MODERN APPROACH TO THE PATIENT WITH ACUTE MYOCARDIAL INFARCTION

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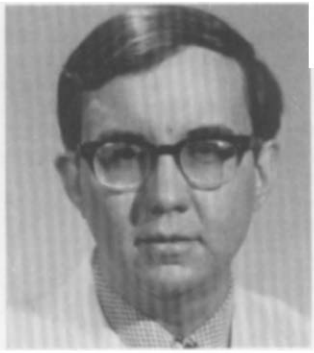
carries out much of his clinical activity in the intensive care unit and diagnostic cardiac catheterization laboratory at the University of Alabama in Birmingham, where he currently serves as Assistant Professor of Medicine, Division of Cardiology. The investigation of unstable ischemic heart disease with emphasis on the pathogenesis of electrophysiologic and hemodynamic disturbances and the response to therapeutic interventions is of special interest to Dr. Mantle. He is also interested in the development of special techniques and computer systems for the quantitative analysis of continuous physiologic data.



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HISTORICAL CHARACTERISTICS

CHEST DISCOMFORT often is the initial feature of acute myocardial infarction that disturbs the patient sufficiently to seek medical attention. Although numerous terms have been used to

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describe the sensation of myocardial infarction, the pain may be variably located in the chest, with radiation to the abdomen, arms, back or neck. A number of atypical aspects of the pain that influence the severity, location and radiation can develop. Furthermore, the physician must be aware that approximately 25% of patients may experience asymptomatic myocardial infarction. These patients may dismiss the chest discomfort merely as indigestion or chest wall discomfort. Although the pain of myocardial infarction may be located anywhere from the abdomen to the neck, there are additional characteristics of the discomfort that should be sought during the patient interview. Aspects of the pain that cause the patient to visit a medical facility have been the elements of fear and anxiety that result from stimulation of the adrenergic system and release of catecholamines. Stimulation of the adrenergic nervous system can generate a state of anxiety and apprehension that often expresses itself clinically as fright or fear. Sometimes the patient who has experienced previous ischemic pain under stable circumstances may have difficulty in explaining the reason for seeking medical attention. Acute left ventricular failure can be another manner of presentation for myocardial infarction. Almost any pre-existing condition that has produced pain or tenderness in or near the thorax may reflect the ischemic pain of myocardial necrosis.

► W. PROCTOR HARVEY: Personally observed or known to me have been a number of patients who have had atypical location of coronary ischemic pain. To cite a few examples:

Recalled is a cardiologist who went to his dentist because of pain localized in a tooth. Much to his chagrin, as well as misfortune, his dentist made the correct diagnosis of acute myocardial infarction. (Patients may complain of jaw pain and not be aware of a substernal component.)

Recently seen was a man in his 70s whose pain was only in his right shoulder. It was mainly nocturnal and was relieved with nitroglycerin.

A surgeon had discomfort in the right upper quadrant of his abdomen, making him feel certain that it was gallbladder disease. He had a documented acute myocardial infarction. It was also of interest that during his hospitalization he had several brief episodes of discomfort (lasting several minutes). Each was in the right upper quadrant, relieved with nitroglycerin, and no substernal component was present.

Another physician with an acute myocardial infarction had his pain limited to his back, "between the shoulder blades."

One can cite many such examples of atypical location of coronary pain. Fortunately, the majority have it in the typical location and with the characteristic radiation.

One that I had not heard of before was the pain of the father-in-law of one of our staff physicians. He complained of pain in each thumb. He had no previous history of heart disease. Naturally, the thumb pain was, at first, not considered coronary ischemic pain. However, he had an acute myocardial infarction and subsequently died of it.

Additional symptoms accompanying the pain include nausea, diaphoresis, lightheadedness and palpitations. The nausea is attributed to vagal stimulation, which may be more prominent in inferior myocardial infarctions. The diaphoresis is another clinical manifestation of stimulation of the adrenergic nervous system. Diaphoresis generally is uncommon with the chest pain of stable angina pectoris. Lightheadedness may be due to apprehension, anxiety or hyperventilation. Serious cardiac arrhythmias may produce transient cerebral ischemia. Finally, it should be emphasized that a most important consideration is that the patient has sought medical attention. Although the severity of the pain may not necessarily have prompted the patient to seek medical care, the associated anxiety and alarm often are principal factors.

In addition to obtaining a detailed description of the presenting discomfort and other attendant features of ischemic pain, the physician should survey for potential risk factors in the patient. Risk factors are considered to be hypertension, cigarette smoking, abnormalities in plasma lipids, a familial history of coronary artery disease and associated diseases, such as diabetes mellitus, which may involve the coronary arteries. An analysis of the risk factors in patients under 45 years of age with an acute myocardial infarction revealed that cigarette smoking was the most prevalent risk factor present in 90% of the patients[1]. A family history of coronary artery disease was present in 57% of the patients. Hypertension was found in 40% of these patients and diabetes and obesity were observed in less than 20%. Patients may be aware of these risk factors from previous medical examinations and laboratory studies.

PHYSICAL EXAMINATION

In acute myocardial infarction, the initial physical examination can be altered by the severity of the chest pain and associated anxiety. Therefore, it is important to document whether the physical examination was done before or after the relief from chest pain by administration of narcotics. In patients with severe ischemic pain prior to the administration of analgesics, the vital signs often reveal tachycardia, tachypnea and elevation of the blood pressure. The skin, eyelids and cornea should be inspected carefully for manifestations of lipid disorders. The fundi should be examined for evidence of chronic hypertension and diabetes. Dilatation of the retinal veins has been observed in acute infarction without diabetes. Auscultation over the neck may reveal murmurs of peripheral vascular disease involving the carotid arteries. Although venous distention in the neck has long been considered a manifestation of chronic left heart failure, this finding indicates abnormal diastolic filling of the right

ventricle. In patients with acute myocardial infarction, the neck veins are not abnormally distended unless the infarction has involved the ventricular septum and right ventricle. An acute myocardial infarction imposed on chronic heart failure can further aggravate the findings of right and left ventricular failure. Careful examination of the lungs for the detection of pulmonary rales is an important part of the physical examination. Pulmonary auscultation is useful in the differential diagnosis of mechanisms for the production of the chest pain. One must be aware that pulmonary rales are common in the early stages of acute infarction and may be produced by several mechanisms. The high incidence of cigarette smoking is associated with chronic bronchitis, which frequently causes basilar rales. If the patient has been in the recumbent position for a prolonged period, decreased diaphragmatic motion and atelectasis of the lower lung fields can produce rales. Obesity may further contribute to reduced diaphragmatic excursions in the recumbent position. If the patient has received morphine for the relief from pain, respirations may be depressed further in the recumbent position. Persistent basilar rales can be due to left ventricular failure. When the patient is examined initially, the recognition of these various mechanisms is not always immediately apparent.

