CARDIOVASCULAR MEDICINE

Regional left ventricular function during transient coronary occlusion: relation with coronary collateral flow

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Objective: To test the hypothesis that regional left ventricular (LV) function during balloon angioplasty is related to the amount of collateral flow to the ischaemic region.

Design: Prospective study.

Setting: Tertiary referral centre.

Methods: In 50 patients with coronary artery disease and without myocardial infarction, regional systolic and diastolic LV function was determined using tissue Doppler ultrasound (TD) before and at the end of a 60 second occlusion of a stenotic lesion undergoing percutaneous transluminal coronary angioplasty (PTCA) through a pressure guidewire. The study population was subdivided into a group with collaterals insufficient (n = 33) and one with collaterals sufficient (n = 17) to prevent ECG ST shifts suggestive of myocardial ischaemia during PTCA. Pulsed TD was performed from an apical window in the myocardial region supplied by the vessel being treated by PTCA. Pressure derived collateral flow index (CFI) was determined by simultaneous measurement of mean aortic (P_{ao}) and distal intracoronary occlusive pressures (P_{occl}), where $CFI = (P_{occl} - 8)/(P_{ao} - 8)$.

Results: At 60 seconds of occlusion, several parameters of systolic and diastolic TD derived LV long axis function were significantly different between the groups. Also, there was a significant correlation between regional systolic excursion velocity, early diastolic excursion velocity, regional isovolumetric relaxation time, and CFI.

Conclusion: During brief coronary artery occlusions, regional systolic and diastolic LV function is directly related to the amount of collateral flow to this territory.

Experimental studies documented 25 years ago that coronary artery constriction is associated with regional and global myocardial dysfunction.¹ However, there have also been data indicating that complete coronary artery occlusion in exercising dogs affects ventricular performance similarly to occlusion in the resting animal.² These seemingly contradictory observations were later resolved by showing that myocardial performance during transient coronary occlusions in running dogs is vastly dependent on the amount of collateral flow to the ischaemic region.³

Clinically, the question of whether regional myocardial function during coronary occlusion is related to recruitable collateral flow has not been directly and quantitatively addressed. On the one hand, this is because until recently only qualitative ultrasound technique has been used for evaluating regional left ventricular (LV) function by depicting myocardial excursion, thickening, and wall motion.⁴ On the other hand, quantitative means to assess collateral flow during angioplasty in the form of pressure or Doppler sensed percutaneous transluminal coronary angioplasty (PTCA) guide wires became available only recently.⁵⁻⁷ Instead of just qualifying regional wall motion abnormalities, a new Doppler ultrasound technique, tissue Doppler ultrasound (TD), allows quantification of intramural myocardial velocities.⁸ Both pulsed and M mode colour TD have been validated recently in experimental animals by using transient coronary occlusions.^{9,10} In one clinical study among patients with coronary artery disease undergoing PTCA, TD was shown to be feasible for the characterisation of regional wall motion changes during coronary occlusion and reperfusion.¹¹

The purpose of this study was to test the hypothesis that regional LV function as assessed by TD during brief coronary occlusion is associated with the amount of collateral flow to the ischaemic vascular territory undergoing PTCA.

METHODS

Patients

Fifty patients (age 63 (10) years, 31 men, 19 women) with one to three vessel coronary artery disease were recruited into the study. All underwent PTCA of one stenotic lesion because of symptoms related to stable coronary artery disease. Patients were prospectively selected on the basis of the following criteria: no previous Q wave infarction in the myocardial area undergoing PTCA, no baseline ECG ST segment abnormalities, and no wall motion abnormalities in the LV region supplied by the vessel undergoing PTCA. The present investigation was approved by the institutional ethics committee and the patients gave informed consent to participate in the study. The investigation conforms with the principles outlined in the Declaration of Helsinki.

