

Coronary anatomy and left ventricular function in the first 12 hours of acute myocardial infarction: the Western Washington Randomized Intracoronary Streptokinase Trial

MICHAEL L. STADIUS, M.D., CHARLES MAYNARD, M.S., JAMES K. FRITZ, M.D.,
KATHRYN DAVIS, PH.D., JAMES L. RITCHIE, M.D., FLORENCE SHEEHAN, M.D.,
AND J. WARD KENNEDY, M.D.*

ABSTRACT The relationships among clinical variables, coronary anatomy, and left ventricular function during the early hours of acute myocardial infarction (AMI) were evaluated from data acquired in the Western Washington Intracoronary Streptokinase Trial. All patients had symptoms and electrocardiographic changes typical of AMI. All data were obtained before treatment with streptokinase. Mean time to catheterization was 4.1 hr after onset of symptoms. Coronary angiograms ($n = 245$) were analyzed for location of infarct-related occlusion and collateral flow to the infarct bed. Left ventricular ejection fraction and regional left ventricular function were quantitated in 227. Sixty-two percent of occlusions were in the most proximal segment of the involved coronary artery. Collateral circulation was seen in 42% overall, in 31% with left anterior descending artery (LAD) occlusion, and in 52% with right coronary artery (RCA) occlusion ($p < .005$). Left ventricular ejection fraction was lowest and regional function was most abnormal in the group with proximal LAD occlusion. Hyperkinesis was present in 32%; in those with hyperkinesis, hyperkinetic segment length was longest in those with RCA or circumflex occlusion. Multivariate analysis identified proximal LAD occlusion as the factor most closely associated with left ventricular ejection fraction and with measures of left ventricular regional hypofunction. We conclude that (1) AMI is usually caused by occlusion or subtotal occlusion in the most proximal portion of the involved coronary artery, (2) collateral circulation is more frequent with RCA than with LAD occlusion, and (3) location of the infarct-related occlusion is the most important determinant of global and regional left ventricular function in the early hours of AMI.

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THERAPY of acute myocardial infarction (AMI) has undergone a series of revolutionary changes in the past 12 years. With the realization that cardiac catheterization can be performed in the early hours of the acute event with minimal additional risk,^{1,2} aggressive therapies for the treatment of AMI have evolved. Emergency coronary artery bypass surgery,^{3,4} intracoronary infusion of thrombolytic agents,^{1,5-7} and percutaneous

transluminal coronary angioplasty^{8,9} are all being used in attempts to improve mortality after AMI. Each of these therapies is dependent on knowledge of coronary artery anatomy. Despite the recent widespread use of these different therapies, systematic description of coronary anatomic findings during the early hours of AMI has not yet been reported. Furthermore, the relationships among baseline clinical characteristics, left ventricular function, and coronary anatomy has not been widely studied in man.

Our objective in this report was to describe the angiographic findings in patients in the Western Washington Intracoronary Streptokinase Trials, to define coronary anatomy and global and regional left ventricular function, and to study the relationships among coronary anatomy, left ventricular function, and clinical features of these patients.

From the Department of Medicine, Division of Cardiology, and the Department of Biostatistics, University of Washington School of Medicine, and the Seattle Veterans Administration Medical Center, Seattle.

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Address for correspondence: J. Ward Kennedy, M.D., Division of Cardiology, RG-22, University Hospital, Seattle, WA 98195.

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*Principal investigators and their associates are listed in an appendix to this article.

Methods

The protocol and early results of the Western Washington Intracoronary Streptokinase Trial, patient selection, and exclusion criteria have been published in detail previously.^{7, 10} Patients were eligible for enrollment if they had symptoms of AMI of less than 12 hr duration, were 75 years of age or less, and had electrocardiographic changes typical of AMI.⁷ Criteria for exclusion were: (1) presence of disease or conditions other than coronary disease involving a substantial increased risk of death (e.g., cancer, severe liver or kidney disease, coma, etc.); (2) failure to give informed consent, (3) prior exposure to streptokinase, (4) any contraindication to anticoagulation therapy, and (5) any treatment for congestive heart failure before the onset of AMI.

After giving informed consent, all patients were taken to the cardiac catheterization laboratory. Clinical variables, including cardiac history before the event and clinical status at the time of catheterization, were recorded. Left heart catheterization with left ventricular angiography in the 30 degree right anterior oblique projection was performed first, followed by coronary arteriography. The noninvolved coronary artery was studied before the infarct-related artery. If a partially or totally occluded vessel serving the region of the suspected infarct was identified, 0.2 mg of nitroglycerin was infused into the artery followed by repeat arteriography to detect coronary artery spasm. Patients with total occlusion or subtotal occlusion with thrombosis were randomly assigned to the treatment or control group.

All available angiograms were reviewed in the central laboratory by a panel of cardiologists. The site of the infarct-related occlusion was recorded according to the Coronary Artery Surgery Study coronary anatomy map (figure 1).¹¹ The severity of the initial occlusion and the response to contrast agent and

intracoronary nitroglycerin were evaluated. Stenosis less than 90% diameter reduction was measured with hand-held electronic calipers.¹² More severe stenosis was estimated visually. The extent of collateral flow to the infarct bed was graded as none, 1+, 2+, or 3+. Collateral flow of 1+ represented very faint opacification of a small portion of the distal infarct vessel, while 2+ collateral flow was faint opacification of a substantial portion of the infarct vessel, and 3+ collateral flow was good opacification of the substantial portion of the infarct-related vessel.

