SYMPOSIUM
Myocardial Infarction 1972
(Part 2)

Determination of the Site, Extent,
and Significance of Regional
Ventricular Dysfunction during Acute
Myocardial Infarction

By Barry L. Zaret, M.D., Bertram Pitt, M.D., and Richard S. Ross, M.D.

SUMMARY
Infarct site, extent, and the degree of associated asynergy are major determinants
of the hemodynamic consequences of myocardial infarction. Although conventional
electrocardiography and vectorcardiography are routinely employed in assessing the
location and size of infarction, they are relatively nonspecific. The newer techniques
of high-frequency electrocardiography and isopotential mapping offer promise but
have yet to undergo systematic evaluation. A rough measure of the extent of infarction
is obtained from serum enzyme measurements. However, they furnish no
information with regard to localization.

The region of infarction may be detected by precordial scanning following the
intravenous or intracoronary injection of a radioisotope. The infarct may be revealed
as an area of decreased perfusion (cold spot) or as an area to which a specific
radioactive label is bound (hot spot). With the availability of newer radionuclides
such as 42potassium and the use of computer techniques, a more precise means of
localizing and quantifying myocardial infarction may become available.

Optimal definition of asynergy is obtained with contrast angiography. However,
the risk of this procedure has limited its use, to date, in acute myocardial infarction.
Apex- and ketocardiography, chest X-ray, and fluoroscopy often suggest regional
ventricular dysfunction, but these techniques are not sufficiently specific. Newer non-
invasive methods for objectively evaluating regional ventricular dysfunction are ECG-
gated cardiac scintiphotography and radarkymography. With ECG-gated scinti-
photography, end-diastolic and end-systolic cardiac isotope images are obtained following
intravenous injection of 199technetium-albumin. From these images, assessment of
asynergy and extent and location of infarct can be made. With radarkymography,
heart-wall motion is assessed and quantitated by tracking segments of the cardiac
silhouette visualized on a cinefluorogram. These techniques are ideally suited to the
acutely ill patient. Echocardiography is another noninvasive technique with potential
application to the study of asynergy. However, at present, only posterior-wall motion
can be measured.

At the time of surgery regions of infarction may be localized by means of chemical
indicators (fluoroscein), isotope techniques, or epicardial electrocardiographic map-
ping. Recently much has been learned about the hemodynamics of myocardial in-
farction. Through the use of the techniques described, further insight into regional
ventricular abnormality and extent and localization of myocardial infarction could be
obtained. With this information better approaches to therapy and prognosis could
be developed.
Many students of the coronary circulation must have noted that the ventricular zone affected by ligating a large coronary branch not only appears cyanotic and dilated, but that it seems to alter in its mode of contraction. The detailed and sequential changes in contraction are not easily followed by the unaided eye and so far have not been recorded myographically. The reasons for this were the lack of an adequate and suitable myograph and a technique for the application of one to a limited ventricular surface so that records obtained represent, at least reasonably well, changes in muscle length and not predominantly artifacts due to position changes, thrusts and vibrations of the vigorously beating ventricle.1

TENNANT AND WIGGERS described regional ventricular dysfunction following coronary occlusion in the dog in 1935.1 Thirty years then elapsed before Harrison proposed the concept of asynergy, an altered pattern of regional ventricular contraction, as a significant factor in the genesis of heart failure in ischemic heart disease.2 Subsequent angiographic studies have demonstrated the frequent occurrence of asynergy in patients following myocardial infarction and in association with transient reversible episodes of myocardial ischemia.3-5

The hemodynamic consequences of acute myocardial infarction have been characterized in recent years by direct measurement of right and left heart pressures and cardiac output.6-8 These hemodynamic manifestations and their clinical and therapeutic implications depend upon the size and location of the infarct and the extent of the associated regional ventricular dysfunction or asynergy.

This report will review those methods currently available for localizing and quantitating the region of infarcted myocardium, methods available for assessing asynergy, and techniques available for the intraoperative delineation of the extent of myocardial ischemia and infarction (table 1). Information obtained by these techniques will be related to the pathophysiology of myocardial infarction. Such information should provide answers to the major questions in the study of acute myocardial infarction: (1) Where is it? (2) How big is it? (3) What is its functional significance?