Examination of the heart in the early phase of acute infarction not only may reveal abnormalities but also can provide a basis of reference for future physical findings that may develop during the early infarction course. If cardiomegaly is detectable on the physical examination, this is evidence for chronic heart disease. A systolic bulge, which may appear in the course of acute infarction during the early hours, may not necessarily be present on the initial examination. Furthermore, this ischemic bulge can be transient the first 24–48 hours after the infarction.

► W. PROCTOR HARVEY: A systolic outward impulse ("bulge") often is palpated between the lower left sternal border and the cardiac apex. With or without an acute myocardial infarction, this often is an abnormal finding and may be a clue to ventricular aneurysm.

Auscultation often reveals an atrial gallop sound. However, this sound is common in chronic coronary artery disease and hypertension and therefore does not provide additional information in assessing the extent of impaired ventricular performance. The ventricular gallop sound as shown in Figure 1 has demonstrated a significant correlation with abnormal elevations of the left ventricular filling pressure as recorded by the Swan-Ganz catheter.[2] The ventricular or protodiastolic gallop sound has long been recognized as a manifestation of left ventricular failure. In patients with acute myocardial infarction, an audible ventricular gallop sound is associated with an abnormally ele-

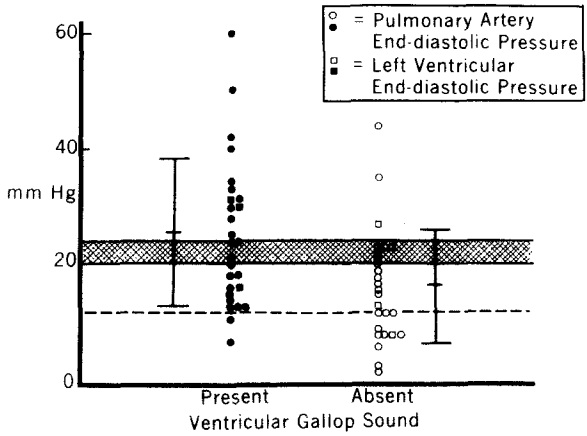


Fig 1.—The relationship between the left ventricular filling pressure and the presence or absence of a ventricular gallop sound is shown for patients with acute infarction. An audible ventricular gallop sound was associated with a left ventricular filling pressure above 12 mm Hg *(dashed line)* in 25 of 27 patients. The cross-hatched area represents the optimal filling pressure of the infarcted left ventricle, 20–24 mm Hg. (Reprinted, with permission, from Riley, C.P., *et al.*[2])

vated left ventricular filling pressure in more than 90% of the patients.

► W. PROCTOR HARVEY: I find atrial (S_4) gallops in most patients with acute myocardial infarction. The ventricular (S_3) gallop, as outlined by the authors, is also detected frequently, although less commonly than the atrial gallop. A useful clinical observation is that the ventricular gallop, persisting for weeks or months after the initial stage of acute myocardial infarction, indicates myocardial damage and carries a poorer prognosis than that for another patient, similar in all respects except not having the ventricular gallop. In the patient with the persistent gallop, digitalization may be beneficial, as well as sodium restriction and intermittent diuretic therapy.

Systolic and diastolic murmurs may be pre-existing unless the patient has developed complications of the acute infarction, such as rupture of the ventricular septum or papillary muscle. A systolic murmur can be detected as a manifestation of papillary muscle dysfunction and involvement of the posterior wall. When produced by abnormal papillary or wall motion, such systolic murmurs may be early, mid or late in the ejection phase. Patients whose course is complicated by ruptured papillary muscle or ventricular septum develop harsh holosystolic murmurs that frequently are accompanied by palpable vibrations.[3] In patients with the mechanical problems of septal or papillary muscle rupture, the location and radiation of the murmur are not as reliable in recognizing the underlying mechanism as in chronic disorders

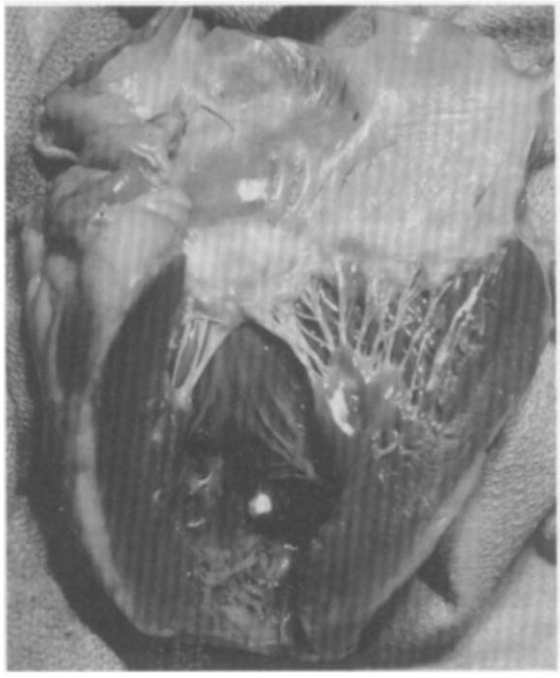
of mitral regurgitation and congenital ventricular septal defects. The harsh systolic murmur in the patient with acute myocardial infarction, whether located at the apex or along the left sternal border, may be produced by rupture of either the septum or the papillary muscle.

► ANTONIO C. DE LEON, JR.: The location of maximal systolic thrill present on precordial palpation may help to distinguish rupture of the interventricular septum (left sternal border) from that of papillary muscle rupture (left ventricular apex).

► W. PROCTOR HARVEY: Drs. William Roberts, James Ronan and I have made observations in a number of our patients with this problem (see Fig. A). In our experience, if one carefully searches for a palpable thrill in a patient with an acute myocardial infarction who has developed a loud systolic murmur, the thrill usually is found and can serve as a good clue as to the differentiation between ventricular septal rupture and papillary muscle rupture.

In order to best detect a palpable thrill, make sure which areas of your hands are the most "sensitive." One can stroke one's palm and fingers with the fingertips of the opposite hand. By doing so, it usually is readily appreciated that the palmar surface at the junction of the fingers is more sensitive than the fingers or the tips of the fingers. In fact, the left hand may be more sensitive than the right (or vice versa).

Fig A. – Ventricular septal perforation complicating acute myocardial infarction.