For quantitative determination of global and regional left ventricular function, angiograms were reviewed in a blinded fashion by an experienced technician and ventricular contours were drawn if the ventricle was adequately opacified during a cardiac cycle not preceded by a premature contraction. End-systole and end-diastole were identified visually. The end-systolic and end-diastolic contours were digitized into a computer and the ejection fraction was calculated by the area-length method developed in this laboratory.¹³ Regional wall motion was measured at 100 equally spaced chords perpendicular to a centerline constructed midway between the end-systolic and end-diastolic contours (figure 2).^{14, 15} Motion at each chord was normalized for heart size by dividing by the end-diastolic perimeter length. Comparison of motion among different chords requires that motion be expressed in comparable units; therefore, the normalized motion of a given chord was converted into units of standard deviation (SD) from the mean motion for that chord as determined in a group of 64 normal patients. This method of normalization allows direct comparison of wall motion between different chords in the same ventricle and chords in different ventricles.¹⁵

Chord motion expressed in units of SD was plotted for each

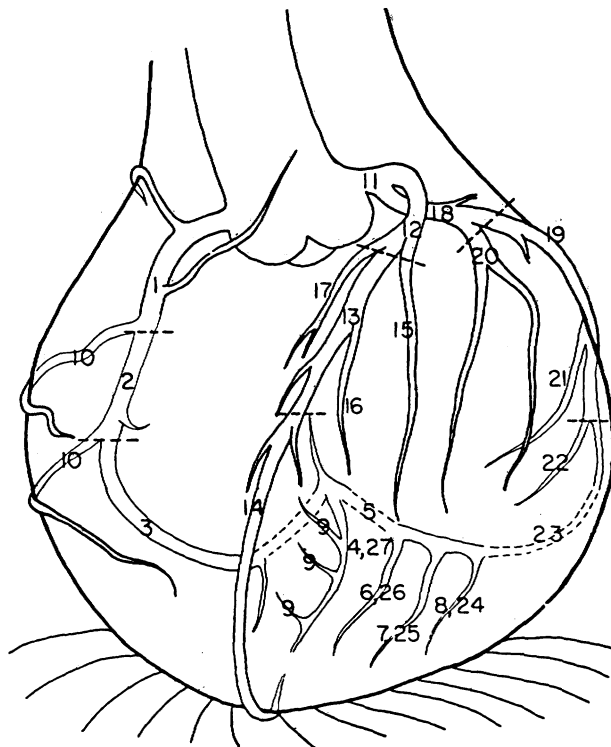


FIGURE 1. Location of the infarct-related occlusion was classified according to this coronary artery anatomy map (from Killip T and the Principal Investigators of the Coronary Artery Surgery Study. *Circulation* 63 (suppl 1): 1-59, 1981. Reprinted with permission of the authors and the American Heart Association, Inc.).

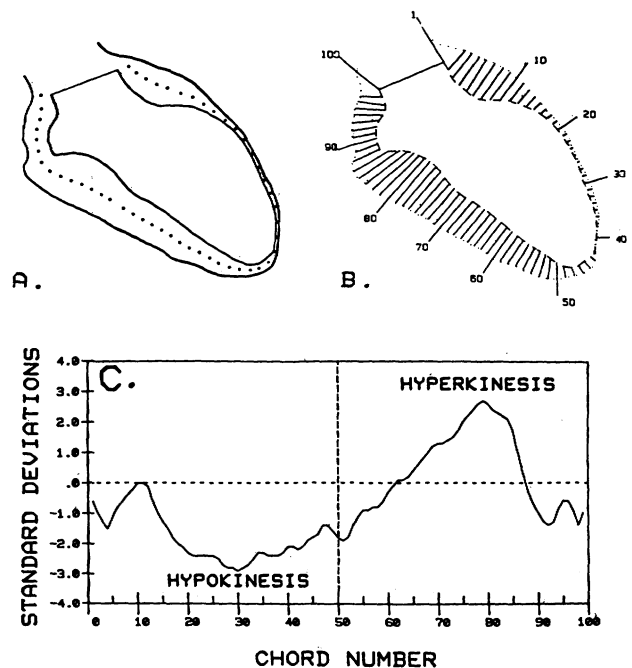


FIGURE 2. A, End-systolic and end-diastolic contours with location of centerline indicated. B, One hundred equidistant chords constructed perpendicular to the centerline. C, Motion at each chord is measured, corrected for end-diastolic perimeter length, then compared with normal expected motion for that chord as previously determined in a group of normal patients. The difference between observed and expected motion is expressed in units of standard deviation from normal mean value and plotted as shown in this N standard plot.

