in the anterior inter-ventricular groove, followed by clockwise rotation to achieve alignment of the color jet, was performed. Alternatively, from the apical foreshortened two-chamber view, LAD diastolic velocity was located in the inter-ventricular groove and counterclockwise rotation of the transducer was performed to optimize alignment with the color jet.

Measurements

Peak diastolic and systolic velocities and their ratios were obtained. In addition, time velocity integrals in diastole and systole were measured and their ratios were calculated. Pressure half-time was obtained from the diastolic component of the LAD velocity profile. Measurements were averaged from three consecutive beats. The LAD diameter was measured from the color flow two-dimensional image (Figure 1). LAD cross-sectional area was calculated as:

$$Area = \frac{\pi\,(Diameter\ (cm))^2}{4}$$

Flow in the LAD was calculated as: *Flow* = (*heart rate*) x (*LAD area*) x (*time velocity integral*). Diastolic and systolic time velocity integrals were used for diastolic and systolic flow, respectively. Their sums and ratios were also calculated.

Coronary angiography

All subjects had coronary angiography within 24 hours of the echocardiographic evaluation using a Siemens system, at 25 frames/sec. Quantitative coronary angiography (QCA) was performed using the McKesson minimal cost algorithm. Angiographers were blinded to the Doppler echocardiographic evaluation of the LAD.

Statistical analysis

The mean and standard deviation of parameters were calculated. Comparisons between LAD flow parameters in patients with severe LAD stenosis and subjects with normal or non-significant LAD lesions were performed using the student t-test, with a $P<0.05$ considered statistically significant.

Results

Severe LAD stenosis without occlusion was found in 10 subjects, involving the proximal segment in five, mid segment in seven, and the distal segment in four subjects. Occlusion of the LAD without collaterals was present in six subjects. Inter- and intra-observer variability of LAD velocities were 2±0.4 and 1.5±0.2 cm/sec, of time velocity integrals 0.4±0.1 and 0.3±0.1 cm, of pressure half-time 10±3 and 8±3 ms, and of the diameter of LAD color jet 0.1±0.05 mm, respectively. Velocities of the LAD were successfully recorded in 36 subjects (86%). In six subjects no LAD velocities were detected. All had apical akinesis, and coronary angiography revealing an occluded LAD.

Two types of velocity profiles were observed (Figure 2): i) predominant diastolic velocity with rapid deceleration in 29 subjects (Figure 2A), and ii) large systolic flow in 10 subjects with slow diastolic deceleration (Figure 2B). The results of quantitative coronary angiography of a stenosis are demonstrated (Figures 2C and D). In patients with severe proximal or mid LAD (94±4% diameter) stenosis, diastolic velocities and time velocity integrals were lower while systolic velocities and time velocity integrals were higher than in those without severe stenosis (Table 1).

In addition, diastolic to systolic velocity and time velocity integral ratios were lower in patients with severe LAD stenosis (Table 1). The patterns of diastolic velocity revealed slow deceleration with prolonged pressure half-times in patients with severe stenosis (Table 1). In patients with severe LAD stenosis, diastolic flow, diastolic/systolic flow ratios, and diastolic flow fractions were significantly lower than in those without significant stenosis (Table 2).

A significant ($P<0.05$) inverse relationship was found between diastolic flow and pressure half-time (Figure 3). Ratios of diastolic to systolic velocities, time velocity integrals, and flows were highly sensitive, specific, and accurate in detecting severe LAD stenosis (Table 3). In addition, a prolonged pressure half-time reflecting the degree of flatness of the diastolic velocity profile helped in predicting the presence of severe LAD stenosis (Table 3).

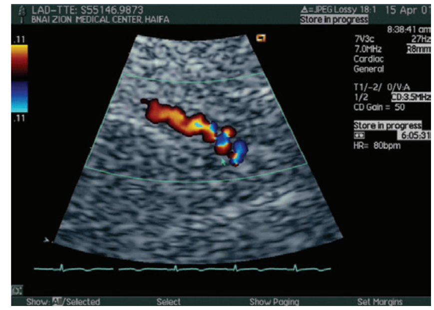

Figure 1. Color jet of diastolic flow velocity in the left anterior descending coronary artery.

