Coronary Atherosclerosis, Coronary Collaterals, and Their Relation to Cardiac Function

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In subjects with coronary artery disease demonstrated by selective coronary arteriography there was a progressively higher prevalence of both ventriculographic abnormalities (asynergy) and collaterals in one-, two-, and three-vessel disease groups, respectively, although no association was demonstrable between these two abnormalities. Subjects with ventriculographic abnormalities had more hemodynamic dysfunction when compared with those with normal ventricular contraction, but there was no correlation between number of coronary vessels involved and hemodynamic abnormalities. The findings suggest that although an abnormal ventricular contraction pattern is associated with hemodynamic dysfunction, the presence of collaterals does not protect from the development of asynergy or hemodynamic abnormalities.

TECHNICAL ADVANCES in cardiac diagnostic studies over the past 10 years have provided increased knowledge about the heart of the patient with coronary artery disease. Selective cine coronary arteriography yields an accurate anatomic display of the location and extent of atherosclerotic lesions (1) and, in addition, shows collateral channels in the disease circulation when present. The pattern of contraction of the left ventricle has been shown to be altered in coronary heart disease by cine left ventriculography (2) as well as by standard hemodynamic measurements. There has been a relative lack of information about the impact of coronary disease, its degree, diffuseness, and compensatory collaterals in relation to the hemodynamic and contractile performance of the left ventricle. These are the subject of the present report.

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Methods

The data obtained during cardiac catheterization from 111 subjects form the basis of this report. The criteria for inclusion of a patient in this study were presence of significant disease of one, two, or three major coronary arteries and absence of other causative forms of heart disease, such as valvular, congenital, or primary myocardial disease. Selective coronary arteriography using the Sones technique was performed with a 9-6-in. dual field image amplifier (GE) and recorded on 16-mm Ilford Pan F film. Each coronary artery was evaluated and classified as having significant disease or not. Significant disease was defined as single or multiple stenoses of greater than 75% of the arterial lumen. Lesser degrees of disease were classified as normal for purposes of this analysis. Criteria for the presence of coronary collateral vessels were: [1] direct visualization of accessory blood vessels either filling the distal segment of an occluded or severely (greater than 90%) stenotic artery or subserving an area of myocardium distal to an occluded or severely stenotic vessel, and [2] visualization of a coronary artery after injection of radiopaque dye into the contralateral vessel. Representative selective angiograms demonstrating absence and presence of collateral vessels can be seen in Figures 1 and 2, respectively. Cineventriculography was performed in the right anterior oblique projection, and the pattern of left ventricular contraction was analyzed for synergy and asynergy using methods previously described (2). Pressure measurements were made with Statham P23d strain gauges and recorded on a Sanborn 560 polybeam photographic recorder. Cardiac output was determined by the dye dilution technique, using indocyanine green and a Gilford densitometer.

Results

Of the 111 subjects studied 37 had significant disease of 1 coronary artery, 36 had significant 2-vessel disease, and 38 had significant involvement of all 3 major coronary arteries.

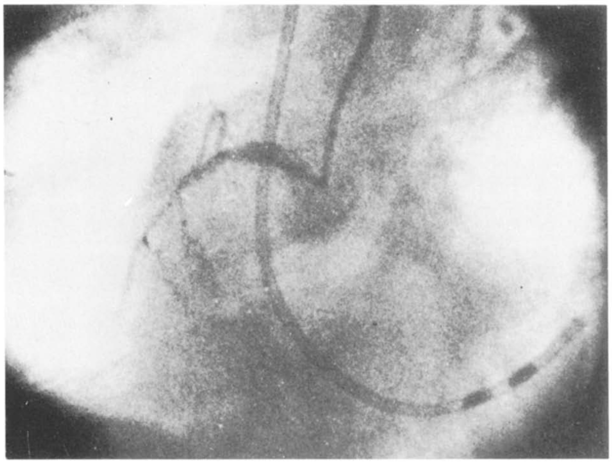

Figure 1. A representative selective angiogram of the right coronary artery showing progressive obliteration of its lumen and occlusion. No detectable collaterals are present.