The study population was divided into two groups according to the presence (insufficient collaterals, n = 33) or absence (sufficient collaterals, n = 17) of signs of myocardial ischaemia during the first 60 second balloon occlusion of the stenosis to be revascularised. Myocardial ischaemia was defined as ST segment changes > 1 mm present on any of three surface leads or on an intracoronary ECG lead obtained from the angioplasty guidewire (fig 1).

Cardiac catheterisation and coronary angiography

Patients underwent left heart catheterisation for diagnostic purposes. LV end diastolic pressure (LVEDP) before PTCA was

Abbreviations: CFI, collateral flow index; CVP, central venous pressure; IVRT_{lv}, regional isovolumetric relaxation time; LV, left ventricle or left ventricular; LVEDP, left ventricular end diastolic pressure; P_{ao} , mean aortic pressure; P_{occl} , distal intracoronary occlusive (wedge) pressure; PTCA, percutaneous transluminal coronary angioplasty; SEE, standard error of the estimate; TD, tissue Doppler ultrasound

Figure 1 Pressure derived collateral flow index (CFI) determination. Simultaneous tracings of surface lead and intracoronary ECG (top), and left ventricular (LVP, mm Hg), mean aortic (P_{ao} , mm Hg), and mean (left side) coronary occlusive (P_{occl} , mm Hg) pressure. Phasic P_{ao} and P_{occl} are shown on the right. The arrows indicate ST segment elevations during coronary occlusion on intracoronary ECG (insufficient coronary collaterals). CFI is calculated as $(P_{occl} - CVP)/(P_{ao} - CVP)$, where CVP is central venous pressure and is assumed to be 8 mm Hg.

obtained in all patients. Aortic pressure was measured using the PTCA guiding catheter. Biplane left ventriculography with online regional wall motion assessment was performed followed by coronary angiography. Coronary artery stenoses were estimated quantitatively as percentage diameter reduction using the guiding catheter for calibration. Area at risk for myocardial infarction at the stenotic lesion undergoing PTCA was determined quantitatively as the summed coronary artery branch lengths distal to the stenosis divided by the summed branch lengths of the entire coronary artery.¹²

Echographic measurements

Echocardiograms were recorded with an Acuson Sequoia C256 (Acuson Inc, Mountainview, California, USA) with a 4 MHz transducer with TD technology. Patients were in the supine non-lateral position and the transducer was positioned at the apical window to obtain four and two chamber views. For TD measurements, a sampling gate of 5–10 mm was placed within the middle part of the ventricular region supplied by the coronary artery undergoing PTCA (see below). Care was taken to align the echogram so that the myocardial wall region of interest was parallel to the TD cursor. Pulsed wave TD was recorded continuously on VHS videotape and images were also stored on the hard disk of the echocardiograph for offline analysis. The spectral Doppler signals were adjusted to obtain Nyquist limits between 10–20 cm/s. The optimal gain setting was used to minimise noise and eliminate signals produced by

the transmitral flow. Sweep was set at 100–150 mm/s. Thus, myocardial velocities were analysed resulting from the long axis motion of the heart (that is, systolic basoapical shortening and diastolic apicobasal lengthening). From TD tracings, the following regional LV function parameters were measured: positive and negative isovolumetric contraction velocities (cm/s), regional isovolumetric contraction time (ms), systolic excursion velocity (V_s ; cm/s), regional systolic contraction time (ms), positive and negative isovolumetric relaxation velocities (cm/s), regional isovolumetric relaxation time (IVRT; ms), and early and late diastolic excursion velocities (cm/s). Three heart beats were averaged for each of these measurements. TD parameters were analysed before and at the end of 60 seconds of coronary occlusion (see below).