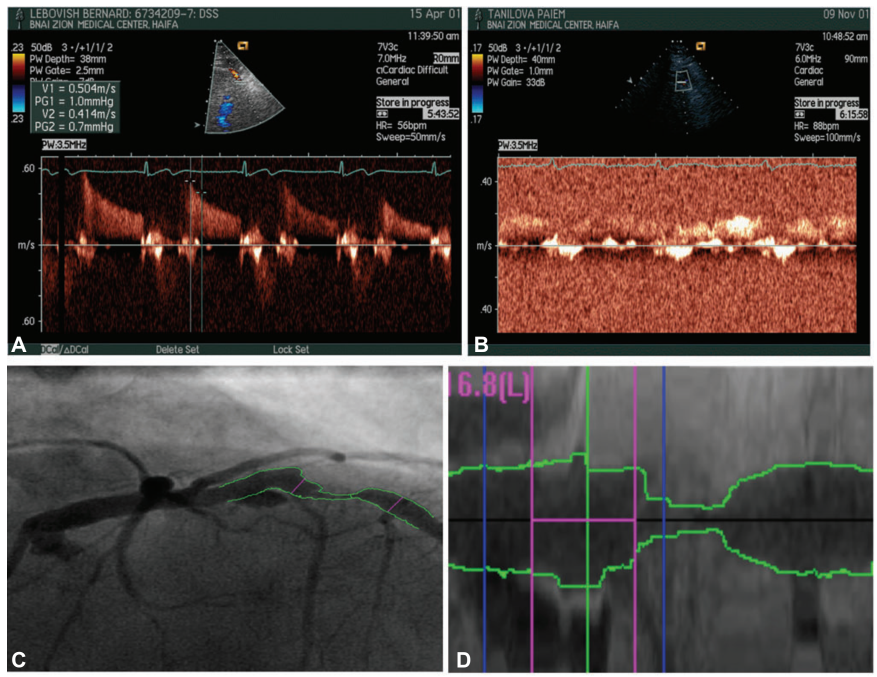

Figure 2. Pulsed Doppler velocity through the left anterior descending coronary artery. (A) Normal dominant diastolic velocity with fast diastolic decay and short pressure half-time. (B) Flat diastolic velocity profile with long diastolic pressure half-time and large systolic velocity component in the presence of severe stenosis. (C) and (D) Analysis of results by quantitative coronary angiography: 80.6% diameter stenosis; 96.2% area stenosis.

Table 1. Parameters of velocity profile in severe and mild left anterior descending coronary artery stenosis.

LAD diameter stenosis	VD (cm/sec)	VS (cm/sec)	VD/VS	TVID (cm)	TVIS (cm)	TVID/TVIS	P1/2T (msec)
80%<LAD<99%	29.9±14.8	28.5±14.1	1.12±0.47	7.14±2.7	5±2.6	1.71±0.75	341±88
LAD<50%	40.6±13.3	14±7.5	3.9±4.7	13.9±9.9	3.1±2.6	4.9±2.3	164±38
P	0.06654	0.01086	0.011794	0.01111	0.1825	3.33×10^{-5}	0.0006

LAD, left anterior descending coronary artery; VD, diastolic velocity (cm/sec); VS, systolic velocity (cm/sec); VD/VS, ratio of diastolic to systolic velocities; TVID, diastolic time velocity integral (cm); TVIS, systolic time velocity integral (cm); TVID/TVIS, ratio of diastolic to systolic velocity integrals; P1/2T, diastolic pressure half-time of the velocity profile.

Table 2. Flow and flow ratios in the left anterior descending coronary artery.

