Changes in Doppler indices of cardiac function during and after percutaneous transluminal coronary angioplasty

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Abstract

Objective—To assess the sensitivities of Doppler indices to changes in global cardiac function during and after controlled myocardial ischaemia induced by coronary angioplasty.

Design—Continuous wave Doppler signals of aortic flow were recorded during coronary angioplasty. The following Doppler indices of cardiac function were measured before, during, and after balloon inflation: V (peak velocity), MA (mean acceleration), V^2/T (T = time from onset to peak ejection), and MD (minute distance corrected for baseline heart rate).

Setting—A tertiary care cardiological unit in a university hospital.

Patients—Sixteen patients undergoing coronary angioplasty of the left anterior descending coronary artery. Eight patients had multivessel disease.

Main outcome measures—The primary outcome measures were planned before data collection began.

Results—12 patients showed a significant fall of three or more Doppler indices from their baseline values during balloon inflation. This occurred in all patients with multivessel disease. The Doppler indices V^2/T , MD, V, and MA fell by 43.7%, 37.7%, 27.4%, and 23% respectively from their baseline values ($p < 0.001$). The relative sensitivities of the Doppler indices to ischaemia were $V^2/T > MD$ ($p < 0.02$), $MD > V$ ($p < 0.001$), and $V > MA$ ($p < 0.01$). The impairment of global left ventricular function resulting from brief balloon inflation during single vessel angioplasty was reversible in all the patients.

Conclusions—The Doppler indices V^2/T , MD, V, and MA are all sensitive, in order of magnitude, to falls in global cardiac function resulting from ischaemia. They may prove useful for assessing cardiac function during ischaemia in the clinical setting.

occlusion in cases of angioplasty in single vessel disease.^{3,4} A carefully controlled study has shown that after balloon deflation, indices of left ventricular systolic function return to normal within 40 s of reperfusion.⁵ The changes in various Doppler indices of cardiac function during myocardial ischaemia have been studied in dogs⁶ and in the exercising patient.^{7,8} Doppler echocardiography has been successful in demonstrating changes in left ventricular function during angioplasty⁹ but there has been little written about the relative sensitivities of Doppler indices in the angioplasty model of ischaemia. The purpose of this study was to assess the sensitivities of various Doppler indices to changes of cardiac function during and after coronary artery balloon occlusion.

Patients and methods

PATIENTS

We studied 16 patients (two women and 14 men), mean age 55 (range 40–70) years. Patients had stable limiting angina despite medical treatment. All the patients were in sinus rhythm and none had valve disease. Each patient gave informed verbal consent before the start of the study. Before enrolment patients were assessed for the presence of a suprasternal echocardiographic window that gave clean continuous Doppler signals of ascending aortic flow.

CORONARY ANATOMY

The 16 patients enrolled in the study required left anterior descending coronary artery angioplasty. The target stenoses had a mean value of 84% (range 75–90) and all allowed antegrade flow of contrast. Eight patients had single vessel disease and eight patients multivessel disease. In the multivessel disease group the diseased vessels associated with the target vessel had stenoses with a mean value of 75.8% (range 50–100) (table 1). None of the patients with single vessel disease had significant collateral supply to the target vessel. Of the eight patients with multivessel disease, four had ventriculographic evidence of pre-existing mild myocardial hypokinesia in the territory of the non-target vessel. These four patients had occlusions of their right coronary arteries, with three of them receiving a collateral supply (Rentrop grade 3–4¹⁰) from the target vessel.

There was no significant difference in the left ventricular ejection fractions between the groups of patients with single vessel and multivessel disease: mean values were

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Balloon inflation during percutaneous transluminal coronary angioplasty produces considerable global and regional impairment of left ventricular function.^{1–3} This impairment was reversible after brief periods of balloon

Table 1 Distribution of coronary artery disease in patients with multivessel disease undergoing angioplasty

Patients	Target LAD (%)	RCA (%)	LCx (%)	Collaterals
1	85	100	0	LAD → RCA (3)
2	95	100	50	0
3	90	50	0	0
4	80	100	50	LAD → RCA (4)
5	80	0	60	0
6	90	50	90	0
7	80	0	70	0
8	70	100	90	LAD → RCA (4)

LAD, left anterior descending coronary artery; LCx, circumflex coronary artery; RCA, right coronary artery; Rentrop gradings in parentheses.

52% (range 40–65) and 69% (range 32–90) respectively.