**Determination of the Site and Extent of Infarction**

**Electrocardiography**

The standard 12-lead electrocardiogram is the most frequently employed clinical means of assessing the site and extent of myocardial infarction. Localization is determined from the combination of leads in which abnormalities are seen. This has led to the widespread clinical use of electrocardiographically derived anatomic terms such as anterolateral, inferior, and anteroseptal myocardial infarction. These ECG-anatomic relationships are, however, often not confirmed by pathologic examination.

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Table 1

Methods for Localizing and Quantifying Myocardial Infarction and Associated Asynergy

<table>
<thead>
<tr>
<th>I. Localization and quantification of the extent of infarction:</th>
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<tr>
<td>Standard 12-lead ECG</td>
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<td>Vectorcardiogram</td>
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<td>High-frequency ECG</td>
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<tr>
<td>Isopotential mapping</td>
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<td>Serum-enzyme measurement</td>
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<td>Myocardial imaging (infarct scanning)</td>
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<th>II. Localization and quantification of asynergy:</th>
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<td>Contrast ventriculography</td>
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<tr>
<td>Coronary arteriography</td>
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<tr>
<td>ECG-gated cardiac scintigraphy</td>
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<tr>
<td>Radarkymography</td>
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<tr>
<td>Apex- and kinetocardiography</td>
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<tr>
<td>Echocardiography</td>
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<th>III. Intraoperative techniques:</th>
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<tr>
<td>Chemical (methylene blue, fluorescein)</td>
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<tr>
<td>Epicardial mapping</td>
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<tr>
<td>Isotope washout and scan</td>
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</table>

Abildskov et al. estimate that only 30% of the ventricular mass contributes to the QRS form.\(^9\) It is thus apparent that major destructive changes may occur without significant alteration in the QRS complex, while strategically placed but small infarcted regions may produce major abnormalities. Horan et al. have also recently reexamined the relationship of Q-wave abnormalities to the pathologic evidence of infarction.\(^10\) They noted that abnormal Q waves indicating uncomplicated anterior or inferior infarction were not reliably associated with pathologic evidence of infarction or scar. In approximately one third of cases with abnormal Q waves in the anterior precordial leads (V₁-V₄), no pathologic evidence of infarction could be found, while infarction was not present in over half the cases with normal Q waves in the inferior leads (II, III, and aV₆). Q waves classified as lateral infarction or those with combinations of more than one anatomic pattern were more reliable predictors of infarction.

Although abnormal Q waves are in themselves thought to indicate transmural infarction, there is evidence from both experimental and human pathologic studies to challenge this concept.\(^11-14\) Small lesions located in the subendocardial and intramural regions of the ventricular wall are capable of producing abnormal Q waves in the standard surface electrocardiogram. Hence, although the standard ECG is used as a major criterion for the diagnosis of myocardial infarction, it can be seen that it has significant limitations for both diagnosis and assessment of infarct size and location.

**Vectorcardiography**

Of the alternative means of displaying ventricular activation, the vectorcardiogram (VCG) has been most widely employed and studied. In a cooperative study in which the diagnostic accuracy of the vectorcardiogram and electrocardiogram were compared, both methods more accurately predicted the presence of infarction (61.4 and 61.1%, respectively) than the localization of the infarcts (44 and 49%, respectively).\(^15,16\) However, the criteria for localization were not well defined, and most cases were not autopsied.

Gunnar et al. recently correlated vectorcardiographic abnormalities with pathologic examination in 53 patients with myocardial infarction.\(^17\) The VCG predicted the presence of infarction in 92% of the cases studied and localized the site of infarction in 74%. There was, however, a 32% incidence of false-positive interpretation. Using conventional electrocardiography the presence of infarction was predicted in 60% of the hearts, with a 42% incidence of false-positive interpretation.

Thus, although the vector appears to be more sensitive than the standard ECG in predicting the presence of infarction, there are frequent false positives (often related to hypertrophy and patchy fibrosis), and localization cannot be consistently predicted.

**High-Frequency Electrocardiography**

Expanding the frequency response of the electrocardiogram to 1000 Hz reveals notching in portions of the QRS complex that are associated with intrinsic myocardial pathol-ogy.\(^18-20\) This abnormality results from desynchronization or fragmentation of the wave front of ventricular depolarization as it either approaches or recedes from the recording.
electrode. Abnormal records have been obtained with this technique in patients with myocardial infarction and a normal standard 12-lead electrocardiogram. Similar abnormalities have been noted in the presence of bundle-branch block, suggesting a potential application of the method in the diagnosis and localization of infarction in patients with conduction disturbances.