In searching for a palpable thrill when the question of septal perforation arises, the palpating hand is placed *lightly* over the precordial, carefully looking for the exact position of the systolic thrill; if it is felt along the mid or lower left sternal border, rather than at the apex, septal rupture is thereby suggested immediately. The systolic murmur heard at this spot generally is loud (Grade 4 or above, grading 1 – 6). The murmur is characteristically holosystolic, crescendo-decrescendo; wide splitting of the second heart sound is also frequent. Most patients have loud murmurs that subsequently may decrease with progression of heart failure. Death often occurs in several days to several weeks. If the patient can be "tided over" for several weeks or longer, it is possible to obtain a good surgical repair. Early operation often is difficult because of the necrotic tissue present, which cannot hold sutures. Sometimes, however, it is successful.

Septal perforation presents with a spectrum of findings, and not all have the rapid, fulminating downhill course associated with congestive heart failure. In fact, we have been following a patient for more than 3 years who has had a documented septal perforation (cardiac catheterization). She remains in chronic cardiac decompensation. She refuses operation, which has been recommended. Obviously, her septal defect is not of the larger size.

Recently, in a coronary care unit, I saw a man 9 days after his acute myocardial infarction. He had a palpable systolic thrill at the 4th left sternal border. His Grade 4 systolic murmur was crescendo-decrescendo and holosystolic. There was wider splitting of the second sound that did not become single with expiration. Heart failure had been persistent. Pulsus alternans, alternation of the second sound and alternation of the systolic murmur were present. A ventricular diastolic gallop was easily heard. Operation was scheduled for the following day. Recognition and treatment of this complication of acute myocardial infarction can be lifesaving.

The papillary muscle rupture is less frequent as compared with ventricular septal rupture. The palpable thrill and maximal intensity of the murmur more likely are present between the lower left sternal border and apex or at the apex.

Although at times the differentiation between rupture of the septum and rupture of the papillary muscle is difficult without cardiac catheterization, we believe that in the majority it can be determined from the clinical evaluation.

The remainder of the physical examination in the patient with acute myocardial infarction should include particular attention to peripheral pulses, evidence of peripheral edema, cyanosis and neurologic status. In addition to the physical findings associated with acute myocardial infarction, one must consider other pathologic mechanisms, such as pulmonary emboli, dissection of the aorta, pericarditis, costochondritis and other thoracic and gastrointestinal disorders. In patients with pulmonary embolism, the pulmonary rales, changes in breath sounds and friction rub may not be present on the initial examination. Often these patients have been confined to bed for prolonged periods

and may present evidence of peripheral edema and chronic cardiopulmonary disease. The patient with a dissecting aneurysm often has pre-existing hypertension. Detectable inequalities in the pulses of the extremities and the development of an aortic regurgitation murmur can further support this clinical suspicion. However, it is important to appreciate that abnormalities in pulses may not be apparent on the first examination. The dissection process may continue over periods of hours, with eventual involvement of the aortic arch and abdominal branches. Patients with pericarditis may not exhibit the friction rub in the early phase. Pericardial friction rubs in the course of myocardial infarction generally develop between the second and fifth days. Costochondritis results in exquisite tenderness over the chondral junctions of the sternum.

► W. PROCTOR HARVEY: A good clinical "cardiac pearl" that has stood the test of time: If a patient with diastolic hypertension develops an aortic diastolic murmur, always suspect pathology in the aortic root, such as aneurysm or dissection. Even more important and diagnostic, if the aortic diastolic murmur is "right-sided," being heard better along the 3d or 4th *right* sternal border as compared with the *left* 3d or 4th sternal border, this adds another very significant clinical finding. We then have a formula: Diastolic hypertension + aortic diastolic murmur + "right-sided" aortic diastolic murmur = aneurysm and/or dissection of the first portion of the ascending aorta.

LABORATORY CONFIRMATION

Laboratory techniques that provide clinical evidence of myocardial necrosis include the electrocardiogram, cardiac enzymes and, more recently, radionuclide scanning.

The electrocardiogram in the early phase of acute myocardial infarction may reveal only subtle ST and T wave changes. The spectrum of infarction-induced electrocardiographic abnormalities consists of characteristic ST segment elevation, depression of the T wave, abnormal Q wave development and conduction disturbances. These four abnormalities constitute the generally recognized electrophysiologic changes observed in patients with acute myocardial infarction. One must appreciate that in the early phases of myocardial necrosis, Q waves may not be present. Therefore, the physician often has to base his initial suspicion of an acute infarction on the ST and T wave changes in the ECG tracing. In young adults with myocardial infarction, the ST segment elevation cannot be invariably separated from that seen with early repolarization. The electrocardiographic changes of early repolarization produce ST segment elevations in inferior leads without T wave abnormalities. If the patient is well known to the physician or has had previous electrocardiographic abnor-

malities, access to records permits recognition of physiologic variations. If the patient is being seen for the first time with severe chest pain, ST segment changes have to be suspected as due to underlying myocardial necrosis. Conduction disturbances, particularly left bundle-branch block, may obscure and prevent the recognition of underlying myocardial infarction. Initial abnormalities in the QRS complex accompany left bundle-branch block, and the secondary ST and T wave changes in this conduction disturbance further complicate the diagnosis of myocardial necrosis. However, in patients who develop right bundle-branch block, the initial forces of the QRS complex are preserved, and therefore development of Q waves can be attributed to underlying myocardial infarction. Left ventricular hypertrophy often exhibits characteristic ST and T wave changes of a left ventricular strain pattern on the ECG. In patients with hypertension, left ventricular hypertrophy can render the recognition of anteroseptal infarction difficult, since the ST and T wave abnormalities of left ventricular strain may be upright in the early precordial leads. Finally, serial changes in the electrocardiogram of acute infarction can confirm the diagnosis, which may not be apparent on the initial tracing. These electrocardiographic changes can develop in minutes or hours during the acute phase of infarction. Nevertheless, the initial ECG tracing cannot conclusively exclude myocardial infarction even if abnormalities similar to normal variations are present.

Cardiac enzymes have been measured for approximately 20 years to indicate release from damaged myocardium. Prior to the development of these enzymatic techniques, other indices for generalized inflammation were used, such as the sedimentation rate, white count and other nonspecific acute phase reactants. The development of clinical techniques for the measurement of SGOT was a major contribution in advancing the specificity of myocardial cell necrosis.[4] Subsequently, the SGOT was followed by the development of LDH enzymes and more recently the CPK enzymes. Isoenzymes for several of these substances have been refined and currently the isoenzyme CPK-MB is considered the most specific for myocardial necrosis.[5] Characteristic patterns for enzymatic release for each of these substances have been established. The SGOT generally reaches a peak value within the first 24 hours after necrosis. The LDH requires slightly longer in achieving its highest value. The CPK-MB appears in plasma from 4 to 10 hours after the acute episode of ischemic damage and reaches a peak value at from 12 to 18 hours. However, the physician must be aware that the SGOT, LDH and CPK can be released from extracardiac sources. The CPK-MB isoenzyme remains the most specific for myocardial necrosis and is not released in significant quantities from other organs.