PROTOCOL FOR PERCUTANEOUS TRANSLUMINAL CORONARY ANGIOPLASTY

All patients underwent angioplasty from the right femoral artery after insertion of an arterial sheath. A standard drug regimen was started at least 48 hours before the procedure. β -Blocking drugs were stopped and the patients were started on oral 300 mg aspirin, 20 mg nifedipine, and 10 mg isosorbide dinitrate. An infusion of isosorbide dinitrate (3 mg/h) was started two hours before and continued throughout the procedure and patients were fully heparinised. We used non-ionic contrast medium and a steerable guide wire angioplasty system.

DOPPLER SYSTEM

Ascending aortic blood velocity was evaluated transcutaneously from the suprasternal notch by a conventional continuous wave Doppler transmitter and a receiver operating at 2.0 MHz (Doptek decoder). The transducer was mounted on a spring loaded carriage held in a constant position by an adjustable frame. The position of the mechanical frame holding the transducer was set when a clean, continuous Doppler signal of maximum amplitude was obtained. Occasionally the transducer position was moved inadvertently by the patient but its position was rapidly corrected and a verbal note made into a roving microphone. This enabled us to avoid analysing unrepresentative Doppler signals recorded at the time of readjustment of the transducer. The received Doppler-shifted blood velocity signal was processed by Fourier analysis at a sampling rate of 5 ms and a spectral velocity envelope was displayed. Digital callipers allowed measurement of peak velocity to the nearest cm/s and time to the nearest 2.5 ms.

All signals obtained throughout the angioplasty procedure were recorded on to magnetic tape by an on line tape recording system. A roving microphone with an input into the recording system allowed events to be verbally recorded simultaneously with the recording of the Doppler signal.

DOPPLER MEASUREMENTS

Continuous wave Doppler recordings were obtained in supine patients at rest within the catheter laboratory throughout the angioplasty procedure. Digital callipers were used to

measure peak velocity (V), time from onset of signal to peak velocity (T), heart rate, and stroke distance from the recorded signals. These measurements were made from five clear, nearly consecutive Doppler signals obtained at each of the following times: just before an inflation (baseline), at the end of a balloon inflation, and 120 s after balloon deflation. A mean of 8.7 consecutive signals (range 5–14) were measured on the initial baseline, and timing these as close to balloon inflation as possible allowed most of these measurements to be made at the time the deflated balloon catheter was across the lesion.

DATA ANALYSIS

We calculated V^2/T (a correlate of peak dP/dt) and MA (mean acceleration = V/T) from all measurements of V and T. The Doppler indices V, V^2/T , and MA were considered as indicators of the contractile state and minute distance corrected for baseline heart rate (MD) as an index of cardiac output. Corrected minute distance was calculated as stroke distance $\times$ baseline heart rate.

The standard deviation (SD) and coefficient of variation were calculated for the initial baseline values of heart rate, V, MA, MD, and V^2/T . We considered that subsequent changes in the magnitude of the Doppler indices that occurred during balloon inflation were significant if the mean value decreased more than two SDs calculated from the initial baseline. Significant changes in cardiac function were deemed to occur in a patient during balloon inflation if three or more of the Doppler indices V, MA, V^2/T , and MD were significantly depressed.

For those patients showing a significant change in cardiac function during balloon inflation, the percentage change of a Doppler index from its baseline value was calculated as

$$\% \text{ change} = \frac{\text{baseline value} - \text{inflation value}}{\text{baseline value}} \times 100$$

Significant differences in the magnitude of change for each of these Doppler indices during a balloon inflation were analysed to determine the relative sensitivity of each Doppler index to the ischaemic insult. Analysis was by statistical comparison of the percentage change from the baseline of each Doppler index during the inflation period and at 120 s after the final inflation.

STATISTICAL ANALYSIS

The SD and coefficient of variation were calculated from the initial baseline values for each Doppler index. Subsequent changes in the indices were considered significant if they exceeded twice the SD. A two tailed *t* test was used to determine the significance of any change in the Doppler index. A paired *t* test was used to find the relative sensitivities of Doppler indices to changes in cardiac function. Statistics were performed on a Hewlett Packard HP-28S scientific calculator and with an Oxstat statistical package.