Isopotential Mapping

Isopotential maps display potentials appearing on the body surface at a particular point in time. Multiple surface electrodes record the body-surface potential distribution, which is then displayed as a contour map with all points of the same potential connected by a single closed line. An abnormal pattern has been demonstrated in several patients with myocardial infarction. Though the technique appears ideally suited for determination of the location and extent of infarction, its utility in comparison with other more standard electrocardiographic techniques has yet to be established. At present, the time, expense, and instrumentation necessary for generating these maps have limited the large-scale investigation of this method.

Measurement of Serum Enzymes

Since the demonstration of the clinical value of transaminase determinations by Karmen et al., measurement of serum-enzyme activity has been used to detect the presence of acute myocardial infarction. Although measurements of serum glutamic oxaloacetic transaminase (SGOT), lactic dehydrogenase (LDH), and creatine phosphokinase (CPK) provide no information with regard to localization, they do furnish a rough measure of the extent of myocardial infarction.

Kibe and Nilsson have demonstrated a reasonably good clinical correlation between the maximum serum-enzyme elevation and the extent of infarction determined at postmortem. The mean elevations in transaminase determinations for small, medium, and large infarction were 108, 178, and 435 units, respectively. A similar relationship existed for LDH.

Witeveen and co-workers have recently proposed a more precise means of quantitating infarct size from enzyme determinations. Their method entails measurement of the distribution volume and half-life time in plasma of the enzyme and an estimation of myocardial enzyme content. This technique, which requires further investigation and pathologic correlation, may prove to be of value.

The frequent association of other clinical conditions that in themselves can lead to serum-enzyme elevations has limited the use of these techniques in precisely estimating the extent of infarction. With further use of isoenzyme fractionation this difficulty may be overcome.

Myocardial Imaging (Infarct Scanning)

There have been two approaches to precordial scanning for the detection of myocardial infarction. The radioactive agent employed may be taken up by the normal but not ischemic myocardium; thus, the infarcted region appears on the scan as a defect or "cold spot." Alternatively, the agent may be selectively incorporated into the infarcted region, producing a "hot-spot" scan. With either hot- or cold-spot scanning there must be a high ratio of concentration of activity between ischemic and nonischemic myocardium if there is to be adequate resolution.

Table 2

<table>
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<th>Table 2</th>
<th>Agents Used for Myocardial Imaging</th>
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<tbody>
<tr>
<td>I.</td>
<td>Cold-scan scan:</td>
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<tr>
<td></td>
<td>A. Intravenous administration</td>
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<tr>
<td></td>
<td>Rubidium</td>
</tr>
<tr>
<td></td>
<td>Cesium—¹³¹Ce,¹²⁶Ce,¹³³Ce</td>
</tr>
<tr>
<td></td>
<td>Potassium—¹⁹¹K,¹³¹K</td>
</tr>
<tr>
<td></td>
<td>Iodine oleic acid</td>
</tr>
<tr>
<td></td>
<td>B. Intracoronary administration</td>
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<tr>
<td></td>
<td>Xenon</td>
</tr>
<tr>
<td></td>
<td>Technetium-MAA</td>
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<tr>
<td></td>
<td>Iodine-MAA</td>
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<tr>
<td>II.</td>
<td>Hot-spot scan</td>
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<tr>
<td></td>
<td>Mercury chloromerodrin</td>
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<tr>
<td></td>
<td>Mercury hydroxyfluoresceins</td>
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<td></td>
<td>Tetracycline</td>
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Abbreviation: MAA = macroaggregated albumin.
radionuclide is ideally administered intravenously and should be rapidly cleared from the blood so that background activity is minimized. Several gamma-emitting radionuclides have been used (table 2) and their activity detected with either a rectilinear scanner or Anger scintillation camera.

Agents currently employed in cold-spot scanning include $^{131}$cesium$^{33,35}$ and $^{42}$potassium$^{36}$ and more recently $^{127}$cesium$^{37}$ $^{133}$cesium$^{38}$ and $^{42}$potassium$^{29,40}$ With these agents infarcts have been detected in both man and experimental animal. Postmortem studies have shown a good correlation with antemortem scanning data.$^{38,39}$ Initial studies with $^{43}$potassium indicate that this isotope will yield better resolution than that obtained with other intravenously administered tracers$^{40}$ (fig. 1). The availability of these agents is limited at present since most are produced in a cyclotron and have relatively short half-lives.