Another noninvasive method for detecting myocardial necro-

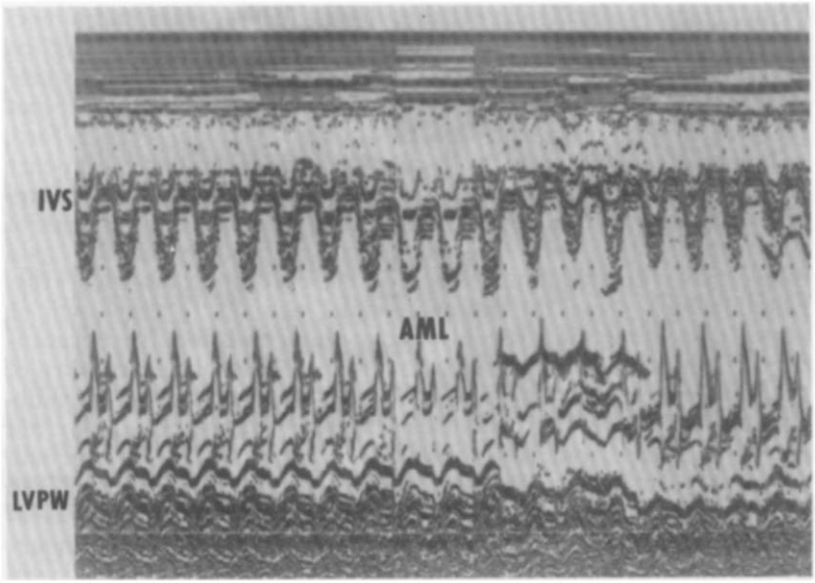


Fig B.—Note in this illustration that there is relative hypokinesis of the left ventricular posterior wall *(LVPW)* and compensatory exaggerated septal excursion *(IVS)* in a patient with a true posterior acute myocardial infarction. *AML* = anterior mitral leaflet.

sis has evolved from the observation that certain radionuclides normally absorbed by bone are also localized in damaged heart muscle. ^{99m}Technetium pyrophosphate is an agent that is concentrated in the area of myocardial necrosis, and initial studies suggest that this is related to intercellular calcium sequestration.[6] However, the pyrophosphate scans do not become positive from the area of necrotic tissue until 12–24 hours after the acute event.[7] In the early stages of the infarction process, myocardial scans can be negative. Furthermore, in 20–30% of patients with unstable angina pectoris, the pyrophosphate scan may reveal areas of positive uptake. The cellular abnormalities that result in the accumulation of the technetium pyrophosphate in necrotic or severely ischemic tissue have not been fully delineated.

► ANTONIO C. DE LEON, JR.: Echocardiographic demonstration of decreased myocardial contractility has also enabled recognition of myocardial necrosis in some instances (see Fig. B).

CHEST X-RAY

The portable standard upright chest film generally is obtained on the patient admitted to the hospital from the emergency room with a diagnosis of suspected acute myocardial infarction.

Primary areas of consideration involve the heart size and abnormalities in vascularity of the lungs. Cardiac enlargement as determined by the cardiothoracic ratio generally indicates preexisting heart disease. Acute myocardial infarction does not produce immediate dilatation of the left ventricle. Therefore, pulmonary congestion or pulmonary edema with a normal heart size often is radiographic evidence of a recent myocardial infarction. A high-quality chest film is desirable in the early stages of the infarction not only for evidence of heart failure but also as a reference for subsequent changes in the cardiopulmonary status. Furthermore, other diagnoses such as pulmonary embolism or aortic dissection may reveal subtle abnormalities on the standard PA chest film. Correlations between the filling pressure of the left ventricle obtained by the Swan-Ganz catheter and radiographic evidence for pulmonary venous congestion have not shown a predictable relationship.[8, 9] In one study, 24% of the patients with acute infarction had abnormal elevations of the left ventricular filling pressure without radiographic evidence of pulmonary venous congestion. Therefore, the evaluation of heart size, pulmonary vascularity, other mechanisms for the severe chest pain and finally a reference for the patient's hospital course are reasons for obtaining a chest roentgenogram on admission to the hospital.

ESTIMATION OF MYOCARDIAL INFARCTION SIZE

Extensive investigations of the clinical and laboratory features of acute myocardial infarction have produced methods for estimating the extent of the infarcted myocardium. Analysis of serial cardiac enzymes, electrocardiographic recordings from multiple precordial sites and radionuclide scans are techniques currently utilized to estimate the size of the myocardial infarction.[10-12]

Sobel *et al.*[10] demonstrated that analysis of the serial CPK enzyme in animals provided an estimate of the amount of myocardium that released the enzyme into the systemic circulation. This technique has been refined further and estimation is based on serial determinations of the CPK-MB isoenzymes as shown in Figure 2. Serial measurements of the CPK-MB isoenzyme are obtained at frequent intervals and the values in the illustration are calculated to provide an estimate of the total release of enzyme. The serial measurements of CPK-MB can be analyzed mathematically to estimate the amount of left ventricular myocardium that contained the enzyme. Although this concept for estimating the size of the myocardial infarction has been challenged, clinical studies have suggested that enzymatic analysis can provide an estimate of the area of myocardial necrosis in the left ventricle.[13]

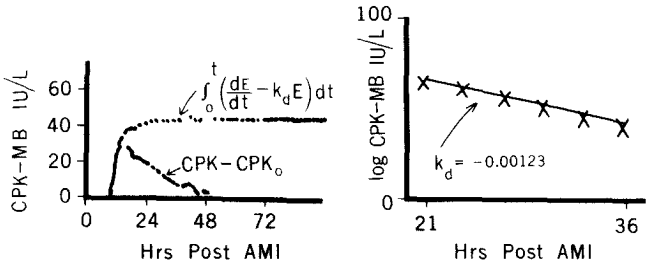


Fig 2.—Estimation of myocardial infarction size. Serial determination of the CPK-MB isoenzyme can be analyzed mathematically as illustrated to estimate the amount of myocardium that released the enzyme.

Multiple precordial electrocardiographic recordings over the chest have been performed in patients with acute infarction in an effort to quantitate the electrical abnormalities. A small blanket consisting of 35 leads was developed by Maroko and associates[11] and this device could be placed over the precordium in a reproducible manner so that recording could be measured and quantitated on a day-to-day basis. Epicardial mapping studies in animals correlated with the histologic and enzymatic changes in the infarcted myocardium. One clinical limitation of this technique is the rapid resolution of ST segment changes during the early phase of acute infarction. Furthermore, the technique is more sensitive in patients with anterior infarctions, since the electrodes are parallel to the injury current whereas inferior infarctions do not project the ST segment abnormalities to the precordial leads. Multiple precordial recordings have also measured QRS changes during the acute phase of infarction to quantitate the loss of electrical activity.