Coronary collateral assessment

Angiographic collateral degrees (0–3) were determined *before* PTCA, where 0 indicates no filling by contrast medium of the distal vessel through the collaterals, 1 indicates small side branches are filled, 2 indicates major side branches of the main vessel are filled, and 3 indicates main epicardial vessel are filled through the collaterals.¹³

In all study patients, coronary collateral flow relative to normal antegrade flow through the non-occluded coronary artery (collateral flow index (CFI)) was determined from intracoronary pressure measurements. Pressure derived CFI was validated in comparison with Doppler derived CFI and

Table 1 Patient characteristics and clinical data

	Insufficient coronary collaterals	Sufficient coronary collaterals	p Value
Number of patients	33	17	
Age (years)	63 (9)	64 (12)	NS
Male sex (%)	22 (67)	9 (53)	NS
Height (cm)	172 (12)	170 (14)	NS
Weight (kg)	74 (15)	75 (13)	NS
Smoking (%)	13 (39)	11 (65)	NS
Hypercholesterolaemia (%)	16 (48)	10 (59)	NS
Hypertension (%)	20 (61)	6 (35)	NS
Obesity (%)	6 (18)	4 (24)	NS
Family history of CAD (%)	10 (30)	9 (53)	NS
Diabetes mellitus (%)	3 (9)	3 (18)	NS
Aspirin (%)	27 (82)	12 (71)	NS
β Blockers (%)	24 (73)	10 (59)	NS
Calcium antagonists (%)	7 (21)	2 (12)	NS
Nitrates (%)	14 (42)	6 (35)	NS
Recent non-Q wave MI (%)	3 (9)	2 (12)	NS

CAD, coronary artery disease; MI, myocardial infarction.

intracoronary ECG signs of ischaemia.⁷ Compared with intracoronary Doppler derived measurements of CFI, the standard error of the estimate (SEE) using pressure measurements was 0.08.⁷

A 0.014 inch fibreoptic pressure monitoring wire (Wavewire, Endosonics, Mountainview, California, USA) was set at zero, calibrated, advanced through the guiding catheter, and positioned distal to the stenosis to be dilated. The intracoronary pressure derived CFI was determined by simultaneous measurement of mean aortic pressure (P_{ao} , mm Hg, through the angioplasty guiding catheter) and distal intracoronary pressure during balloon occlusion (P_{occl} , mm Hg; fig 1). Central venous pressure (CVP) was estimated to be 8 mm Hg. CFI was calculated as $(P_{occl} - CVP)/(P_{ao} - CVP)$.⁶ Pressure derived CFI (no unit) expresses collateral flow relative to normal flow through the patent vessel.

Study protocol

Following diagnostic coronary angiography including angiographic collateral assessment, an interval of at least 10 minutes was allowed for dissipation of the effect of the contrast medium on coronary vasomotion. Oral glyceryl trinitrate spray was given at the beginning of the study protocol. In 28 patients, a 5 French gauge pigtail catheter was placed in the LV through a second introducer sheath for subsequent LVEDP measurements during vessel occlusion (fig 1). The pressure

guidewire was positioned distal to the stenosis to be dilated. During the entire protocol, an intracoronary ECG obtained from the guidewire and a three lead surface ECG were recorded. PTCA was performed using balloon dilatation catheters ranging in diameter from 2.5–4.0 mm. Balloon inflation was uniformly maintained for 60 seconds. P_{occl} , simultaneous P_{ao} and LVEDP, and intracoronary and surface lead ECGs were recorded towards the end of the occlusion period (fig 1). Echographic measurements were started before placement of the pressure guidewire distal to the stenosis undergoing PTCA. Baseline and occlusive measurements included TD recordings in the midventricular myocardial region supplied by the coronary artery undergoing PTCA (that is, also supplied by the collateral donor artery): anterior (two chamber view) or septal wall (four chamber view) with the left anterior descending coronary artery; lateral wall (four chamber view) with the left circumflex coronary artery; and inferior wall (two chamber view) with the right coronary artery (dominance in all cases with right coronary artery PTCA).