Another approach to cold-spot scanning depends upon the utilization of fatty acids by cardiac muscle. Following intravenous $^{131}$iodine oleic acid (RIFA), infarction has been detected and localized in both man and experimental animals.$^{41,42}$ Resolution has not, however, been ideal.

Myocardial infarction has also been detected by cold-spot scanning following the intracoronary injection of gamma-emitting tracers. The use of coronary arteriography early in the course of acute myocardial infarction may allow use of this technique in the future.$^{133}$ Xenon, a diffusible agent classically used to measure nutritive myocardial blood flow,$^{43}$ provides good imaging of the myocardium following intracoronary administration. Pathologically confirmed regions of experimental infarction have been well visualized with this technique.$^{44}$ (Strauss HW, Zaret BL, Pitt B: Unpublished observations.) With an associated computer system, regional disappearance curves can also be determined, thus allowing the detection of ischemic as well as infarcted regions.$^{45-47}$ (Zaret BL, Pitt B, Natarajan TK: Unpublished observations.) Ashburn and co-workers have employed the principle of capillary blockade as used in perfusion lung scanning.$^{48}$ With this technique, labeled macroaggregates of human serum albumin (MAA) are injected into the coronary circulation. Scans are then obtained

Figure 1

$^{131}$Potassium myocardial scan performed during the convalescent stage of acute anterior myocardial infarction. The scan was performed in the anterior view. The extensive region in which there is a decreased uptake of radioactivity (arrow) corresponds to the infarcted anterior left ventricular wall. The patient's electrocardiogram is shown to the right. (Reprinted from J Nucl Med, $^{39}$ by permission.)
in multiple projections with the Anger scintillation camera. Although particulate matter is injected directly into the coronary artery no untoward reactions have been reported, and regions of decreased perfusion have been adequately delineated.

Radioactive substances such as intravenously administered $^{203}$mercury chloromerodrin, $^{131}$iodine tetracycline, and $^{206}$mercury fluorescein derivatives have been used as hot-spot scanning agents.\(^{49-54}\) The mechanism of the binding of these compounds is incompletely understood, but in the case of the mercurials it is due at least in part to interaction with the sulphydryl groups of denatured proteins within the infarcted myocardium.\(^{52}\) Preliminary studies of these compounds in experimental infarction have been promising. The assumption that sufficient tracer can be delivered to the infarcted zone is implicit in the use of these agents. However, in several of the experimental studies the coronary occlusion used to produce infarction was released prior to the administration of the isotope.\(^{52,54}\) Hence, adequate imaging may be in part related to the reinstitution of flow to the infarcted region, which artificially allows adequate entrance of radioactive label into the ischemic area. Whether there is adequate collateral flow in man to allow access of these tracers to infarcted regions remains to be proved. The long half-life of $^{206}$mercury (45 days) and the high radiation dose to the kidney make this agent unsuitable for use in man.\(^{54}\)

These scanning techniques have the potential for providing a more precise quantification and localization of myocardial infarction. By employing computer techniques it should be possible to obtain three-dimensional constructions of the left ventricle. However, there has been no large prospective systematic examination of these techniques in man. The true incidence of false-positive and false-negative determinations has yet to be determined for each agent. The ability of each technique to differentiate infarcted from partially ischemic myocardium and the degree of ischemia that can be detected remain to be determined.

**Localization of Asynergy**

**Left Ventricular Contrast Angiography and Coronary Arteriography**

At present, optimal definition of the dynamic changes in left ventricular dimensions is obtainable with single-plane and preferably biplane left ventricular contrast angiography.\(^3,5\) Asynergy detected by this method has been categorized into four types: (1) akinesia—absence of contraction of a ventricular region; (2) asyneresis—diminished regional contraction; (3) dyskinesia—paradoxic systolic expansion; and (4) asynchronous—disturbed temporal sequence of contraction.\(^3\) Kong et al. have recently employed the coronary arteriogram to evaluate regional ventricular function.\(^{55}\) Branch points of the coronary arteries are used as epicardial markers, and from their movement during the cardiac cycle an assessment of left ventricular segment shortening is made.