Radionuclide scanning in patients with acute myocardial infarction has provided images that can be quantitated. The area of uptake of the technetium pyrophosphate in the infarcted myocardium can be measured directly.[12] Although the gamma camera can provide myocardial scans in different positions, the anterior projection presents the most readily recorded positive scans. Improved technology has permitted inferior and lateral wall infarcts to be detected with a greater accuracy by the technique. Although radionuclide scans can provide quantitative information on the area of the myocardial necrosis and serial scans can be obtained, this technique requires additional correlation and confirmation by enzymatic and angiographic electrophysiologic techniques for estimating myocardial damage.

Another clinically available approach for estimating the size of the residual scar from myocardial infarction involves cardiac catheterization and quantitative biplane angiocardiography.[14] Although this method cannot be performed during the acute phase of the infarction, information still can be obtained 3 or 4

weeks after the acute event. The angiographic method involves superimposition of systolic and diastolic ventricular silhouettes from the AP and lateral positions with a common reference system. In this manner, the areas of abnormal ventricular wall motion can be identified and quantitated in the patient with a single previous infarction. The area of akinesia can be assumed to represent the residual scar from the healed myocardial infarction. This technique provides another clinical method for obtaining an estimate of the residual myocardial damage resulting from the myocardial infarction and can be compared to the enzymatic, electrophysiologic and radionuclide techniques for estimating infarction size. Since each of these techniques measures a different specific abnormality of the damaged myocardium, one must anticipate some degree of variability between the enzymatic, electrical, isotopic and mechanical measurements.

MONITORING DURING THE ACUTE PHASE OF MYOCARDIAL INFARCTION

Continuous monitoring of the electrocardiogram was an early contribution of the coronary care unit for the specialized care of patients with acute myocardial infarction. Clinical experience revealed a much higher incidence of rhythm disturbances in the early hours after infarction than estimated previously. Prior to the availability of electrocardiographic monitoring, the incidence of ectopic activity in patients with acute infarction was reported at 15%. However, with continuous ECG monitoring, almost 80% of patients with acute infarction were observed to have significant disturbances in the heart rhythm. Not only did continuous ECG monitoring provide increased awareness of ventricular irritability but it also permitted immediate medical attention to the treatment of these arrhythmias. The recognition and treatment of cardiac arrhythmias have resulted in a significant reduction of mortality in patients with acute myocardial infarction. Recent modifications in the ECG monitoring system include not only continuous signal analysis from a central station but also the application of computer technology to analyze beat-to-beat variations in heart rhythm.[15] Computer programs continue to undergo refinement and should provide continuous analysis of the variations in impulse formation in patients with acute infarction.

Echocardiography can generate a noninvasive signal that can be obtained frequently to assess left ventricular function during the course of acute myocardial infarction.[16] Although the necessary probes and crystals have not been developed for continuous monitoring of the echocardiogram, current instrumentation is portable and can be applied to the patient in the early phase of acute infarction. Figure 3 shows an echocardiogram that dis-

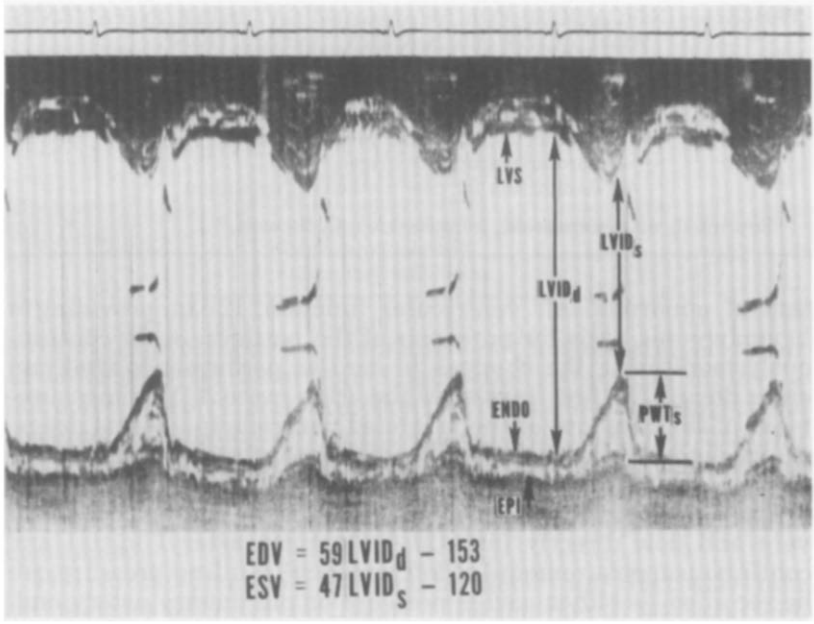


Fig 3.—Diastolic and systolic dimensions from the echocardiogram can be used to calculate end-diastolic volume *(EDV)*, end-systolic volume *(ESV)* and ejection fraction. *LVS* = left ventricular septum. $LVID_d$ = left ventricular internal dimension in diastole; $LVID_s$ = left ventricular internal dimension in systole; *ENDO* = endocardium; *EPI* = epicardium and PWT_s = posterior wall thickness in systole (Reprinted, with permission, from Rackley, C. E., *et al.*[16])

plays left ventricular chamber dimensions, septal and posterior wall motion and the posterior pericardial space. These dimensions can be quantitated to provide estimates of end-diastolic and systolic volumes and ejection fraction.[17] Wall motion abnormalities can be quantitated and utilized to recognize the area of the infarcted muscle and the motion of the noninfarcted myocardium.[18] Serial echocardiograms can be useful in the detection of pericardial perfusion, recognition of abnormalities that produce sudden systolic murmurs and the differential diagnosis considered in the patient with severe chest pain, such as dissection of the aorta.