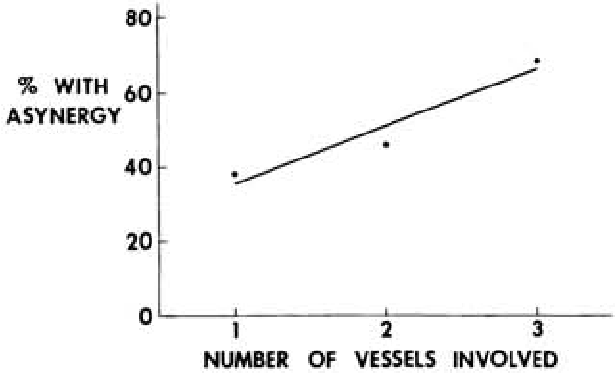

Figure 3. Relationship between extent of coronary artery disease and ventricular asynergy. Fitted regression line illustrates that as the number of significantly stenotic coronary arteries increases, there is a progressively higher prevalence of disordered ventricular contraction patterns (ventricular asynergy).

VENTRICULOGRAPHIC ABNORMALITIES

There was a progressively and significantly ($P < 0.01$) higher prevalence of ventriculographic abnormalities in the one-, two-, and three-vessel disease groups, respectively (Figure 3, Table 1).

LEFT VENTRICULAR END DIASTOLIC PRESSURE AND CARDIAC INDEX

Ventriculographic Abnormalities: Subjects with ventriculographic abnormalities had a significantly higher mean left ventricular end diastolic pressure ($P < 0.001$) and lower cardiac index ($P < 0.05$) than those with a normal pattern of ventricular contraction.

Table 1 shows that subjects with abnormal ventricular contraction have a higher left ventricular end diastolic pressure and lower cardiac index in each vessel group than those with a normal contraction pattern.

Number of Involved Vessels: No correlation could be shown between the number of major coronary arteries involved with significant disease and either left ventricular end diastolic pressure or cardiac index (Table 2). The random scatter of values for left