The risks associated with left ventricular and coronary artery catheterization and intracavitary injection of large volumes of hypertonic contrast media in acutely ill patients have limited the use of these techniques during the acute phase of myocardial infarction. However, a small number of patients with both uncomplicated myocardial infarction\(^{56}\) and cardiogenic shock\(^{57-59}\) have recently undergone coronary arteriography and left ventriculography without immediate increased morbidity. Nevertheless, at present it seems prudent to evaluate regional function in a less invasive manner and withhold contrast ventriculography and coronary arteriography for patients in whom surgical intervention is considered.

**Chest X-Ray and Fluoroscopy**

Chest X-ray and fluoroscopy by virtue of being readily available and noninvasive are useful screening measures. The chest X-ray, however, is not sufficiently specific for either localizing or quantitating regional abnormality. In a recent review of ventricular aneurysm, Cheng noted the classic aneurysmal bulge on X-ray in only seven of 35 patients.\(^{60}\) The detection of more subtle and often overlooked

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bulges or irregularities of the cardiac silhouette can increase diagnostic accuracy. The most common roentgen abnormality is non-specific cardiac enlargement, which is roughly proportional to the size of the asynergetic region. Nevertheless, normal heart size in the presence of a significant degree of asynergy is well described. Indeed, 20% of the 35 patients with proven ventricular aneurysms reported by Cheng had normal chest X-rays.

Chest fluoroscopy can increase the yield in detection of asynergic regions. However, it is also not sufficiently specific for quantitation of left ventricular asynergy. False-positive interpretations are not infrequent, and indeed false paradoxic motion of the posterior wall has been routinely observed when the patient is viewed in the lateral position.

**Precordial Movement (Apex- and Kinetocardiogram)**

Abnormalities of regional function often result in abnormal systolic precordial pulsations, which can be palpated. The low-frequency vibrations can be recorded with the apex- and kinetocardiograms. The transducer of the apexcardiogram is fixed to the chest wall and therefore moves with it while the transducer of the kinetocardiogram is clamped to a fixed metal bar above the patient and does not move with the chest wall. The abnormal systolic vibrations (most typically a mid-late systolic bulge), although suggestive of regional abnormality, are not entirely specific and can be seen in patients with both hypertrophied and dilated left ventricles. These bulges have been noted in 70% of patients with acute transmural infarction studied with kinetocardiograms and have persisted in 60% of these patients. Bulges have been noted with both anterior and posterior infarction and transiently during the course of angina pectoris. This benign and totally noninvasive procedure thus often suggests distinct regional abnormalities but does not localize or quantify the defect.

**ECG-Gated Cardiac Scintiphotography**

Isotope angiocardiography has found increasing application in the study of patients with cardiovascular disease. This technique involves continuous recording by a scintillation camera of the passage of an intravenous injection of isotope through the right and left heart, lungs, and great vessels. This method permits the identification of individual cardiac chambers and intracardiac shunts and provides a rough estimate of chamber size as well. However, there is not sufficient activity in the left ventricle for a long enough time to allow adequate definition of changes in wall motion from end-diastole to end-systole. ECG-gated cardiac scintiphotography represents a recent modification of this technique, which can be applied to the study of regional ventricular function.

In this technique, technetium-serum albumin is injected intravenously as a bolus. The initial ungated isotope angiocardiogram is recorded in the right anterior oblique position (RAO) and is used for orientation and identification of the mitral and aortic valve planes. Then without changing patient position, at a time when radioactivity is distributed throughout the intravascular space, the ECG-gated portion of the study is performed. An R-wave triggered gating circuit selects 40–60 msec intervals from each cardiac cycle for imaging. Data from the selected portion of each cardiac cycle are summed to accumulate an integrated 300,000-count image of the heart and great vessels in end-systole and end-diastole. Each image requires about 200–300 beats. From superimposed traced outlines of the scintiphotographs, estimates of regional wall movement can be made (fig. 2). In the RAO position, activity in the right ventricle is superimposed upon that within the left ventricle and falls within its margins, thereby not affecting measurement. Data obtained by this method have been compared to similar measurements obtained by single-plane contrast angiography. There has been highly significant correlation with measurements of the shortening of various ventricular axes and the measurement of left ventricular ejection fraction. Akinesis or dyskinesis of the anterior, apical, and inferior regions as well as generalized hypokinesis have been detected (fig. 2).
This technique furnishes an objective measurement of the location and extent of infarction as determined from a quantitative assessment of the asynergic region. The hemodynamic consequences of regional dysfunction as measured by left ventricular ejection fraction can also be obtained safely and repeatably with this technique. A single study with duplicate determinations requires 15-30 min. The Anger scintillation camera, although costly, is an instrument with a variety of diagnostic applications and is now available in most centers. Adaptation of the instrument for use in this study requires only minor modification. Difficulties may be encountered if an adequate triggering signal cannot be obtained and if there is significant irregularity in the cardiac rhythm. The technique appears promising in its ability to provide quantitative anatomic information previously requiring left ventriculography, while avoiding left ventricular catheterization and the injection of hypertonic contrast media. It is currently being employed in a prospective study of patients with acute myocardial infarction. (Zaret BL, Pitt B, Hurley PJ, Ross RS: Unpublished observations.)