HEMODYNAMIC MONITORING

In addition to ECG monitoring in the coronary care unit, one of the most significant developments in recent years has been the Swan-Ganz catheter and continuous hemodynamic monitoring.[19] The indications for insertion of the Swan-Ganz catheter in a patient with acute infarction are delineated in Table 1. The information from this catheter can be useful (1) in assessing the ex-

TABLE 1.—INDICATIONS FOR SWAN-GANZ CATHETER IN PATIENTS WITH ACUTE MYOCARDIAL INFARCTION*

1. Assessment of left ventricular function
2. Patient prognosis
3. Monitoring of cardiac performance
4. Cardiac response to drugs
5. Parameters for new methods of treatment

*Reprinted, with permission, from Rackley, C. E., *et al.*[20]

tent of abnormal left ventricular function; (2) in providing a hemodynamic basis for prognosis of the patient; (3) for continuously monitoring the changes in cardiac performance that can occur during the first days after the acute event; (4) for measurement of the response of the infarcted ventricle to various drugs; (5) for determining the effect of new types of treatment in acute myocardial infarction.[20]

The Swan-Ganz catheter can be inserted through a peripheral vein and flow directly into the pulmonary artery. Initial and continuous measurements of left ventricular filling pressure can be recorded as either wedge pressure or pulmonary artery end-diastolic pressure. The cardiac output frequently can be measured using the thermodilution technique. In Figure 4 is shown

Fig 4.—A Swan-Ganz catheter is superimposed on a chest film to illustrate the position of the catheter tip in the pulmonary artery. (Reprinted, with permission, from Mantle, J. A., *et al.*[15])

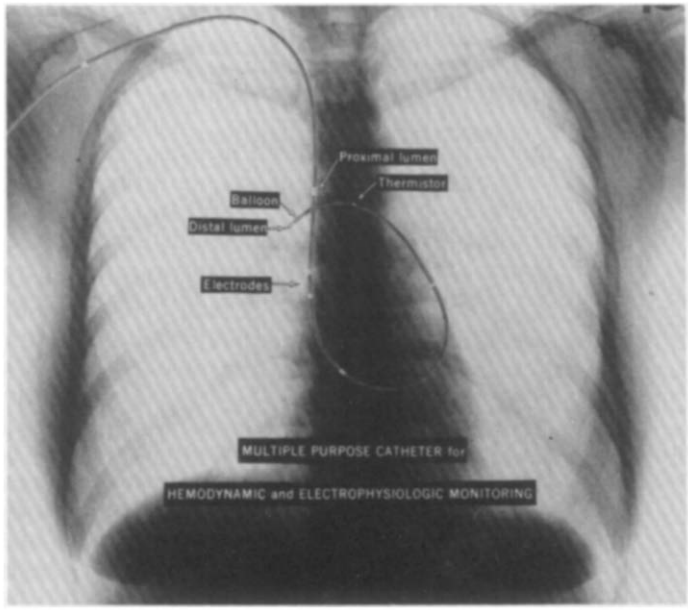


TABLE 2.—CARDIAC DIAGNOSES WITH THE SWAN-GANZ CATHETER

1. Cardiogenic shock
2. Hypovolemic shock
3. Right ventricular infarction
4. Ruptured ventricular septum
5. Mitral regurgitation
6. Low cardiac output syndrome
7. Cardiac tamponade
8. Pulmonary embolism

a Swan-Ganz catheter superimposed on the standard chest film. In addition to the distal tip of the catheter, which can record the pulmonary artery pressure, the thermistor is recessed several centimeters proximal to the tip. A modified catheter with a bipolar atrial electrode at the level of the right atrium can record the atrial electrogram and heart rate. Using an external impulse source, the sinus node can be paced through these atrial electrodes.

The cardiac diagnoses that can be made from the Swan-Ganz catheter are delineated in Table 2. In addition to assessing and recognizing left ventricular failure, a left-to-right shunt due to rupture of the ventricular septum can be recognized. Pericardial tamponade can be suspected from comparison of the wedge PAEDP and right atrial pressure. The presence of cardiogenic shock and particularly hypovolemic cardiogenic shock can be recognized from measurements of left ventricular filling pressure and cardiac index. The Swan-Ganz catheter can provide physiologic information on the circulatory state of the left ventricle that may not be detected accurately from bedside examination.

Application of the Swan-Ganz catheter in the coronary care unit in recent years has increased the recognition of hemodynamic complications. The incidence of cardiac arrhythmias during right heart catheterization has been greatly reduced with the Swan-Ganz catheter, since the balloon tip usually floats through the right side of the heart from the right atrium into the pulmonary artery. Clinical complications reported with the Swan-Ganz catheter are shown in Table 3. Optimal positioning

TABLE 3.—CLINICAL COMPLICATIONS WITH THE SWAN-GANZ CATHETER

1. Arrhythmias
2. Balloon rupture
3. Knotting
4. Pulmonary infarction
5. Pulmonary artery rupture
6. Infection

of the catheter in the pulmonary artery under fluoroscopy and monitoring the pulmonary artery end-diastolic pressure rather than the pulmonary wedge pressure have greatly reduced the incidence of pulmonary infarction due to catheter wedging. Insertion of the catheter under sterile techniques and daily dressing of the cutdown site will decrease the potential for infection.

Not only can the initial measurement of the left ventricular filling pressure and the cardiac index provide a quantitative estimate of cardiac function but also the response to a mild stress, such as expansion of the blood volume with low molecular weight dextran, can provide information on the reserve capacity of the infarcted left ventricle.[21] Infusion of low molecular weight dextran into the pulmonary artery can produce an elevation in the filling pressure that is associated with an increase in the cardiac index as shown in Figure 5. These changes in cardiac function are the result of an increase in the preload on the left ventricle. In Figure 6, the infusion of low molecular weight dextran and changes in the pulmonary artery end-diastolic pressure and cardiac index are recorded on day 1 of the acute infarction and repeated on day 3. Such measurements not only reveal the reserve capacity of the ventricle but also document the spontaneous improvement of ventricular function as manifested by a decline in the PAEDP and the concomitant increase in cardiac index during the first 3 days after infarction.

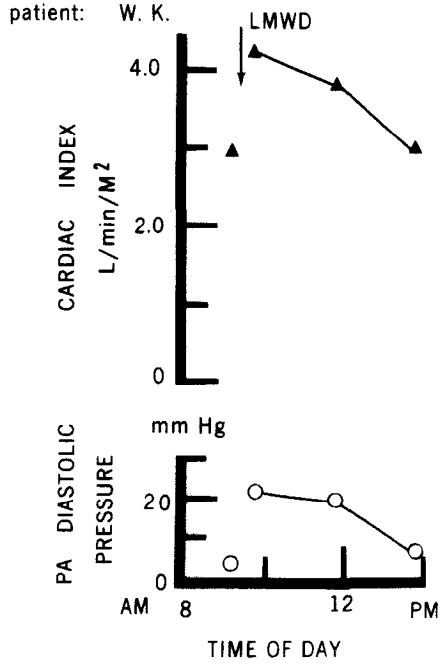


Fig 5.—Persistence of LMWD-induced changes. The infusion of low molecular weight dextran (LMWD) in a patient with acute infarction elevated the pulmonary diastolic pressure and increased the cardiac index. (Reprinted, with permission, from Rackley, C. E., and Russell, R. O., Jr.[22])