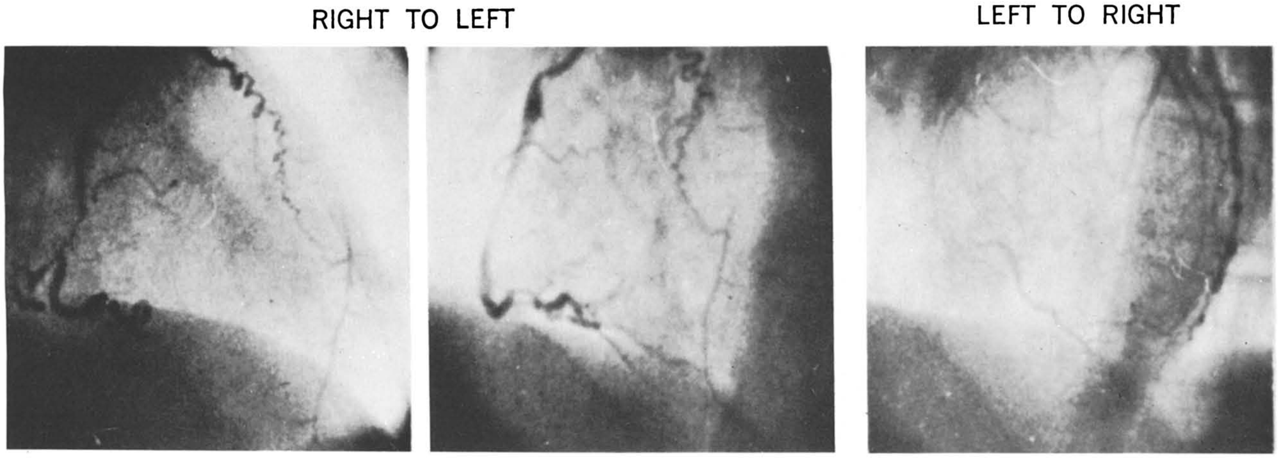

Figure 2. Representative selective angiograms demonstrating coronary collateral formation.
The left and center panels (labeled **Right to Left**) are right and left anterior oblique views, respectively, of the same patient showing the right coronary artery on the left side of each frame. A severe stenosis of this vessel can be seen about two thirds from its origin before it reaches the base of the heart. In addition, a highly tortuous vessel coursing toward the right side of each frame and one at the base coursing left to right are both seen supplying collateral vessels to the left anterior descending coronary artery, which is seen running vertically in the right lower portion of each frame.
The panel on the right (labeled **Left to Right**) shows the lower two thirds of left coronary artery system in the same patient in the left anterior oblique view. There is a severe diffuse stenosis of the left anterior descending coronary artery which cannot be seen. The left circumflex system is not well visualized in this projection. Collateral vessels from the circumflex system have filled the posterior descending branch of the right coronary artery up to and beyond the crux. This can be seen at the bottom of the frame going from the lower right to upper left.

Table 1. Prevalence of Ventriculographic Abnormalities and Effect on Left Ventricular End Diastolic Pressure and Cardiac Index

Number of Vessels Involved	Ventriculogram Abnormal	Ventriculogram Normal	Percent Abnormal	Left Ventricular End Diastolic Pressure (Mean): Ventriculogram Abnormal	Ventriculogram Normal	Difference ± SE	Cardiac Index (Mean): Ventriculogram Abnormal	Ventriculogram Normal	Difference ± SE
				←mm Hg→			←liters/min/m²→		
1	14	23	38	18.8	11.8	7.0 ± 3.5	2.4	2.7	0.3 ± 0.23
2	16	19	46	16.0	12.4	3.5 ± 2.5	2.3	2.4	0.1 ± 0.22
3	26	12	68	17.7	9.8	8.0 ± 2.7	2.3	2.9	0.6 ± 0.23
Total	56	54		17.5	11.6	5.9 ± 1.6	2.3	2.6	0.3 ± 0.13

ventricular end diastolic pressure and cardiac index found in the three groups of subjects is illustrated in Figure 4.

COLLATERALS

As the number of diseased coronary vessels increased, the evidence of collaterals rose significantly ($P < 0.001$). This can be seen in Figure 5. As shown in Table 3, there was no significant difference in either mean left ventricular end diastolic pressure or cardiac index between subjects with and without collaterals.

Ventriculographic Abnormalities: Despite the fact that both collaterals and ventriculographic abnormalities increased progressively as the number of vessels involved increased, there was no association between the two. As shown in Table 4, subjects with collaterals did not have an increased or decreased prevalence of ventricular contraction abnormalities except perhaps with single-vessel disease. Fifty-five percent of subjects with collaterals had ventriculographic abnormalities compared with 45% of subjects without collaterals.

CORRELATION WITH INDIVIDUAL- AND MULTIPLE-VESSEL DISEASE

Of the subjects with single-vessel disease those with left anterior descending lesions had both a somewhat higher mean left ventricular end diastolic pressure and a higher prevalence of ventriculographic abnormalities than those with isolated right coronary or circumflex lesions (Table 5). No difference was found in either left ventricular end diastolic pressure or cardiac index in subjects with any combination of two-vessel diseases. However, there was a 71% prevalence of ventriculographic abnormalities in subjects with combined disease of the left anterior descending

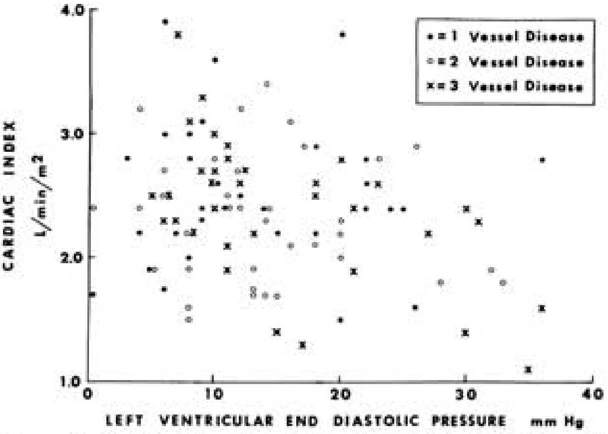

Figure 4. Relationship of cardiac index, left ventricular end diastolic pressure, and extent of coronary artery disease. Cardiac index and left ventricular end diastolic pressure have no relationship to the extent of coronary artery disease as can be seen by the random scatter of subjects with significant stenosis of one, two, or three coronary arteries.