**Radarkymography**

Radarkymography is another noninvasive technique that can be applied to the quantitative study of cardiac-wall motion in acutely ill patients. This method employs cinefluoroscopy with tracking of the motion of multiple segments of the heart border. Bedside videotape recordings of the mediastinum are made using a standard image intensifier and a television camera. The change in density at the interface of the cardiac border and the lung is represented as a voltage peak, the locus of which is followed by a tracking.
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Figure 3

Chest roentgenogram and radarkymogram from four areas of the cardiovascular silhouette in a patient with a left ventricular aneurysm. In the tracing from the mid-left ventricle (LV) there is outward movement of the left ventricular border coincident with the onset of ventricular ejection (dyskinesis). (Reprinted from Amer J Cardiol, 75 by permission.)

system similar to that employed by conventional radar. Motion of the tracker is translated into an analogue signal that can be continuously displayed and recorded. On playback of the videotape, that portion of the cardiovascular silhouette to be studied is selected by a manually positioned cursor. By viewing the patient in several positions, various regions of the left ventricle can be tracked (fig. 3).

Kazamias et al. have employed this technique in the study of patients with acute myocardial infarction. Asynergy was recorded in 44 of 56 patients studied. The authors could distinguish three patterns of regional abnormality: dyskinesis, akinesis, and hypokinesis. The most common regional abnormality was dyskinesis. Over a follow-up period ranging from 6 weeks to 18 months, 28 of the surviving patients continued to manifest paradoxical pulsations, four showed hypokinesis, four akinesis, and 18 regained or retained normal pulsation. The size of the asynergic region was shown to decrease during the follow-up of several patients, and the pattern often changed from dyskinesis to akinesis.

The method compares quite favorably with fluoroscopy and correlates well with contrast cineangiography. It is reproducible, safe, and noninvasive. Since the data are stored on videotape, the patient receives no more radiation than from conventional fluoroscopy.

Although the technique appears to be excellent in evaluation of the anterior and lateral left ventricular walls, motion of the inferior and posterior wall cannot be recorded with regularity. This is due to the absence of a clearly visible interface between the left

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ventricular wall and diaphragm. Pulmonary edema also obscures the clear interface and makes adequate tracking difficult.

Echocardiography

Another bedside technique with potential for evaluation of left ventricular performance is echocardiography (ultrasound). Extremely high-frequency inaudible sound waves are directed toward cardiac structures from which they are reflected. The reflected waves (echoes) are detected and presented in graphic form. Accurate estimates of left ventricular volume and ejection fraction have been made and correlated with contrast angiographic measurements.

As yet, this technique has not been applied systematically to the study of acute myocardial infarction. However, Kraunz and Kennedy have used echocardiography to study posterior-wall motion in normal subjects at rest and following exercise. At present only posterior-wall motion can be measured. With the further development of instrumentation it may become possible to quantitate the extent of contraction of multiple ventricular regions and, hence, assess regional ventricular function.

Intraoperative Localization of Infarction

Early direct surgical intervention during acute myocardial infarction requires precise intraoperative localization of viable and non-viable myocardium. The acutely infarcted region appears cyanotic and contracts abnormally. Techniques developed to refine this initial visual assessment include the use of chemical indicators, isotopes, and epicardial electrocardiographic mapping.

Zikria et al. first utilized the intravascular injection of methylene blue to label those ventricular regions with adequate perfusion. However, this method has largely been abandoned because of possible toxicity. Following intravenous injection of fluorescein, the ventricular fluorescence observed under ultraviolet light is proportional to the degree of vascularity. Although with this technique Armellini et al. could distinguish well-perfused from avascular and marginally vascular regions of the left ventricle, the method is limited since fluorescence cannot be observed through greater than 2 mm of epicardial fat.