Statistical analysis

Continuous demographic, haemodynamic, angiographic, collateral flow, and echographic data were compared between groups by an unpaired Student's *t* test. A χ^2 test was used for comparison of categorical variables between the study groups. A paired Student's *t* test was used to compare intraindividual

Table 2 Non-occlusive* haemodynamic, coronary structural, and collateral flow data

	Insufficient coronary collaterals	Sufficient coronary collaterals	p Value
Number of patients	33	17	
Haemodynamic data*			
Heart rate during (beats/min)	71 (12)	69 (14)	NS
Mean blood pressure (mm Hg)	92 (11)	95 (8)	NS
LV end diastolic pressure (mm Hg)	14 (7)	13 (5)	NS
LV ejection fraction (%)	65 (10)	69 (4)	NS
Coronary angiography*			
Number of vessels diseased	1.8 (0.8)	1.8 (0.9)	NS
PTCA vessel: LAD/LCX/RCA	19/4/10	7/5/5	NS
Stenosis location proximal/mid/distal	2/17/14	1/7/9	NS
Diameter stenosis (%)	74 (13)	85 (13)	0.02
Area at risk for MI (%)	47 (22)	53 (29)	NS
Collateral flow assessment			
Angina pectoris during PTCA (%)	20 (61)	7 (41)	0.02
Angiographic collateral degree* (0–3)	0.3 (0.6)	1.4 (1.5)	0.03
Collateral flow index	0.14 (0.07)	0.40 (0.12)	0.0001

Data are mean (SD).

LAD, left anterior descending coronary artery; LCX, left circumflex coronary artery; LV, left ventricular; PTCA, percutaneous transluminal coronary angioplasty; RCA, right coronary artery.

Insufficient collaterals (CFI = 0.19)

Figure 2 Doppler tissue imaging (TD) derived myocardial long axis velocities obtained at the interventricular septum before and at the end of a 60 second occlusion in a patient with collaterals to the left anterior descending coronary artery insufficient to prevent myocardial ischaemia (collateral flow index (CFI) = 0.19). There is a general decrease in the recorded velocities (vertical axis; m/s) during occlusion. CT_r, regional systolic contraction time; IVCT_r, regional isovolumetric contraction time; IVRT_r, regional isovolumetric relaxation time; V_A, late diastolic excursion velocity; V_E, early diastolic excursion velocity; V_{+IVCT}, positive isovolumetric contraction velocity; V_{-IVCT}, negative isovolumetric contraction velocity; V_{+IVRT}, positive isovolumetric relaxation velocity; V_{-IVRT}, negative isovolumetric relaxation velocity; V_S, systolic excursion velocity.

changes of parameters during (60 seconds) versus before occlusion. Linear regression analysis was used to assess the relation between CFI and TD data. Mean (SD) values are given. Significance was defined at $p < 0.05$.

RESULTS

Patient characteristics and clinical data

There were no significant differences between the study groups in age, sex, height, weight, frequency of cardiovascular risk factors, use of vasoactive substances, and presence of a recent non-Q wave myocardial infarction (table 1).

Haemodynamic, coronary artery structural, and collateral flow data

The following parameters obtained before coronary artery balloon occlusion were not statistically different between the study groups (table 2): heart rate, mean blood pressure,

LVEDP, LV ejection fraction, number of vessels with coronary artery disease, the coronary artery, and location of the stenotic lesion within the vessel undergoing PTCA. The area at risk for myocardial infarction was not statistically different between the groups. The lesion severity of the stenosis undergoing PTCA was less pronounced in the group with insufficient collaterals than that with sufficient collaterals. In accordance with the study groups, angina pectoris during PTCA occurred more often, angiographic collateral degree obtained during vessel patency was lower, and CFI was lower among patients with than those without signs of myocardial ischaemia during PTCA (table 2).