patient (figure 2). Analysis of regional wall motion was carried out between chord numbers 10 and 80. Chords 1 to 9 and 81 to 100 were not analyzed because they reflect motion related to the aortic and mitral valves. For each patient, hypokinetic segment length, abnormally contracting segment length, and hyperkinetic segment length were determined. The hypokinetic segment represents chords with hypokinetic, akinetic, or dyskinetic motion; chord motion was hypokinetic if it was -2.00 SD or less (i.e., equal to or more depressed than 2 SD below normal). The hyperkinetic segment length includes chords with motion 2.00 SD or greater above the normal (see figure 3). The abnormally contracting segment represents chords with akinetic or dyskinetic motion and includes those with absolute motion of 0 or less. Hypokinetic segment length, hyperkinetic segment length, and abnormally contracting segment length each included all chords between 10 and 80 that met criteria for inclusion; that is, chords did not have to be contiguous to be included in a given segment length. Each segment length was expressed as the percentage of the total left ventricular perimeter for each patient. To derive a single numerical value describing all possible forms of abnormal regional function, the "regional function score" was calculated as hypokinetic segment length $-$ hyperkinetic segment length.

Statistical methods. Differences between patient groups were determined with the chi-square statistic for discrete variables and the *t* and *F* tests for continuous variables. The *t* test was used when two groups were compared, the *F* test when more than two groups were examined. Stepwise multiple regression was used to select clinical and angiographic variables

related to key indexes of left ventricular function, namely left ventricular ejection fraction, hypokinetic segment length, abnormally contracting segment length, and hyperkinetic segment length. Variables with *F* values of 4.0 or greater ($p < .05$) are included in this report. Values are expressed as the mean ± 1 SD.

Results

Left ventricular and coronary cineangiograms were available for review in 245 of the 250 patients. Men composed 86.1% of this group. The mean age was 56.5 ± 10.6 years and the mean time from onset of symptoms to randomization was 4.6 ± 2.1 hr. Cardiac catheterization preceded randomization and is estimated to have taken about 30 min to perform. Therefore the mean time to onset of angiography is estimated to be 4.1 hr. Thirteen percent of the patients had a history of prior MI.

Coronary anatomy. The locations of the infarct-related occlusions according to the Coronary Artery Surgery Study anatomy map are listed in table 1. The infarct-related vessel was the left anterior descending artery (LAD) in 114 patients (47%), the right coronary artery (RCA) in 111 patients (45%), and the circumflex artery in 20 patients (8%). In patients with LAD infarct-related occlusions, the occlusion was in the proximal vessel (segment 12) in 67.5%, in the mid-LAD (segment 13) in 30.7%, and in the first diagonal artery in 1.8%. In patients with RCA infarct-related occlusions, the occlusion was proximal to the first acute marginal branch (segment 1) in 57.7%, between the first acute marginal branch and the posterior descending artery (segments 2 and 3) in 38.7%, and more distal (segments 4 and 5) in 3.6%. Of the 20 patients with infarct-related occlusion in the circumflex artery, five had left dominant coronary circulations. The infarct-related occlusion was in the circumflex vessel in 16 patients, and in the obtuse marginal arteries in four patients. Two hundred eight patients (84.9%) demonstrated total occlusion of the infarct-related vessel on initial injection of that vessel. The rate of total occlusion did not vary when analyzed by vessel (84.7% for the RCA, 90.0% for the circumflex, and 84.2% for the LAD).

Hand injection of contrast agent and bolus infusion of intracoronary nitroglycerin had little effect on the severity of the infarct-related occlusions. Only nine patients (3.7%) showed any improvement in the infarct-related occlusion after hand injection of contrast agent (change in mean stenosis from 100% to 94%) and 12 patients (4.9%) showed improvement after bolus intracoronary administration of nitroglycerin (from 99% to 89%). In two patients the response to nitrogly-

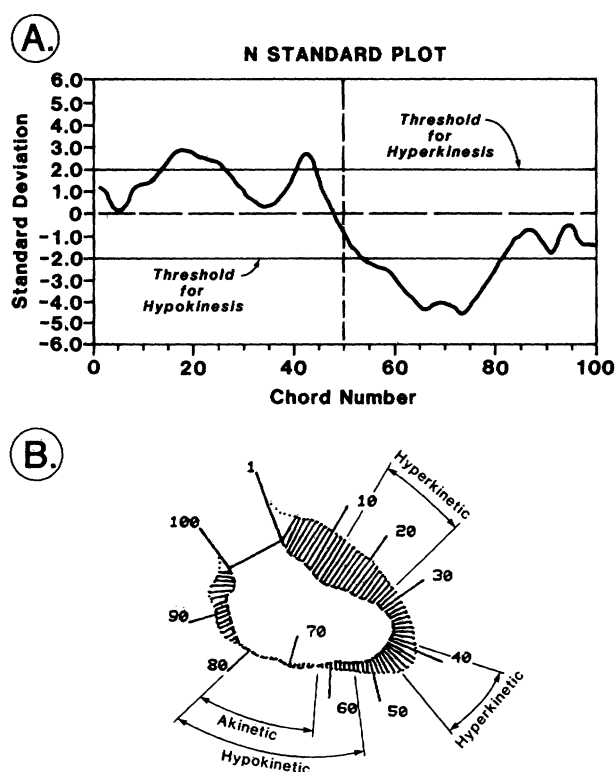


FIGURE 3. A, N standard plot from a patient with inferior AMI. Thresholds for hyperkinetic and hypokinetic motion are indicated by solid lines. B, End-systolic and end-diastolic contours from N standard plot above. Akinetic, hypokinetic, and hyperkinetic segments determined from analysis of the N standard plot are indicated. The akinetic segment corresponds to the abnormally contracting segment described in the text.