Using intraoperative epicardial ECG mapping, Kaiser et al. have noted a more precise correlation with pathologic examination than could be obtained with either fluorescein or methylene blue. Ischemic or infarcted regions are detected by the presence of unipolar Q waves, delayed subepicardial bipolar complexes, or epicardial S-T-segment elevation. This technique has proven useful in defining regions of ischemic myocardium at the time of surgery. Mapping has also been used to detect abnormal ventricular regions in patients with normal surface ECG and VCG and has been applied to the study of the effects of various interventions on experimental infarct size in the dog.

Regional myocardial blood flow can be assessed at the time of surgery by examining the rate of disappearance of isotope injected directly into the myocardium (depot injection). From the decay constants derived from injections at multiple sites, a contour map based on regional flow can be constructed. Similarly, intracoronary injection of isotope (such as 133Xenon) with scintillation-camera detection could provide information concerning site and size of infarction.

Functional Significance of the Localization and Extent of Asynergy

Recently, emphasis has been placed upon the hemodynamic characterization of patients with acute myocardial infarction. A summary of available data suggests that patients with uncomplicated myocardial infarction have a normal cardiac output and peripheral vascular resistance and a mild to moderate elevation of left ventricular filling pressure. In patients with mild uncomplicated congestive heart failure the major change is a fall in stroke volume. Cardiac output is maintained by increasing heart rate at a slightly greater left ventricular filling pressure. In those patients with more severe cardiac decompensation and congestive heart failure there is a dramatic fall.
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Systems diagram of the mechanisms by which the location, size, and associated asynergy of acute myocardial infarction affect hemodynamic outcome. See text for details. LV = left ventricle; MVO₂ = myocardial oxygen consumption.

Hemodynamic Determinants of Myocardial Infarction

Infarct Location

Infarct Size

Decreased Total Contractility

Increased Contractility in Noninfarcted Myocardium

Wall Tension

Asynergy

Unchanged or Increased LV Volume

Increased LV End-Diastolic Pressure

Strategic Anatomic Region

Strategic Contractile Region (i.e. Anterior LV Wall)

Increased MVO₂

Increased ischemia

Decreased Stroke Volume or Cardiac Output

LV = left ventricle; MVO₂ = myocardial oxygen consumption.

Figure 4

in cardiac output, increased peripheral vascular resistance, and usually a marked elevation of left ventricular filling pressures. In the presence of cardiogenic shock the changes in output and peripheral resistance are usually more profound although the elevation in left ventricular filling pressure may not be as great. The site and extent of infarction and the degree of associated asynergy play a major role in the production of these hemodynamic abnormalities (fig. 4).

The hemodynamic abnormalities associated with anterior myocardial infarction have recently been found to be more severe than those with inferior infarction. The greater hemodynamic consequence of anterior myocardial infarction may be a result of both its location and its size. Anterior infarctions probably involve a greater muscle mass than those of the inferior wall. The hemodynamic consequences of experimental anterior infarction have been shown to correlate directly with the extent of resultant anterior akinesia. The site of infarction may be of equal importance. Herman et al. and Kong et al. have shown in the normal ventricle that there is greater segmental shortening during systole of the anterior wall as compared to the inferior wall. Thus, anterior-wall contraction should make a more important contribution to left ventricular ejection than do other regions. Infarction of the anterior wall may therefore produce greater hemodynamic compromise than would result from equivalent loss of the inferior wall.

The site of infarction is obviously also of great significance in relation to involvement of important structures such as the mitral valve apparatus, interventricular septum, and conduction system. It is important to know whether the mitral regurgitation associated with myocardial infarction is a result of actual ischemia of the papillary muscles or has arisen as a compensatory response to generalized left ventricular decompensation and dilation.

Harrison first called attention to asynergy resulting from myocardial ischemia. He postulated that with asynergy, or uncoordinated
ventricular contraction, there was wasted cardiac work, that is, work that resulted in alteration of the shape or position of the cardiac chambers without producing efficient contraction. Actively contractile regions would expend energy in stretching either acontractile or poorly contractile ischemic regions.