LAD diameter stenosis	FD (mL/min)	FS (mL/min)	FD+FS	FD/FS	FD/(FD+FS)
80%<LAD<99%	21.8±13	15.7±8.3	37.4±19.3	1.53±0.6	0.58±0.11
LAD<50%	48.5±20	12.5±8.7	60.3±25.7	5.1±2.3	0.82±0.1
P	0.00128	0.4288	0.03084	1.43×10^{-5}	0.0006

LAD, left anterior descending coronary artery; FD, diastolic flow; FS, systolic flow; (FD+FS), sum of diastolic and systolic (total) flow (mL/min); FD/FS, ratio of diastolic to systolic flow; FD/(FD+FS), ratio of diastolic to total flow.

Discussion

In the present study, sampling of LAD velocity by transthoracic Doppler was feasible. Undetectable distal LAD velocity in the presence of apical left ventricular wall motion abnormalities was suggestive of LAD occlusion. Severe LAD stenosis was associated with decreased diastolic velocity and flow and increased systolic velocity. Diastolic/systolic velocity and flow ratios were decreased in severe LAD stenosis. Pressure half-time was prolonged in severe LAD stenosis. Parameters obtained from transthoracic diastolic LAD velocity profiles were sensitive, specific, and accurate in detecting severe LAD stenosis and occlusion, and thus may be of use in the clinical evaluation of patients with suspected coronary artery disease.

Coronary artery blood flow has a distinctive biphasic pattern, with a predominant diastolic component.[7] In the absence of coronary artery stenosis, the normal LAD velocity profile is predominantly diastolic and does not reveal a significant velocity gradient or change in velocity pattern along the coronary artery.[8-11] Normal peak diastolic velocities in our study were similar to those reported previously by invasive Doppler flow wires.[9] Furthermore, the ratios of diastolic to systolic velocities in subjects without significant LAD stenosis were similar to those reported previously by invasive methods.[8] These consistencies with invasive findings demonstrate the potential relevance of non-invasive Doppler methods.

According to the law of conservation of energy and the Bernoulli principle, velocities are increased just distal to a significant stenosis.[12-14] Therefore, to avoid turbulence when a Doppler flow wire is used, the tip of the wire should be about six times the vessel diameter distal to the site of stenosis.[10] In our study, LAD velocities were recorded in segments located far distal to the site of stenosis, which accounts for the fact that high velocities were not recorded. On the contrary, lower than normal diastolic velocities were found in subjects with severe LAD stenosis and are similar to findings in invasive studies before and after angioplasty.[15] Thus, in patients with severe LAD stenosis, diastolic velocities and flows in the distal LAD were reduced at rest. However, it should be noted that, in previous studies, velocities just distal and close to the site of stenosis were higher than at the pre-stenotic region, and the ratio of these velocities could be used in the diagnosis of LAD stenosis.[16,17]

In accordance with a previous surgical study,[18] patients with severe LAD stenosis in our study had higher systolic velocities. The increase in systolic velocities in the presence of severe LAD stenosis is analogous to the increase in diastolic velocities in the presence

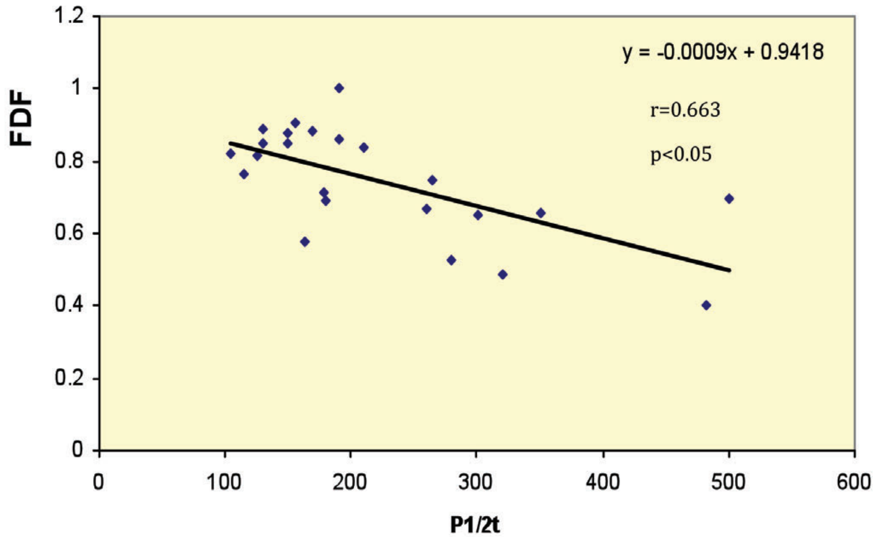

Figure 3. Linear relationship between the fraction of diastolic flow (FDF) from total flow in the left anterior descending coronary artery and the diastolic pressure half-time (P1/2t) of the velocity profile.