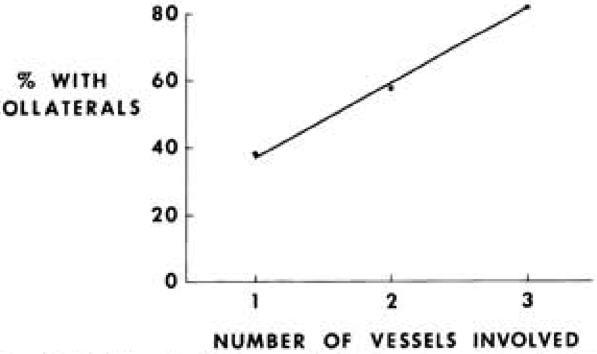

Figure 5. Relationship between extent of coronary artery disease and prevalence of collaterals. Fitted regression line illustrates that as the number of significantly stenotic coronary arteries increases, there is a progressively higher prevalence of collaterals.

Table 2. The Effect of Number of Vessels Involved on Left Ventricular End Diastolic Pressure and Cardiac Index

Number of Vessels Involved	Number of Subjects	Left Ventricular End Diastolic Pressure (Mean)	Cardiac Index (Mean)
		mm Hg	liters/min/m²
1	37	14.4 (SD ± 10.7)	2.6 (SD ± 0.63)
2	36	14.1 (SD ± 7.5)	2.3 (SD ± 0.65)
3	38	15.2 (SD ± 8.6)	2.5 (SD ± 0.76)

Table 3. Prevalence of Collaterals and Relationship to Left Ventricular End Diastolic Pressure and Cardiac Index

Number of Vessels Involved	Number of Subjects	Percent with Collaterals	Collaterals Present		Collaterals Absent	
			LVEDP* (Mean)	Cardiac Index (Mean)	LVEDP* (Mean)	Cardiac Index (Mean)
			mm Hg	*liters/min/m²*	*mm Hg*	*liters/min/m²*
1	37	38	12.1	2.6	15.9	2.6
2	36	58	15.0	2.4	12.8	2.2
3	38	82	15.5	2.5	14.0	2.2

* LVEDP = left ventricular end diastolic pressure.

Table 4. Effect of Collaterals on Prevalence of Ventriculographic Abnormalities

Number of Vessels Involved	Collaterals Present			Collaterals Absent		
	Number of Subjects	Abnormal Ventriculograms		Number of Subjects	Abnormal Ventriculograms	
		no.	*%*		*no.*	*%*
1	14	3	21	23	11	48
2	20	9	45	15	7	47
3	31	24	77	7	2	29
Total	65	36	55	45	20	45

and circumflex vessels. This compared with a 31% prevalence of ventriculographic abnormalities in subjects with left anterior descending and right coronary disease and a 20% prevalence in those with right coronary and circumflex lesions (Table 5).

Discussion

LEFT VENTRICULAR PERFORMANCE

In the present study a progressively higher prevalence of disordered patterns of ventricular contraction has been shown in subjects with significant involvement of one, two, and three major coronary vessels, respectively. A previous report from this laboratory has shown that depressed left ventricular function in coronary heart disease, as reflected in either a low cardiac index or high left ventricular end diastolic pressure, can best be related to these regional disturbances in ventricular contraction. These can only be appreciated angiographically (2). This is further substantiated by the data presented in this study.