LV function variables during coronary occlusion

Fig 2 and fig 3 illustrate the behaviour of regional systolic and diastolic TD parameters in a patient with insufficient (fig 2) and in one with sufficient collaterals (fig 3). Velocities

Sufficient collaterals (CFI = 0.55)

Figure 3 TD derived myocardial long axis velocities obtained at the interventricular septum before and at the end of a 60 second occlusion in a patient with collaterals to the left anterior descending coronary artery sufficient to prevent myocardial ischaemia (CFI = 0.55). The recorded velocities (vertical axis; m/s) remain unchanged during occlusion.

Table 3 Variables of regional and global LV function before and at 60 seconds of coronary occlusion

	Insufficient coronary collaterals			Sufficient coronary collaterals			p Value (between groups at occlusion)
	Before	At 60 s	p Value (within group)	Before	At 60 s	p Value (within group)	
Heart rate (beats/min)	71 (12)	71 (12)		70 (14)	67 (13)		NS
Systolic LV function							
V _{+IVCT} (cm/s)	7.7 (2.9)	6.9 (2.5)	0.04	9.8 (3.7)	9.0 (2.7)	NS	0.02
V _{-IVCT} (cm/s)	6.6 (2.2)	7.4 (3.6)	NS	8.1 (3.4)	7.4 (2.8)	NS	NS
IVCT _r (ms)	96 (44)	102 (31)	NS	92 (30)	114 (46)	0.009	NS
V _s (cm/s)	7.4 (1.6)	6.1 (1.8)	<0.0001	8.0 (1.6)	7.4 (1.5)	NS	0.02
CT _r (ms)	284 (39)	263 (48)	0.01	265 (47)	273 (37)	NS	NS
Diastolic LV function							
LVEDP (mm Hg)	14 (7)	23 (9)	0.0002	13 (5)	18 (6)	NS	0.03
V _{+IVRT} (cm/s)	7.9 (8.5)	6.4 (3.1)	NS	8.3 (5.0)	8.7 (4.2)	NS	NS
V _{-IVRT} (cm/s)	5.9 (2.4)	5.5 (2.2)	NS	7.5 (2.5)	7.7 (3.3)	NS	0.04
IVRT _r (ms)	135 (42)	148 (44)	0.06	116 (34)	124 (26)	NS	0.04
V _E (cm/s)	9.4 (3.1)	8.1 (2.9)	0.01	9.8 (2.6)	10.0 (2.2)	NS	0.02
V _A (cm/s)	8.6 (3.4)	8.6 (3.4)	NS	9.7 (3.0)	9.6 (3.9)	NS	NS

CT_r, regional systolic contraction time; IVCT_r, regional isovolumetric contraction time; IVRT_r, regional isovolumetric relaxation time; LVEDP, left ventricular end diastolic pressure; V_A, late diastolic excursion velocity; V_E, early diastolic excursion velocity; V_{+IVCT}, positive isovolumetric contraction velocity; V_{-IVCT}, negative isovolumetric contraction velocity; V_{+IVRT}, positive isovolumetric relaxation velocity; V_{-IVRT}, negative isovolumetric relaxation velocity; V_s, systolic excursion velocity

decreased during coronary occlusion in the former and remained unchanged in the latter. Table 3 shows paired comparison between TD parameters before versus at the end of the transient 60 second occlusion for patients with insufficient and those with sufficient collaterals. Significant changes occurred almost exclusively in patients with insufficient collaterals.

The following LV function variables obtained at 60 seconds of vascular occlusion were significantly different between the study groups, where those in patients with insufficient collaterals indicate more dysfunction than those in the group with sufficient collaterals: positive isovolumetric contraction velocity, V_s, negative isovolumetric relaxation velocity, IVRT_r, early diastolic excursion velocity, and LVEDP (table 3).

There was a significant correlation between CFI and the following simultaneously obtained regional LV function parameters (table 4, fig 4, and fig 5): positive isovolumetric contraction velocity, V_s, IVRT_r, and early diastolic excursion velocity. CFI correlated inversely with LVEDP in the 28 patients in whom it was measured (fig 6).