Table 3. Diagnostic value of velocity and flow criteria in predicting severe left anterior descending coronary artery stenosis.

	VD/VS<1.5	TVID/S<2	FD/FS<2.2	FD/(FD+FS)<0.7	P1/2T>300 (msec)
Sens (%)	100	100	100	100	72
Spec (%)	94	94	94	94	100
PPV (%)	90	88	88	88	100
NPV (%)	100	100	100	100	90
DAc (%)	96	96	96	96	91

Velocity and flow abbreviations as in Tables 1 and 2. Sens, sensitivity; Spec, specificity; PPV, positive predictive value; NPV, negative predictive value; DAc, diagnostic accuracy.

of coarctation of the aorta or severe carotid artery stenosis. Similar to previous invasive and surgical studies,[15,18,19] the decreased diastolic velocities and increased systolic LAD blood velocities account for our finding of the lower diastolic to systolic velocity ratio in severe LAD stenosis.

Although some concern may be raised about the accuracy of measurements of Doppler jet diameter of flow through the LAD, our findings were reproducible and, therefore, we used these measurements in calculating flow through the LAD. Temporal redistribution with an increase in the systolic component of flow was found in subjects with severe LAD stenosis. Moreover, as expected, with severe LAD stenosis diastolic and total flow at rest were reduced.

The envelope of the diastolic component of the blood velocity profile of the LAD was flat in subjects with severe stenosis and pressure half-time was applied, analogous to its application in mitral stenois.[20] Thus, the longer the pressure half-time, the more severe the stenosis. Evaluation of all the above parameters using the transthoracic Doppler technique revealed that reduced diastolic to systolic velocity and flow ratios, as well as prolonged diastolic pressure half-times, were sensitive, specific, and accurate in diagnosing severe LAD stenosis.

Often it is important to know whether the LAD is patent or not, irrespective of the degree of stenosis. Our findings indicate that inability to find LAD flow, especially in the presence of wall motion abnormality in the territory of the LAD, is consistent with vessel occlusion and absent significant collateral flow. It should be emphasized that in previous studies in subjects with chronic LAD occlusion and collateral flow, retrograde LAD flow could be detected[21] and coronary artery collateral flow reserve could be assessed.[22] These facts have important implications in diagnosing LAD occlusion and reperfusion in the setting of acute anterior myocardial infarction.

In accordance with results of a previous study,[23] we found a decreased diastolic/systolic velocity ratio in subjects with LAD stenosis. However, in our study, this ratio was lower owing to the more severe LAD stenosis required in our study population. Detection of "normal" LAD velocities and ratios enabled us to predict hemodynamically insignificant LAD lesions or a normal LAD, while a "venous-like" forward LAD velocity pattern predicted the presence of a severe LAD stenosis before the coronary angiogram was performed. Recently, we have gained experience in transthoracic sampling of velocities of the posterior descending coronary artery and the proximal-mid segments of the circumflex artery. We believe that transthoracic sampling of coronary artery velocities may become a routine part of echocardiographic studies.

Limitations

Despite the similarity of the LAD velocity profile achieved by transthoracic Doppler to the findings obtained by Doppler flow wires, we did not provide invasive verification of flow measurements. Doppler sampling of blood velocities is angle dependent, which may affect velocity measurements and flow calculations. However, we tried to achieve long segments of LAD color flow images and alignment of the Doppler sample with the color signal. Another limitation is concern about accuracy of the diameter measurement of the LAD from the color flow image. Nevertheless, diameter measurements were reproducible.

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