TABLE 1
Site of infarct-related occlusion

Artery	CASS segment number	n	% of total by artery
RCA			
Proximal to AM ₁	1	64	57.7
AM ₁ to AM ₂ or to acute angle	2	31	27.9
AM ₂ to PDA	3	12 ^A	10.8
PDA	4	1	0.9
LV extension	5	3	2.7
LAD			
Proximal to S ₁ and D ₁	12	77	67.5
S ₁ or D ₁ to S ₃ or D ₃	13	35	30.7
D ₁	15	2	1.8
Circumflex artery			
Proximal to OM ₁	18	11	55
OM ₁ to OM ₂	19	5	25
OM ₁	20	3	15
OM ₂	22	1	5

CASS = Coronary Artery Surgery Study; AM = acute marginal artery; PDA = posterior descending artery; LV = left ventricular; S = septal perforator artery; D = diagonal artery; OM = obtuse marginal artery; subscript numerals refer to branch number.

^AOne patient in this group had occlusion of a saphenous vein bypass graft to segment 3 of the RCA.

erin was dramatic, with a change from total occlusion to 55% diameter stenosis in one and from total occlusion to 70% diameter stenosis in the other.

Adequate coronary angiograms for assessment of collateral blood flow to the infarct bed were available in 238 patients. At least some degree of collateralization was present in 100 patients (42%) (figure 4). Only 34 of the 109 patients (31%) with LAD occlusion had visible collateral flow, while 63 of 109 patients (58%) in the group with RCA occlusion demonstrated collat-

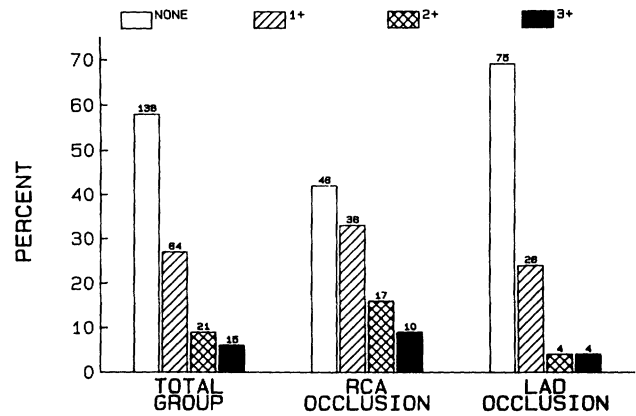


FIGURE 4. Distribution of patients according to assessment of collateral flow to the infarct bed. The grading system used for classification of collateral is discussed in the Methods section. Collateral flow was more prevalent in those with RCA occlusion compared with LAD occlusion ($p < .001$).

eral flow ($p < .005$). The higher frequency of collateral flow in patients with RCA occlusions persisted when patients with prior AMI were excluded (57% vs 34%; $p < .001$). Collateral flow of 3+ was rare (present in only 15 of the 238 patients, 6%).

Left ventricular function. Left ventricular angiography was performed in 236 of these 245 patients. In nine the angiograms were not suitable for quantitative analysis because of premature contractions or faint opacification. Global left ventricular ejection fraction and regional left ventricular function correlated significantly with the location of the infarct-related occlusion (table 2). Patients with proximal LAD occlusion had the lowest left ventricular ejection fraction, the longest abnormally contracting segment and hypokinetic segment lengths, and the shortest hyperkinetic segment length. Akinesis was present in 94% of patients with LAD

TABLE 2
Global and regional left ventricular function according to the site of the infarct-related occlusion

Location ^A	n	Ejection fraction	Abnormally contracting segment		Hypokinetic segment		Hyperkinetic segment	
			% of LV perimeter	n, % by location	% of LV perimeter	n, % by location	% of LV perimeter	n, % by location
Proximal LAD (segment 12)	68	41.3 ± 10.7	22.0 ± 11.6	64, 94%	43.5 ± 12.1	68, 100%	7.0 ± 9.0	17, 25%
Mid-LAD (segment 13)	30	51.0 ± 11.4	17.3 ± 11.1	28, 93%	31.3 ± 14.5	30, 100%	5.9 ± 3.1	13, 43%
Proximal RCA (segments 1 to 3)	104	53.3 ± 10.0	8.3 ± 6.5	53, 51%	21.5 ± 10.6	100, 96%	14.5 ± 10.3	38, 37%
Proximal circumflex (segments 18 to 20)	17	48.4 ± 11.0	12.2 ± 6.0	6, 35%	19.8 ± 10.3	17, 100%	17.3 ± 17.9	3, 18%
		$p < .0001$	$p < .0001$	$p < .001$	$p < .0001$	$p = \text{NS}$	$p < .01$	$p = \text{NS}$

LV = left ventricular.