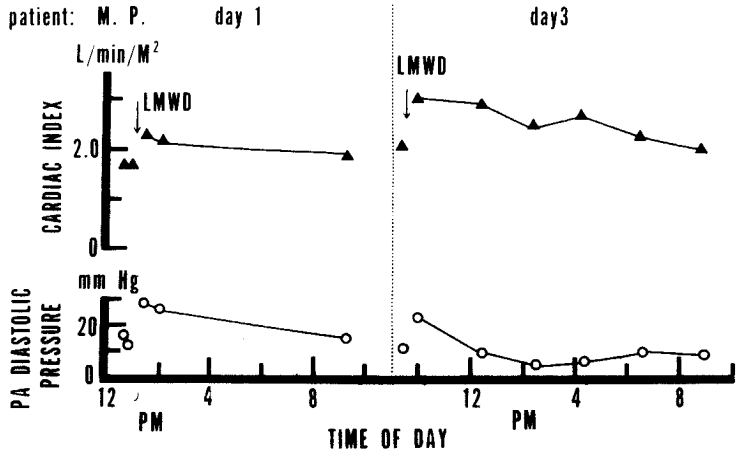


Fig 6. – Persistence of LMWD-induced changes. The hemodynamic response to the infusion of low molecular weight dextran (LMWD) is shown on day 1 and day 3 after acute infarction. The decline in pulmonary artery end-diastolic pressure and the increase in cardiac index on the third day indicate spontaneous improvement in left ventricular function. (Reprinted, with permission, from Russell, R. O., Jr., *et al.*[21])

The relationship between diastolic measurements such as the left ventricular filling pressure and a systolic expression of mechanical performance such as the cardiac index can be compared before and after volume expansion to describe a ventricular function curve as illustrated in Figure 7. On day 1, the function curve constructed from the stroke index, stroke work index and stroke power index demonstrated a descending limb after an optimal filling pressure had been obtained. In Figure 8, the same volume of dextran was infused on the third day after infarction and the descending limb of the ventricular function curve no longer was present.

In addition to monitoring the circulatory responses to volume expansion and construction of ventricular function curves, the heart rate and pulmonary artery end-diastolic pressure can be continuously monitored as shown in Figure 9. During the initial phase of the infarction, biologic events and activities can be evaluated by changes in heart rate and filling pressure of the left ventricle. Episodes of ischemic pain often are preceded by changes in heart rate and blood pressure. Therefore, continuous monitoring of the heart rate via the Swan-Ganz catheter can document circulatory alterations with ischemic pain. This can be clinically useful in differentiating the various mechanisms and etiologies of recurrent chest pain.

Measurements obtained from the Swan-Ganz catheter can also be combined with noninvasive techniques, such as echocardiography, to provide estimates of distensibility or compliance

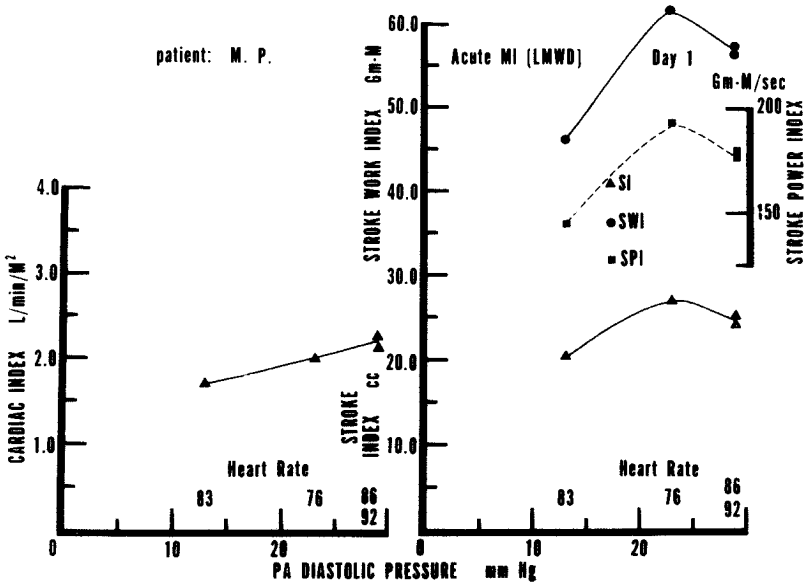
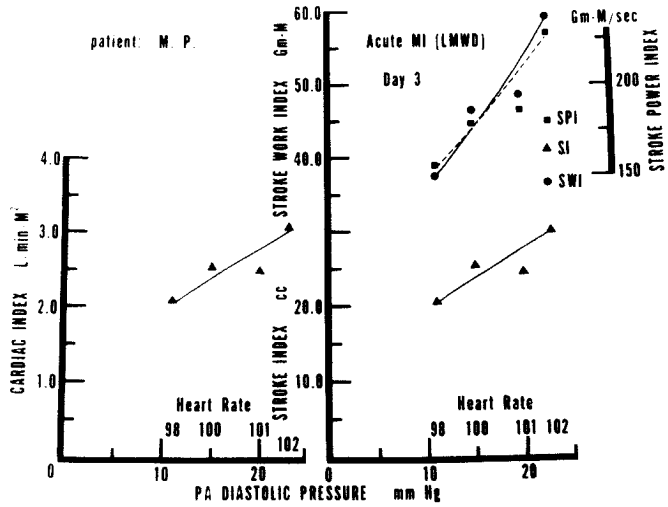


Fig 7.—The pulmonary artery end-diastolic pressure is related to the cardiac index during the infusion of low molecular weight dextran on day 1 and the hemodynamic alterations describe a ventricular function curve. At the right, changes in the stroke index *(SI)*, stroke work index *(SWI)* and stroke power index *(SPI)* describe a descending limb of the ventricular function curve. (Reprinted, with permission, from Rackley, C. E., and Russell, R. O., Jr.[22])

Fig 8.—The ventricular function curve has a steeper slope on the third day on the left when compared to the first day in Figure 7. The function curves for stroke index *(SI)*, stroke work index *(SWI)* and stroke power index *(SPI)* have lost the descending limbs on the right. (Reprinted, with permission, from Rackley, C. E., and Russell, R. O., Jr.[22])