Results

Sixteen patients had a total of 33 inflations with

Table 2 Mean values of baseline Doppler indices for inflations in patients showing significant reductions in three Doppler indices during angioplasty

Patient	1st Inflation					2nd Inflation					3rd Inflation					4th Inflation				
	HR	V	V ² /T	MA	MD	HR	V	V ² /T	MA	MD	HR	V	V ² /T	MA	MD	HR	V	V ² /T	MA	MD
1	66	65.2	57.7	0.88	720						65	78	78	1	799					
2	61	71.8	103	1.43	660															
3	73	81.8	128	1.56	858															
4	58	62.8	61.7	0.98	621	66	72	86.4	1.2	818	60	71	85.9	1.2	786					
5	93	66.3	69.2	1.04	824	84	70	71	1.01	863										
6						89	43	23.7	0.55	746	92	45	27	0.6	925					
7	73	57.4	52	0.91	790	56	57	55	0.97	590	59	57	57	1.0	602					
8	91	50	29	0.58	830	95	56	41.8	0.75	874	92	48	34	0.71	811	90	50	34.2	0.69	754
9	54	88.5	121	1.39	696															
10	120	47.8	32.1	0.67	941	117	54	43.5	0.81	779										
11	85	67	93	1.39	574	64	79	138	1.75	629										
12	77	73	100	1.4	717															

HR, heart rate (beats/min); V, peak velocity (cm/s); T, time from onset to peak velocity (s); MD, minute distance corrected for baseline heart rate (cm); MA, mean acceleration (cm/s² × 10³). Patients 1–8, multivessel disease; patients 9–12, single vessel disease.

Table 3 Mean values of Doppler indices after 60 s inflation in patients showing significant reductions in three Doppler indices during angioplasty

Patient	1st Inflation					2nd Inflation					3rd Inflation					4th Inflation				
	HR	V	V ² /T	MA	MD	HR	V	V ² /T	MA	MD	HR	V	V ² /T	MA	MD	HR	V	V ² /T	MA	MD
1	67	66	61.5	0.91	780						65	51	34.3	0.67	490					
2	58	48	51	1.1	532															
3	63	64	64	1.0	397															
4	72	44	40	0.91	516	51	58	55.7	0.96	459	53	51.3	47.7	0.93	411					
5	92	62	56.5	0.91	795	84	58	48.1	0.82	755										
6						90	29	15.3	0.53	357	93	25	8.9	0.35	375					
7	61	44	32.8	0.75	416	57	39	28.2	0.72	335	60	41	28	0.68	400					
8	95	39	20.8	0.53	505	94	39	22.4	0.57	448	91	39	22	0.56	442	89	36	20.7	0.57	396
9	62	71.6	79	1.1	442															
10	121	29	12.9	0.45	531	104	25	11.6	0.46	362										
11	90	60	65	1.09	420	88	75	125	1.66	602										
12	69	56	56	1.0	631															

For explanations see footnote to table 2. Underlined figures indicate no significant reduction in values from baseline.

Table 4 Initial and final baseline mean values of Doppler indices in patients showing significant reductions in three Doppler indices during angioplasty

Patient	Initial baseline					Final baseline				
	HR	V	V ² /T	MA	MD	HR	V	V ² /T	MA	MD
1	66 (0) (0)	65.2 (3.2) (5)	57.7 (11.9) (20)	0.88 (0.14) (16)	720 (44.6) (6)	64	71	74.1	1.0	794
2	61 (1.13) (2)	71.8 (4.2) (6)	103 (14) (14)	1.43 (0.14) (10)	660 (100) (15)	56	74	96	1.3	509
3	73 (0.89)	81.8 (4.2) (5)	128 (21.6) (17)	1.56 (0.22) (14)	858 (89) (10)	52	112	208	1.9	642
4	58 (1.1) (2)	62.8 (1.5) (2)	61.7 (3.2) (5)	0.98 (0.04) (4)	621 (39) (6)	54	65	76.7	1.18	650
5	93 (0.6) (0.7)	66.3 (3.2) (5)	69.2 (9.7) (14)	1.04 (0.1) (10)	824 (54) (6)	84	68	68	1.0	819
6	90 (0.8) (0.9)	46.5 (2.9) (6)	27.8 (3.6) (13)	0.57 (0.07) (12)	710 (69) (10)	93	59	51.2	0.87	964
7	73 (7.6) (10)	57.4 (1.64) (3)	52 (4.6) (9)	0.91 (0.07) (8)	790 (91.2) (11)	61	56	52	0.93	618
8	91 (1.2) (1)	50 (2.4) (5)	29 (1.6) (6)	0.58 (0.03) (5)	830 (70) (8)	90	54	41.1	0.76	757
9	54 (0.7) (1)	88.5 (3.1) (4)	121 (8.9) (7)	1.39 (0.08) (6)	696 (44) (6)	57	89	121	1.36	481
10	120 (0.7) (0.6)	47.8 (2.95) (6)	32.1 (3.9) (12)	0.67 (0.05) (7)	941 (50) (5)	77	61	53.9	0.88	662
11	85 (1.9) (2)	67 (1.6) (2)	93 (8.4) (9)	1.4 (0.11) (8)	574 (44) (8)	78	90	147	1.7	890
12	77 (0.8) (1)	73 (4.3) (6)	100 (15.4) (15)	1.4 (0.18) (12)	717 (36) (5)	71	75	102	1.36	923