^AData from eight patients fell outside this classification scheme: four had distal RCA (segments 4 or 5) occlusions, two had diagonal (segment 15) occlusions, one had distal obtuse marginal (segment 23) occlusion, and one had occlusion of a bypass graft to the distal RCA.

occlusion, while only 53% with RCA occlusion and 35% with circumflex occlusion had akinesis ($p < .001$).

Because global left ventricular function can be influenced by a number of variables related to the patient's history and coronary anatomy, stepwise multiple regression was performed to evaluate the relationship of these variables with left ventricular ejection fraction. The following variables were considered in this analysis: patient age, sex, history of prior myocardial infarction, time to randomization (randomization immediately followed cardiac catheterization), severity (% diameter reduction) of infarct occlusion on initial angiographic view, extent of collateral flow to infarct bed, number of vessels with 70% or greater stenosis, and location of infarct-related occlusion. The result of the analysis is presented in table 3. Occlusion in the proximal LAD was the variable most closely related to left ventricular ejection fraction. Other variables that were significantly related to ejection fraction were (in order of decreasing importance): severity of the initial infarct-related occlusion, number of coronary arteries with 70% or greater diameter stenosis reduction, and history of prior AMI. Stepwise multiple regression analysis with the variables listed above was also performed for measures of regional left ventricular function as well. Only proximal and mid-LAD location of the infarct-related occlusion and patient age were significantly related to the abnormally contracting segment length (table 4). These same three variables were also significantly related to the hypokinetic segment length (table 4). Surprisingly, longer hypokinetic segment lengths were associated with absence of prior history of AMI and with higher degrees of collateral blood flow to the infarct bed. The correlation between abnormally contracting segment length and left ventricular ejection fraction was fair ($r = -.52$), while the correlation between hypokinetic segment length and left ventricular ejection fraction was good ($r = -.78$). The left ventricular ejection fraction correlated best with "regional function score" ($r = -.83$).

TABLE 3
Significant variables identified by multiple regression analysis relating global ejection fraction to clinical and angiographic variables

Variable	F value	p value
Proximal LAD occlusion	54.403	<.001
Severity of infarct-related occlusion on initial injection of contrast	7.905	<.01
No. of vessels with $\geq 70\%$ stenosis	6.211	<.01
History of prior MI	4.207	<.05

MI = myocardial infarction.

TABLE 4
Significant variables identified by multiple regression analysis relating regional wall motion parameters to clinical and angiographic variables

Variable	F value	p value
Abnormally contracting segment		
Proximal LAD occlusion	144.1	<.0001
Mid-LAD occlusion	30.3	<.001
Age	7.2	<.01
Hypokinetic segment		
Proximal LAD occlusion	183.8	<.0001
Mid-LAD occlusion	16.3	<.001
Age	11.3	<.01
History of prior MI	8.8	<.01
Extent of collateral flow	4.8	<.05
Hyperkinetic segment		
Proximal RCA occlusion	6.8	<.05
Age	5.7	<.05

MI = myocardial infarction.

Hyperkinesis was seen in 72 (32%) of the patients. When patients with hyperkinesis were compared with those without, there was no significant difference in age, sex, history of prior AMI, time from onset of symptoms to cardiac angiography, initial infarct-related occlusion (percent diameter reduction), and left ventricular end-diastolic pressure (table 5). The incidence of hyperkinesis was similar when analyzed by infarct-related artery (RCA, 35% with hyperkinesis; LAD, 31%; circumflex, 17%; $p = .29$). In those with hyperkinesis, the length of the hyperkinetic segment was related to the location of the infarct-related occlusion. Patients with infarct-related occlusion in the proximal RCA or proximal circumflex artery had long-

TABLE 5
Baseline characteristics in patients with and without hyperkinesis^a

	Hyperkinesis present (n = 72)	Hyperkinesis absent (n = 155)
Age	56 \pm 10	58 \pm 10
Sex (% male)	79	88
History of prior MI (% positive)	7	16
Time to randomization from onset of symptoms (hr) ^b	4.7 \pm 2.0	4.6 \pm 3.6
LV end-diastolic pressure	21 \pm 7	22 \pm 9
Infarct-related occlusion (% diameter reduction)	99 \pm 6	97 \pm 10

MI = myocardial infarction; LV = left ventricular.

^aThere were no statistically significant differences between the two groups.

^bCatheterization preceded randomization and is estimated to have taken about 30 min.

er hyperkinetic segment lengths than those with occlusion in the LAD (table 2).

Global left ventricular ejection fraction was significantly higher in the group of patients with hyperkinesis than in the group without hyperkinesis (56.8 ± 9.6 vs 45.3 ± 10.5 ; $p < .0001$). Likewise, the hypokinetic segment length was shorter in the groups with hyperkinesis; however, there was no difference in akinetic segment length between these two groups (table 6). When analyzed by infarct-related vessel, left ventricular ejection fraction remained significantly higher and hypokinetic segment length was shorter in patients with hyperkinesis (table 6).