DISCUSSION

This is the first clinical study documenting that the degree to which regional LV function is impaired during a brief coronary artery occlusion is directly related to the amount of collateral flow to the ischaemic territory.

Permanent coronary occlusion and the collateral circulation

The coronary collateral circulation in the setting of myocardial infarction has been of special interest in recent years. Well developed collaterals in a high risk population of patients assessed at the time of acute myocardial infarction have been shown to be associated with lower mortality than poor collaterals.¹⁴ Similarly, patients with good collaterals at the low risk end of the coronary artery disease spectrum—that is, those with stable angina pectoris—undergoing elective PTCA are at lower risk of suffering a myocardial ischaemic event than those with poor collaterals.¹⁵ Pérez-Castellano and others¹⁴ in their study among patients with acute myocardial infarction documented that improved survival in the presence of enhanced angiographic collateral degree is related to reduced incidences of cardiogenic shock. Several other studies have shown that residual blood flow carried by collateral vessels at the time of permanent coronary occlusion exerts beneficial effects such as reduction in infarct size,¹⁶ prevention of LV aneurysm formation,¹⁷ and improvement in residual ejection fraction or other parameters of systolic LV function.¹⁸

While those cross sectional investigations, performed at least hours after the occurrence of coronary occlusion, have unequivocally shown the preserving effect of collaterals on ventricular pump function, no clinical studies have elucidated the relation between both systolic and diastolic LV function and simultaneously measured collateral flow at the start of events, thus allowing pathophysiological insight into the

Table 4 Correlations between coronary collateral flow index and occlusive LV function parameters

LV function parameter	Intercept	Slope	r	p Value
Systolic LV function				
V _{+IVCT} (cm/s)	6.2	7.4	0.40	0.01
V _{-IVCT} (cm/s)	7.2	0.3	0.02	NS
IVCT _r (ms)	104	8	0.03	NS
V _s (cm/s)	5.3	5.2	0.47	0.003
CT _r (ms)	258	38	0.13	NS
Diastolic LV function				
LVEDP (mm Hg)	27	-26	-0.44	0.06
V _{+IVRT} (cm/s)	6.4	2.6	0.10	NS
V _{-IVRT} (cm/s)	4.8	6.1	0.32	NS
IVRT _r (ms)	160	-89	-0.34	0.02
V _E (cm/s)	8.2	5.3	0.30	0.04
V _A (cm/s)	7.9	4.5	0.19	NS

Figure 4 Correlation between TD derived systolic myocardial long axis velocity indices during occlusion (V_s , cm/s, vertical axis, top; V_{+IVCT} , cm/s, vertical axis, bottom) and simultaneously obtained CFI (horizontal axis, no unit). There was a significant direct association between the variables. SEE, standard error of estimate.

evolving interdependence of these factors. Aside from the importance of quantitative characterisation of LV function and collateral flow parameters, it is crucial that they be measured at the same time to reduce the potential influence of variables in the interrelations. For example, collateral flow recruitment during repetitive coronary occlusions¹⁹ can distort the association between collateral flow and LV function if the latter is measured after or before the former.

Temporary coronary occlusion, LV function, and collateral circulation

Rentrop and colleagues¹³ non-simultaneously measured occlusive collateral flow (during the second balloon occlusion) and angiographically determined global LV ejection fraction (during the third occlusion) in 29 patients, where the ratio of coronary wedge pressure to P_{a0} was directly related to LV ejection fraction. By stratifying patients according to the location of the lesion—proximal or mid-left anterior descending coronary artery—the authors of that study sought to account for the fact that only a *global* systolic function parameter was measured; the association between LV ejection fraction and collateral flow was better in patients with large than in those with small risk areas. When the only recently available non-invasive tool for *regional* LV function assessment—TD—is used, it is not unexpected that the size of the risk territory had no influence on any of the associations between LV function and collateral flow (data not shown). The clinical setting of PTCA with TD derived quantification of regional ventricular function ($n = 13$) was also used by Bach and colleagues,²⁰

Figure 5 Correlation between TD derived diastolic myocardial long axis velocity and time indices during occlusion (V_E , cm/s, vertical axis, top; $IVRT_r$, ms, vertical axis, bottom) and simultaneously obtained CFI (horizontal axis, no unit). There was a significant association between the variables.