Initial baseline values and mean (SD) (coefficient of variation %). Final baseline values are means only. For other explanations see footnote to table 2.

a mean duration of 58.5 s per inflation. Fifteen inflations were performed in patients with single vessel disease and 18 inflations in patients with multivessel disease. Of the 16 patients undergoing angioplasty, 12 had significant falls ($p < 0.001$) in three or more Doppler indices during one or more inflations. This occurred in all patients with multivessel disease (tables 2 and 3). We found no significant fall in Doppler indices when the first baseline was compared with the final baselines (table 4). In fact a significant increase ($p < 0.001$) in two or more Doppler indices occurred in five patients (31%) at 120 s after the end of the final inflation. Three of these five patients had single vessel disease and two had multivessel disease. The relative sensitivities of the Doppler indices to changes

in cardiac function were V^2/T , MD, V, and MA in order of magnitude. The significance levels in comparisons between V^2/T and MD, MD and V, and V and MA were $p < 0.02$, $p < 0.001$, and $p < 0.01$ respectively (table 5).

Discussion

This is the first report of the relative sensitivities of Doppler indices to changes in global cardiac function that occur during controlled myocardial ischaemia produced by coronary angioplasty. Angioplasty produces a regional myocardial dysfunction in the mass of cardiac muscle supplied by the coronary artery undergoing balloon occlusion and, as in this study, past reports have also shown changes in

Table 5 Mean percentage change (SD) in Doppler indices of all patients having significant falls in three Doppler indices during balloon inflation and the relative sensitivities of these Doppler indices to change

	V^2/T	MD	V	MA
Percentage change	43.71 (12.6)	37.71 (12.8)	27.38 (10.3)	23 (9.93)
Sensitivity of index	$V^2/T > MD$ $p < 0.02$		$MD > V$ $p < 0.001$	
			$V > MA$ $p < 0.01$	

For explanations see footnote to table 2.

global cardiac function during angioplasty.¹ The global left ventricular function that results from balloon occlusion represents an interplay between the reduced contractility of the ischaemic region of myocardium and the compensating hypercontractility of the non-ischaemic cardiac muscle. For this reason, while indices of global left ventricular function are not an accurate measure of regional myocardial dysfunction they do reflect overall haemodynamic cardiac performance in a patient during an ischaemic insult. Doppler echocardiography has advantages over other techniques for assessment of global left ventricular function during angioplasty; it is entirely non-invasive and allows continuous recording during and after each coronary occlusion. Cross sectional echocardiography successfully detects changes in left ventricular wall motion during balloon occlusion of the coronary artery.^{2,4,11} Doppler echocardiography has been used to detect changes in left ventricular function during angioplasty in patients with poor collateral supply to their target vessel.⁹ The disadvantages of Doppler echocardiography are variability of sampling axis, beat to beat variability in signal size, and interobserver variation. In our study we held the transducer sampling axis constant in relation to the patient by mounting the transducer on an adjustable metal frame. The same operator made measurements on all Doppler signals. We lessened the effect of beat to beat variability by averaging the measurements from five nearly consecutive Doppler signals recorded immediately before and at the end of the balloon inflation. It was difficult always to obtain consecutive signals of requisite quality but when this situation arose, we chose signals that were nearly consecutive. We considered a significant change in the value of a Doppler index to have occurred if the change in magnitude exceeded two SDs as calculated from the initial baseline.

In some patients the baseline values of the Doppler indices fluctuated substantially between inflations. This may have resulted from the smaller number of Doppler signals measured to obtain subsequent baseline values after the initial baseline recording. Therefore, in some cases, a decline in the values of Doppler indices from their baselines occurring during the balloon inflations after the first inflation may have under or overestimated the real magnitude of change in the Doppler index. This potential error has been reduced by ensuring that analysis of changes of individual

Doppler indices was undertaken only in those patients who had a fall in three or more Doppler indices from their baseline. This improved the specificity when the changes that occurred within an individual Doppler index were analysed. Furthermore, all four Doppler indices fell in all inflations after the first, except for patient 6. We found a fall in MD during all inflations after the first in every patient. This more functional Doppler index of cardiac function was measured from reference points on the Doppler signal that were different from those used in measuring the other indices. This adds further support to the view that the significant falls from the baselines in Doppler indices, during balloon inflation, reflect real decreases in global cardiac function and that the apparent variability in the baseline values has not led us to false conclusions.