Discussion

Coronary anatomy. Thrombosis is the proximate cause of AMI in patients presenting with ST segment elevation on their initial electrocardiograms.² The majority of patients in our series had thrombotic occlusion or subtotal occlusion with thrombosis in the most proximal segment of the involved coronary vessel. Interestingly, involvement of the circumflex artery was uncommon. Only 20 patients (8.1%) had involvement of the circumflex artery; furthermore, five of

these 20 had left dominant coronary distributions. Thus only 6.1% of this group had infarction limited to the lateral left ventricular wall. One explanation for this finding is that elevation of the ST segment, a criteria for entry in this study, is an uncommon finding in those with circumflex disease leading to AMI. Other explanations are more speculative. Certainly, from pathologic series, significant atherosclerosis appears to be evenly distributed among the three coronary beds.^{16, 17} However, whether thrombosis occurs with similar frequency in all three coronary beds remains open to question.

Our observations on the frequency of collateral flow to the infarct bed are consistent with the findings and conclusions of prior reports.^{18, 19} Extensive collateral flow in the early hours of AMI was very common (present in only 6% of the patients). On the other hand, lesser collateral circulation was present in an additional 36% of this group. Presence of collateral flow had no beneficial effect on global or regional left ventricular function in these short-term studies. However, angiographically detectable collateral flow in the early hours of AMI may be associated with evolution of smaller infarctions. Schwartz et al.²⁰ reported in a small series of patients that resting thallium defects late after AMI appeared to be smaller in patients with faint collaterals present early in the infarction compared with resting defect size in patients without early collateral flow. Nitzberg et al.¹⁹ likewise reported that presence of early collateral circulation was associated with improved left ventricular ejection fraction in late follow-up studies. These two reports at least raise the possibility that the presence of faint collateralization early in AMI may provide some protective effect to the infarct zone. If this is true, then some protective effect from collateral flow may be present in a third or more of patients with AMI.

At this time, we can only offer speculation as to why collateral flow is more frequent in those with RCA occlusion compared with those with LAD occlusion. The LAD and circumflex arteries serve only left ventricular myocardium, a relatively high-resistance bed. The RCA, on the other hand, serves both left and right ventricular myocardium and the latter is a relatively low-resistance bed. It is likely that the resistance in the RCA bed remains lower in the presence of an occlusion proximal to the acute marginal branches. The presence of the two different myocardial resistance beds in the RCA may well explain why collateral circulation is more common with RCA than with LAD or circumflex occlusion.

Left ventricular function. This study illustrates the im-

TABLE 6
Relationship of hyperkinesis to other measures of left ventricular function

	HYPO	ACS	LVEF
Total group			
Hyperkinesis absent (n = 155)	30.7 ± 15.7	10.5 ± 11.7	45.3 ± 10.5
Hyperkinesis present (n = 72)	25.3 ± 14.7	11.2 ± 12.5	56.8 ± 9.6
	p < .05	p = NS	p < .0001
LAD occlusion			
Hyperkinesis absent (n = 70)	41.4 ± 13.9	19.0 ± 11.8	40.8 ± 10.3
Hyperkinesis present (n = 31)	35.9 ± 13.4	19.5 ± 13.4	52.2 ± 10.8
	p < .05	p = NS	p < .0001
RCA occlusion			
Hyperkinesis absent (n = 70)	22.1 ± 11.5	3.5 ± 5.3	49.5 ± 9.2
Hyperkinesis present (n = 38)	17.5 ± 9.9	5.2 ± 7.5	60.2 ± 6.8
	p < .05	p = NS	p < .0001
Circumflex artery occlusion			
Hyperkinesis absent (n = 15)	21.1 ± 10.2	4.5 ± 7.2	45.9 ± 9.2
Hyperkinesis present (n = 3)	15.0 ± 11.1	2.3 ± 4.0	60.3 ± 10.7
	p = NS	p = NS	p < .05

HYPO = hypokinetic segment length; ACS = abnormally contracting segment length; LVEF = left ventricular ejection fraction.

portant relationship between coronary anatomy and global and regional left ventricular function in the setting of AMI. The location of the infarct-related occlusions was identified as the single most important variable related to every measure of left ventricular function. Proximal LAD occlusion (segment 12) was associated with the lowest mean ejection fraction (41.3%) and was identified by multiple regression analysis as the variable most closely associated with left ventricular ejection fraction. Likewise, proximal LAD occlusion was associated with the longest mean abnormally contracting segment and hypokinetic segment lengths, and in both cases was identified by multiple regression analysis as the best predictor of these measures of regional left ventricular function. On the other hand, in patients with hyperkinesis, location of the infarct occlusion in the RCA or circumflex artery was associated with longer (but not more frequent) hyperkinetic segment lengths.

This very strong relationship between location of the infarct-related occlusion in the coronary bed and left ventricular function has not been emphasized in the past. Pathologic study has demonstrated a somewhat predictable relationship between a coronary artery and the size of its myocardial perfusion bed in man.²¹ By injecting coronary arteries with contrast medium then serially slicing the left ventricular myocardium (free wall and whole interventricular septum), it was possible to determine the relative size of the three coronary perfusion beds in a series of 171 postmortem heart specimens. Approximately two-thirds of the left ventricular myocardium received its blood supply from the LAD in this analysis. Our observations provide the physiologic correlate to these anatomic observations. Location of the infarct-related occlusion in the LAD was associated with the greatest decrease in ejection fraction and with the longest hypokinetic and abnormally contracting segment lengths.