In a postmortem study Ellis and associates (3) found that the prevalence of chronic clinical congestive heart failure increased in relation to the degree of coronary artery disease as well as the presence of old myocardial infarction. In light of these observations it seems somewhat paradoxical that the extent of anatomic disease of the coronary vessels does not show a direct relationship to the hemodynamic changes ordinarily associated with cardiac failure, elevated left ventricular end diastolic pressure or reduced cardiac index (Table 2). This finding, however, is in agreement with a recent study of Linhart and co-workers (4). This apparent paradox can perhaps be explained by the following postulated relationship: Anatomic coronary artery disease may or

Table 5. Effect of Individual Vessel and Combination of Vessel Disease on Left Ventricular End Diastolic Pressure, Cardiac Index, Prevalence of Collateral, and Ventriculographic Abnormalities

Vessel Involved*	Number of Subjects	Left Ventricular End Diastolic Pressure (Mean)	Cardiac Index (Mean)	Ventriculogram Abnormalities		Collaterals	
				Number of Subjects	Percent	Number of Subjects	Percent
		mm Hg	*liters/min/m²*				
LAD alone	18	16.4	2.7	10	56	6	33
RCA alone	15	13.1	2.6	3	20	7	47
LCF alone	4	10.8	2.4	1	25	1	25
LAD and RCA	17	13.9	2.5	5	31	12	71
LAD and LCF	14	14.4	2.2	10	71	7	50
RCA and LCF	5	13.6	2.1	1	20	2	40

* LAD = left anterior descending; RCA = right coronary artery; LCF = left circumflex.

may not lead to regional disturbances in left ventricular contraction. Such contraction disorders are a prerequisite for abnormalities of left ventricular end diastolic pressure or cardiac index, although hemodynamic values can remain normal in the presence of asynergy, at least at rest. Thus, in each group of subjects in this study those with ventriculographic abnormalities had a higher left ventricular end diastolic pressure and a lower cardiac index than those with a normal pattern of contraction (Table 1). Linhart and colleages (4) have also shown that the response to angiotensin infusion was always abnormal in subjects with both coronary artery disease and an abnormal ventricular cineangiogram.

The severity of the contraction abnormality (that is, poor contraction, no contraction, paradoxical systolic expansion) and the amount of left ventricular myocardium involved must play an important role in their effect on total ventricular function. Difficult technical and theoretical problems exist in further evaluating these relationships either in terms of exact quantification of regional contraction abnormalities or in analysis of ventricular function in terms of force-velocity relations. The specific problem in applying force-velocity analysis to humans with coronary heart disease is the nonhomogeneous nature of the disease process.

CORONARY COLLATERALS

The significance of coronary collaterals has been a subject of debate. It has been reported that the presence of collaterals is a reliable indication of severe coronary artery obstruction (5, 6) and that they have dilated in response to reduced postobstructive intravascular pressure. Collaterals are thought to exert a beneficial effect, and therefore "stimulation" of collateral vessel formation, particularly through exercise, is one of the major objectives of therapeutic programs in patients with coronary heart disease (7). In a recent study of the coronary collateral circulation it was postulated that the presence of those vessels may account for a normal resting electrocardiogram in patients with major arterial occlusion (6). In the present study, although it was found that as the number of diseased coronary vessels increased there was a significant increase in the prevalence of collaterals, such collaterals did not protect from the development of either an abnormal ventricular contraction pattern or hemodynamic abnormalities. The left anterior descending coronary artery alone supplies about one half of the left ventricular muscle mass and in that respect is the major coronary vessel (8). This seemed to be borne out in the present study since subjects with isolated lesions of the left anterior descending artery had both a higher prevalence of ventriculographic abnormalities and a higher mean left ventricular end diastolic pressure than those with either right or circumflex lesions (Table 5). Subjects with combined disease of the left anterior descending and circumflex vessels had a higher (71%) prevalence of ventriculographic abnormalities when compared with those with other combinations of vessel disease (Table 5).

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Question of the Month

Endocrinology and Metabolism

Question 553

In osteomalacia the most helpful roentgenographic sign is

(A) Generalized decrease in radiodensity
(B) Decreased prominence of the end plate, and ground glass appearance of the vertebrae
(C) Subperiosteal bone resorption
(D) Pseudofractures
(E) "Beaten-copper" appearance of the skull

[*This* Question of the Month *is from the* Medical Knowledge Self-Assessment Program *of the ACP. The answer and a reference are given on p. 224 of this issue.*]