Doppler echocardiography to measure peak acceleration has been used to assess systolic function during angioplasty⁹; other studies have used the Doppler determined stroke integral index of mitral inflow¹² to investigate changes of cardiac function during angioplasty. The Doppler indices measured in this study are all indicators of global systolic left ventricular performance. Mean acceleration has been used effectively to assess changes in left ventricular contractility during myocardial ischaemia.¹³ The index of peak velocity has been shown to be significantly reduced during ischaemia in animal^{6,14} and clinical studies.^{7,15} In a previous study we showed a good correlation between the index V^2/T and left ventricular peak dP/dt .¹⁶ Doppler indices incorporating V were not significantly affected by heart rate.^{6,13} Consequently we did not correct the Doppler indices V, MA, and V^2/T for heart rate in our study. Indices of cardiac output are affected by heart rate⁶ and we corrected the minute distance accordingly. Although aortic pressure influences peak velocity,⁶ previous careful study has not shown a significant change in mean aortic pressure during angioplasty.³

CHANGES IN DOPPLER INDICES OF LEFT VENTRICULAR FUNCTION DURING INFLATIONS

We defined changes in cardiac function during an inflation as significant if three or more Doppler indices decreased significantly from the baseline during that inflation. This definition increases the specificity of the positive results at the expense of the sensitivity. The finding of significant lowering of Doppler indices of cardiac function during balloon inflation accords with other reports that have shown decreases in Doppler indices and invasive indices of cardiac function.^{1,3,9} In four patients with single vessel disease no significant fall in Doppler indices occurred during balloon occlusion. This may have been due to a compensating hypercontractility of the non-ischaemic myocardium or possibly recruitment of a collateral circulation.¹⁰

CHANGES OF DOPPLER INDICES OF LEFT VENTRICULAR FUNCTION AFTER INFLATION

We found no difference in the size of reductions in Doppler indices when we compared the first

inflations with the last inflations and the first baselines with final baselines. This supports other studies that found a reversible impairment of left ventricular function after brief periods of ischaemia.^{3,5} The conditions for the occurrence of a prolonged impairment of left ventricular function were optimal in the patients with multivessel disease and apparent lack of collateral supply to the target vessel. In particular the four patients with occluded right coronary arteries and mild myocardial hypokinesia would have been susceptible to prolonged impairment. Yet in our study this group of patients tolerated the after-effects of ischaemia as well as patients with single vessel disease. In 31% of patients there was a significant rise in the Doppler indices at 120 s after the final inflation. This increase in the value of Doppler indices occurred both in patients who did and those who did not show a fall in the Doppler indices of cardiac function during balloon inflation. It was also not related to the presence or absence of multivessel disease. This phenomenon has been described previously and hypercontractility of the reperfused myocardial wall⁴ secondary to reactive hyperaemia in the target vessel¹⁷ probably accounts for it.

SENSITIVITY OF DOPPLER INDICES TO CHANGES IN LEFT VENTRICULAR FUNCTION

The Doppler indices of contractility (V^2/T) and cardiac output (MD) were the most sensitive indicators of changing cardiac performance after the ischaemic insult of angioplasty. Both of these indices are more sensitive than V, which is known to be very sensitive to changes in left ventricular performance.¹³ The indices V^2/T and MD are indicators of global cardiac contractility and cardiac output respectively. As such, they give a dynamic as well as functional assessment of global cardiac performance, much like the use of ejection fractions. The value of using Doppler indices of cardiac function lies in their ability to monitor non-invasively and continuously the changes in global cardiac performance that occur during and after myocardial ischaemia in an individual patient. They do not measure the regional myocardial dysfunction and are therefore not a useful measurement of the mass of ischaemic myocardium.

In conclusion, we used Doppler indices of aortic blood flow to measure changes in cardiac function during balloon occlusion of the coronary arteries. We have shown that the

indices V^2/T , MD, V, and MA are sensitive to changes in global cardiac function during balloon occlusion. The more sensitive indices, V^2/T and MD, may be useful in clinical practice to assess global changes in cardiac performance.

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