The relationship between location of the infarct-related occlusion and ventricular function has implications for the design of interventional trials in AMI. If serial studies of left ventricular function are selected as an end point for evaluation of a proposed intervention, then the intervention should have the same success rate in all coronary beds before measures of left ventricular function from all patient studies can be grouped together. If the intervention varies in rate of success according to location of infarct-related occlusion or if distribution of locations of the infarct-related occlusions vary in treatment and control groups, then measures of left ventricular function would need to be evaluated by location of the infarct-related occlusion.

Factors other than location of the infarct-related occlusion were related to measures of left ventricular function. For left ventricular ejection fraction, three other variables were identified. Percent diameter obstruction of the infarct-related vessel on initial injection of contrast agent presumably influences function within the infarct zone. The other two factors, history of prior AMI and number of noninfarct zone vessels with 70% or greater diameter stenoses, influence ventricular function outside the infarct zone. Patient age and sex, collateral flow to the infarct bed, and time from onset of symptoms to study were not related to ejection fraction in our study. Animal studies have shown that the major portion of myocardial dysfunction occurs within several minutes of coronary occlusion.^{22, 23} Thus the angiographically determined ejection fraction at 3 to 6 hr is probably very similar to that a few minutes after occlusion. Although age was not related to left ventricular ejection fraction, it was related to each of the measures of regional left ventricular function. Older age was associated with longer abnormally contracting segment and hypokinetic segment lengths and shorter hyperkinetic segment length. This effect of age is not well understood, but the results of the multivariate analysis suggest that it is not related in a simple manner to more advanced coronary disease or prior AMI.

In this analysis, we have described three measures of regional left ventricular function. The abnormally contracting segment has been described previously.²⁴ Hypokinetic and hyperkinetic segment lengths are analogous to the abnormally contracting segment. They represent our attempts to measure quantitatively hypokinesis and hyperkinesis in addition to akinesis and dyskinesis. Each is based on the statistical nature of the centerline method for regional wall motion analysis^{14, 15}; that is, motion at a given point is classified as abnormal if it is 2.00 SD or greater from the expected normal mean value for that point. As with any measure of function based on the 30 degree right anterior oblique contrast angiogram, some caution must be used in interpretation of the data. The anterior wall and apex are well represented in this single-plane image, but lateral, septal, and some parts of the posterobasal aspects of the left ventricle are not represented in the image. Realignment of end-systolic and end-diastolic contours further complicate regional wall motion analysis.^{25, 26} The relatively low percentage of patients with RCA and circumflex occlusions who have akinesis may be explained in part by these limitations of the 30 degree right anterior oblique angiogram.

Sheehan *et al.*²⁷ and Stack *et al.*²⁸ have previously

demonstrated that global left ventricular ejection fraction in the setting of AMI is a relatively poor indicator of potential for salvage of regional function in the infarct zone. The global ejection fraction was in many cases influenced by hyperkinesis in the nonischemic myocardium outside the infarct zone. These authors concluded that the best measure of functional recovery was assessment of the regional function in the infarct zone, not evaluation of serial changes in the global ejection fraction. Our observations also illustrate the important disparity between function in the infarct zone and left ventricular ejection fraction. In the absence of prior AMI, the abnormally contracting segment length should be closely correlated with infarct size. However, the correlation between abnormally contracting segment length and ejection fraction here was only fair ($r = -.52$). On the other hand, correlation between ejection fraction and the "regional function score" ($r = -.83$) was much better. This regional function score represented all possible types of regional dysfunction, including dyskinesis, akinesis, hypokinesis, and hyperkinesis.

Because abnormally contracting segment length has been used in prior investigations^{24, 29, 30} in patients several days to 12 months after AMI, a comparison of findings can be made. Feild et al.²⁴ found no significant difference in the abnormally contracting segment length when they compared patients with anterior and inferior myocardial infarction. However, their report included only 17 patients in the analysis. Rigaud et al.²⁹ studied 62 patients and found a significant difference in abnormally contracting segment length between groups with anterior and inferior infarction at 2 to 6 days after AMI (anterior, $34 \pm 14\%$; inferior, $28 \pm 7\%$; $p < .02$). Likewise, Bertrand et al.,³⁰ in patients 7 to 21 days after AMI, found that the abnormally contracting segment length was $39 \pm 2\%$ in those with anterior AMI and $28 \pm 2\%$ in those with inferior AMI ($p < .001$). When our data for abnormally contracting segment length from the groups with proximal LAD and proximal RCA occlusion are compared with the data of Rigaud et al. and Bertrand et al., it is clear that the abnormally contracting segment length recorded 2 to 21 days after AMI is substantially longer than that recorded in the first hours of AMI, particularly in patients with inferior AMI. Some of these differences may be due to technique. Our computer-based method for measuring abnormally contracting segment length included all points with the criteria for akinesis or dyskinesis but did not include points with hypokinetic wall motion within the akinetic region. Planimetry by hand, as was done in prior studies, would tend to