Figure 6 Correlation between left ventricular end diastolic pressure obtained during coronary occlusion ($LVEDP_{occ}$, mm Hg, vertical axis) and simultaneously measured CFI (horizontal axis, no unit).

who did not determine collateral flow. They observed a large variability of systolic and diastolic myocardial velocities between -9 and 10 cm/s and between -9 and 9 cm/s, respectively. In comparison, occlusive systolic peak velocities in our study ranged between 3 – 10 cm/s. Velocities did not become negative because ischaemic myocardial bulging

(negative vector) is detected much more easily in the short axis projection (used by Bach and colleagues²⁰) than during assessment of LV long axis function.

In this context, questions may be raised as to which echographic projections provide optimal TD measurements but, more generally, whether TD accurately characterises systolic as well as diastolic LV function. With regard to the latter issue, several experimental validation studies including the temporary coronary occlusion model have documented that TD can quantify regional myocardial dysfunction^{8,9} and that this technique even allows the characterisation of transmural myocardial velocity distribution.¹⁰ Clinical investigations have provided evidence that diastolic LV function as characterised by the rate of LV pressure decay and by LV filling pressure can be accurately estimated from mitral annular velocity measurements.^{21,22}

Although Derumeaux and colleagues⁹ did not measure collateral flow in their study evaluating pulsed TD in quantifying regional myocardial dysfunction, it is evident from four measurements of occlusive myocardial perfusion relative to non-ischaemic zone (9 (2%)) that the low respective data variability coincides with low occlusive TD data variability. Thus, uniform collateral deficiency appears to be associated with minimally varying occlusive TD measurements during systole as well as diastole. The mentioned relative myocardial perfusion values were obtained during coronary occlusion by radioactive microspheres, the reference method for collateral assessment in the experimental setting. The data correspond exactly to the PTCA-Doppler or pressure guidewire derived CFI.⁷ Aside from this, which was our reference method for collateral determination, we strengthened the study method by a second, independent, dichotomous subdivision of patients into a group with insufficient and one with sufficient collaterals, determined by occlusive ECG. In spite of this, there is obviously still a large variability in the relation between CFI and the various systolic and diastolic TD parameters (fig 4 and fig 5), some of the possible reasons for which are considered below.

Co-determinants of occlusive LV function aside from collateral flow and study limitations

That the variability in LV function parameters is influenced up to 90% by factors other than CFI can be explained on pathophysiological and technical grounds. Potential pathophysiological co-factors are the size of the area at risk and the functional capacity of the collateral circulation. Area at risk did not differ between the two groups (table 2) and the relation between LV function parameters and CFI was influenced only in the case of a global variable—that is, occlusive LVEDP, where the relation became significant ($p = 0.04$) in patients with large (but not small) areas at risk $\geq 50\%$. The functional capacity of collaterals not accounted for in our investigation may have influenced the outcome substantially, as a study by Vanoverschelde and colleagues²³ indicates. They elucidated the mechanism of regional LV dysfunction in patients with chronic total coronary occlusion without infarction by dividing the study population into a group without and one with regional wall motion abnormalities in the collateral dependent region. Collateral supplied myocardial resting perfusion obtained by positron emission tomography was similar in the two groups, in keeping with, for example, our finding that regional occlusive systolic peak velocities in our study ranged between 4–10 cm/s at a CFI = 0.2 (fig 4). That all the relevant measurements in our study were made simultaneously does not account for the probability that some patients with variable collateral vasomotor function had identical baseline CFI. Vanoverschelde and colleagues²³ found that chronically depressed systolic LV function in a collateral dependent region is associated with a diminished capacity of the collaterals to increase flow following a hyperaemic stimulus. The finding of similar baseline collateral flow in the pres-

ence of normal and abnormal collateral dependent systolic LV wall motion in the mentioned study can, conversely, not be interpreted as being contradictory to our results because the patients have to be selected with exceedingly high CFI of about 0.8–1.0 in this chronic total occlusion model.