The exact mechanism of the almost immediate occurrence of asynergy (dyskinesis) following acute infarction is not clear. Katz and Hecht have offered the following explanation in the light of current knowledge of the physiology of contractile proteins. \(^\text{95}\) Within less than a minute after infarction, anaerobic glycolysis becomes the dominant form of metabolism in the ischemic myocardium, and lactic acid production is increased by 50 times its normal rate. Excess hydrogen ion then displaces calcium ion that is bound to the protein troponin. It is thought that troponin, in combination with another protein tropomyosin, serves to inhibit the interaction of actin and myosin. Systolic contraction occurs when calcium interacts with troponin-tropomyosin, releasing the inhibition of actin-myosin interaction. As a result of the localized acidosis and consequent displacement of calcium by hydrogen ion from the tropin molecules, there will be a greater and more persistent inhibition of the actin-myosin interaction. Thus, less tension will be developed in the ischemic acidic region, and pressure generated by the remainder of the intact ventricle will result in paradoxical expansion of the infarcted area early in the course of infarction.

In initial studies of asynergy, attention was focused upon the classic aneurysm or dyskinetic region. In the presence of dyskinesis, systolic contraction results in paradoxical expansion of the aneurysm. Blood enters the aneurysm, which acts as a volume reservoir, just as blood enters the left atrium in mitral regurgitation, thus tending to reduce forward ejection. It has been postulated that the dyskinetic region might also act as a "'slack' elastic element in series with the contractile portions of the remaining left ventricle."\(^\text{4}\) Hence, less contractile-element shortening would be available for efficient ejection of blood from the ventricle. Hood has recently quantitated the degree of increased fiber shortening in noninfarcted myocardium following experimental myocardial infarction and has noted that the larger the asynergic infarcted region, the greater the contractility and hence oxygen consumption of the remaining myocardium.\(^\text{96}\)

From the experimental work in canine myocardial infarction and studies of postinfarction left ventricular function, it appears that dyskinesis with concomitant systolic translocation of blood within the left ventricle occurs most frequently during the acute phase of infarction. Shortly thereafter regional absence of motion or akinesis develops.\(^\text{60, 61, 97, 98}\) Klein et al. have demonstrated in theoretical models that when 20–25% of the left ventricular surface area is akinetic, the stroke volume will fall unless compensatory ventricular dilatation occurs.\(^\text{99}\) Hence, akinesis alone if of sufficient magnitude may result in significant hemodynamic alterations.

The asynergic region has distinct compliance characteristics that will also affect hemodynamic function. In the conscious dog, ventricular compliance is uniformly reduced 3–5 days following myocardial infarction. The compliance of the infarcted akinetic region is altered, while that of adjacent nonischemic myocardium remains normal. Thus, the altered compliance and hemodynamic characteristics of the entire left ventricle in the early stages following myocardial infarction are due entirely to regional abnormalities.\(^\text{98}\) This stiffening of the ventricle is probably a favorable occurrence resulting in increased stroke volume and improved left ventricular function.\(^\text{100}\) That the diminished compliance associated with postinfarction akinesia may not always be favorable is demonstrated in the cardiogenic-shock model of Regan et al.\(^\text{101}\) These workers noted that animals with large transmural scars from previous infarction and associated elevated left ventricular end-diastolic pressure and low ventricular volumes (presumably due to marked ventricular stiffness) tended to develop shock in response to further acute ischemia more readily than those.
animals without transmural scar and an increased compliance.

It can thus be seen that size, asynergy, and location of acute myocardial infarction are major factors in determining hemodynamic outcome (fig. 4). The larger the infarction, the greater the decrease in total contractility and the greater the contractility required of noninfarcted ventricular regions. This results in greater myocardial oxygen consumption, which can secondarily increase ischemia in regions adjacent to the infarction and further increase infarction size. Recent experimental studies suggest that the pattern and extent of asynergy will determine the compliance characteristics of the infarcted ventricle.95,100 In the less compliant stiffer ventricles, primarily exhibiting akinesis or hypokinesis, ventricular volume remains relatively unchanged while ventricular filling pressure rises. On the other hand, in the presence of extensive dyskinesis the ventricle may be more compliant and volume may increase, leading to greater wall tension, which would further increase myocardial oxygen consumption. Infarction of strategic anatomic or contractile regions may result in greater hemodynamic compromise than would infarction of a comparable muscle mass from other regions.

In the past decade we have learned much about the hemodynamics of myocardial infarction. Through the use of the techniques described in this report, further insight into regional ventricular abnormalities could be obtained. This will furnish better answers to the questions posed at the beginning of the paper: where is the infarct, how big is it, and what is its functional significance? With such information a more rational approach to therapy and prognosis in myocardial infarction could be developed.

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