include hypokinetic points within the akinetics region, thus leading to longer abnormally contracting segment lengths. We also excluded chords 81 to 100 because they corresponded to motion of the mitral valve apparatus and not to myocardial wall motion. Inclusion of these chords would decrease the discrepancy in the abnormally contracting segment length at the different intervals, particularly in the group with inferior AMI. However, it is doubtful that these methodologic differences account for all the discrepancy between our early abnormally contracting segment lengths and those reported by others from later in the course of AMI. Thus it is quite possible that the abnormally contracting segment continues to enlarge between 4 and 5 hr after onset of AMI and 2 to 21 days later. Only serial studies in the same patients will provide definite answers on this issue.

Hyperkinesis in AMI has been reported previously.^{27, 28, 31, 32} However, factors potentially related to hyperkinesis have not been evaluated in detail. In this series, 32% of patients had evidence of at least some amount of hyperkinesis. Patient age, sex, history of prior AMI, time from onset of symptoms to study, left ventricular end-diastolic pressure, and severity of occlusion on initial injection of contrast agent appear unrelated to the ability of the left ventricle in a given patient to mount a hyperkinetic response. We could not evaluate any potential relationships between medications and hyperkinesis because of lack of detailed data about medications given between presentation and study. Importantly, global left ventricular ejection fraction was significantly higher in the group of patients with hyperkinesis than in the group without hyperkinesis. Whether presence of hyperkinesis has important clinical implications for the patient remains unclear. Only Nieminen et al.³² have explored the relationship between occurrence of hyperkinesis (defined by echocardiography) and clinical status of the patients at the time of study. They concluded that hyperkinetic function was seen only in patients with uncomplicated or "moderately" complicated AMIs. Hyperkinesis was absent in those with complicated infarction and cardiogenic shock. These findings have yet to be confirmed; furthermore, the long-term implications of occurrence of hyperkinesis have not been evaluated.

In summary, the following clinical implications can be drawn from this analysis: (1) anterior infarction results in lower left ventricular ejection fraction and larger measures of regional left ventricular dysfunction than inferior infarction; (2) collateral flow to the infarct bed is common but has no beneficial effect on global or regional left ventricular function in the early hours of

AMI; (3) hyperkinesis is common and, when present, results in improved ejection fraction; and (4) involvement of the circumflex artery is rare when patients with AMI are selected because of ST segment elevation.

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Appendix

The principal investigators and their associates of the Western Washington Intracoronary Streptokinase Trial (italics denote investigators administratively responsible for the trial at their institutions): J. W. Kennedy, Director; J. L. Ritchie, Co-Director; K. B. Davis, Investigator; J. K. Fritz, Investigator. Angiographic Analysis Committee: J. W. Kennedy, J. K. Fritz, M. L. Stadius. Policy Board: S. Rubenstein, Chairman; P. B. Beeson, T. S. Inui, L. Fisher. Data Coordinating Center: K. B. Davis, C. Maynard. Technicians: C. Alcock, A. Coleman, K. Gaines. Nurses: D. Erickson, K. McFadden. Clinical Associates: Overlake Hospital (Bellevue, WA), *C. E. Hansing*, K. M. Hynes, R. E. Haynes, D. B. Ferrin, J. S. Schneider, J. T. Holder; St. Joseph Hospital (Bellingham, WA), *R. S. Trenouth*, D. C. Brown, D. D. McAfee; Everett General Hospital (Everett, WA), *J. P. Nolan*, D. J. Stewart, W. J. MacDonald, K. H. Prindle, N. D. Smith, J. Schmitt; Providence Hospital (Seattle), *G. A. Logan*, *F. M. Tobis*, T. A. Block, J. G. Doces, M. T. English, P. C. Albro, A. L. Sytman, R. A. Crone, C. G. Hale, B. Green; Swedish Hospital (Seattle), *F. A. Short*, W. E. Samson, R. J. Westcott, J. L. Peterson; University Hospital (Seattle), *D. K. Stewart*, J. A. Murray, K. F. Hossack, J. A. Werner, G. Frank, B. G. Brown, D. W. Weaver, G. B. Trobaugh; Veterans Administration Hospital (Seattle), *J. W. Kennedy*, *J. L. Ritchie*, J. H. Caldwell, J. Stratton; Virginia Mason Hospital (Seattle), *R. R. Johnston*; Madigan Army Hospital (Tacoma, WA), *J. L. Hill*, T. Steudel, R. Chamusco; Tacoma General Hospital (Tacoma, WA), *E. Lapin*, T. Reagan; St. Joseph's Hospital (Tacoma, WA), *J. R. McDonough*, M. Henry; Vancouver General Hospital (Vancouver, BC), *R. R. Ricci*; Wenatchee Valley Hospital (Wenatchee, WA), *D. Larson*, J. Gorham; St. Elizabeth Hospital (Yakima, WA), *D. A. Monick*, R. D. Twiss, A. B. Preacher, R. K. Spiegel.

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