Technical sources of data variability concern mainly poor Doppler echographic image quality and related intraobserver and interobserver variabilities. In 150 patients with normal echocardiograms at our laboratory, the intraobserver and interobserver variability (that is, SEE) of IVRT_i was 17 and 21 ms, respectively.²⁴ Patients in this study were examined in the supine non-lateral position, in which the intraobserver and interobserver variability (SEE) of IVRT_i increased to 20 and 24 ms, respectively; intraobserver and interobserver variability (SEE) of V_s and early diastolic excursion velocity was 0.25 and 0.41 cm/s, respectively, and 0.32 and 0.52 cm/s, respectively. Also, TD parameters of the target region are potentially influenced by dragging of adjacent myocardial segments and by ventricular afterload changes, and subepicardial velocities overestimate subendocardial velocities.

A further potential source of variability comes from taking a fixed estimate of CVP of 8 mm Hg instead of directly measuring CVP; this introduces an SEE relative to average CFI of 17%. These are not results from the present but from a more recent study performed at our laboratory of 50 patients with CFI assessment based on simultaneous aortic pressure, coronary wedge pressure, and CVP measurements. Among those patients, CVP ranged between 1–22 mm Hg (average 8.4 mm Hg). Measured CFI = $1.02 \times$ calculated CFI (by assumed CVP) – 0.03 ($r^2 = 0.92$, SEE = 0.04).²⁵ It can be expected that the results of the present study would have been even more in favour of the study hypothesis if CFI had been determined more precisely by using measured instead of estimated CVP.

With respect to one of the reference methods used—intracoronary ECG ST segment changes during occlusion—care was taken that occlusion lasts exactly 60 seconds in all patients and to assess the ST segment at the end of the occlusion. A non-standardised ST assessment may lead to misclassification of sufficient and insufficient collaterals since ST segment changes require a certain time to develop. When using one minute occlusions, the risk of falsely categorising patients as having sufficient collaterals is higher than vice versa. To account for this potential limitation, the standard method of deriving CFI from aortic and coronary wedge pressure was used. Conversely, prolonged occlusions of up to two minutes might have recruited more collateral flow than one minute occlusions.

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IMAGES IN CARDIOLOGY

Unruptured aneurysm of the sinus of Valsalva obstructing the right ventricular outflow tract: magnetic resonance imaging findings

A 49 year old man was admitted to our hospital because of exertional dyspnoea and chest discomfort. On admission, physical examination revealed a grade 2/6 systolic ejection murmur that was most prominent at the second intercostal space along the left sternal border. An echocardiogram demonstrated an aneurysm originating from the base of the aorta. Because the wall of the aneurysm wall was thin, it was difficult to detect it by two dimensional echocardiogram. Colour Doppler imaging showed the flow moving from the aorta inside the aneurysm and hyperdynamic flow towards the pulmonary artery, which was split by the aneurysm. Magnetic resonance images (MRI) revealed an aneurysm of the sinus of Valsalva originating from the right cusp, 20 × 18 mm in size and obstructing the right ventricular outflow tract (RVOT) (below). An aortogram (right, A, B) and right ventriculogram (C, D) confirmed an aneurysm of the sinus of Valsalva in the RVOT. The aneurysm is visualised by aortogram and the defect in the contrast is shown in the right ventriculogram (arrow).

In this case, it was of particular interest that MRI was useful to demonstrate the structural relation between the aneurysm and surrounding cardiovascular organs.

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