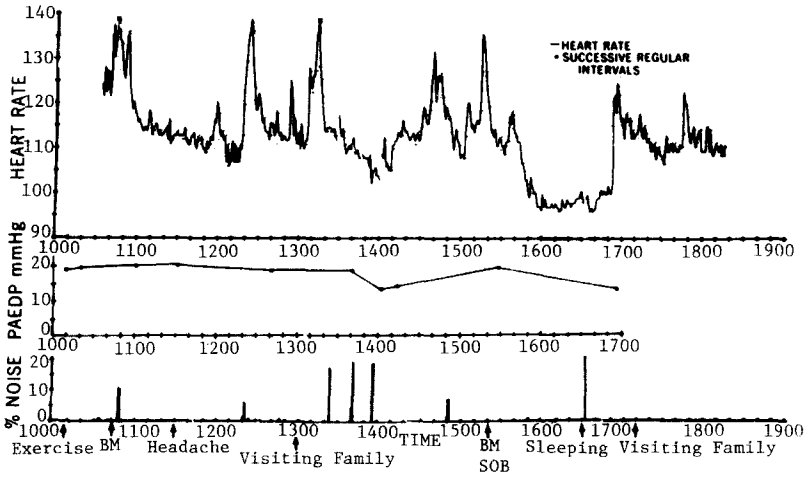
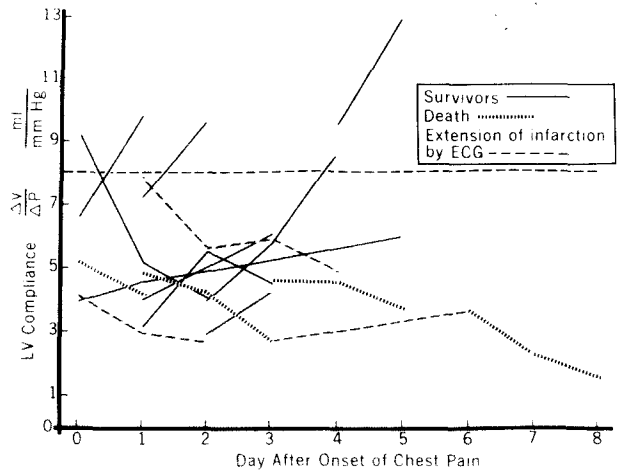


Fig 9.—The Swan-Ganz catheter modified with a bipolar atrial electrode can monitor the heart rate and PAEDP as illustrated. This patient experienced a significant increase in heart rate when visited by the family.

changes in the acutely infarcted ventricle.[23] In Figure 10 are shown serial changes in left ventricle compliance in patients with acute myocardial infarction. Those patients surviving an acute infarction exhibited a serial increase in the compliance or distensibility of the ventricle whereas those patients whose ventricles became stiffer during the diastolic filling phase experienced a considerably higher mortality in the hospital.

Fig 10.—Consecutive compliance changes of the left ventricle were measured following acute infarction. Survivors demonstrated an increase in ventricular compliance whereas nonsurvivors and extension of the infarction exhibited a decrease in compliance. (Reprinted, with permission, from Smith, M., *et al.*[23])



PROGNOSTIC INDICES

From the time the physician begins taking the history and performing the physical examination of the patient with acute infarction there is simultaneous assessment of the extent of damage and the seriousness of the patient's condition. The physician utilizes clinical information, which can be supplemented by laboratory studies, to develop a prognosis for the individual patient. This is important not only in discussing the nature of the illness with the patient and his family but also in making decisions concerning additional studies and various forms of treatment. Several indices have been developed by cardiologists in the study of patients with acute infarction to predict survival and nonsurvival of these patients. These indices include information obtained from the history, the physical examination, the electrocardiogram and laboratory studies. With availability of the Swan-Ganz catheter, hemodynamic measurements can assess the extent of left ventricular mechanical damage and provide another prognostic index.

Although the extent of the myocardial infarction cannot be estimated from the standard electrocardiogram, the development of certain conduction disturbances indicates that the patient may be at high risk. Acute myocardial infarctions often are designated as transmural and nontransmural based on the presence or absence of abnormal Q waves in association with the characteristic ST and T wave changes in the electrocardiogram. Although the transmural infarction is assumed to involve the full thickness of the ventricular wall, the electrocardiogram in the early phases may not reveal Q waves, which can develop during the subsequent course. Therefore, in the early phase, designation as transmural or nontransmural infarction based on the electrocardiogram may not be a sensitive index. Patients who develop right bundle-branch block with acute infarction have been reported in some studies to experience a mortality exceeding 60%. Patients presenting with left bundle-branch block also have a high mortality, but this does not approach that encountered with right bundle-branch block.

Clinical indices for predicting the course of the patient with acute infarction have been developed by Killip,[24] Peel[25] and Norris.[26] The clinical, physical and laboratory components in these indices are shown in Table 4. The Killip index separates the patients into categories based on the presence or absence of heart failure and cardiogenic shock. Patients without audible pulmonary rales or ventricular gallop sounds are considered uncomplicated and compose category 1. Patients with mild heart failure with basilar rales and an audible ventricular gallop are in category 2, patients with pulmonary edema are in category 3 and, finally, those presenting in cardiogenic shock compose category

TABLE 4.—HISTORICAL, PHYSICAL AND LABORATORY FINDINGS FOR THE PROGNOSTIC INDICES OF KILLIP, PEEL AND NORRIS

PARAMETER	KILLIP	PEEL	NORRIS
Age	0	X	X
History of			
Myocardial infarction	0	X	X
Angina	0	X	X
Dyspnea on exertion	0	X	0
Hypertension	0	X	0
Other cardiovascular disease	0	X	0
Physical examination			
Heart rate	0	X	0
Systolic blood pressure	X	0	X
Shock	X	X	0
S_3 gallop	X	X	0
Rales	X	X	0
Dyspnea, edema, orthopnea, hepatomegaly	0	X	0
Laboratory data			
ECG			
Infarct location	0	0	X
Infarct extent	0	X	X
Dysrhythmia	0	X	0
Chest x-ray			
Heart size	0	0	X
Lung fields	X	0	X

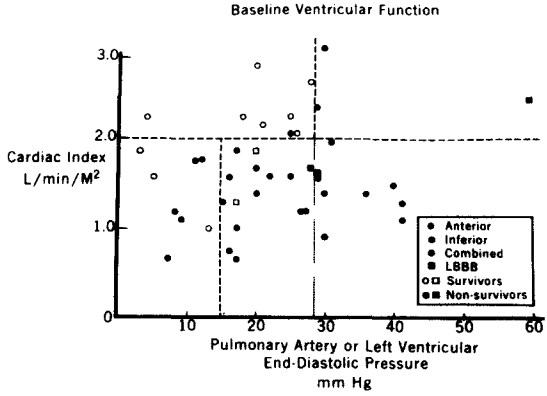
4. In Killip's original report, the respective mortality for categories 1, 2, 3 and 4 were 6%, 17%, 38% and 80%. The indices of Peel and Norris incorporate additional clinical features, such as age of the patient, history of previous myocardial infarction, heart failure and angina as well as the physical examination and radiographic findings. In all these prognostic indices, numerical scores are tabulated, and the higher value indicates a higher mortality during the hospital stay.

The Swan-Ganz catheter and hemodynamic monitoring have provided further physiologic information that can be utilized to construct the prognostic score of the patient. When the initial pulmonary artery end-diastolic pressure in patients with acute infarction exceeded 20 mm Hg there was a 66% mortality in an earlier study.[27] Measurements of pulmonary artery end-diastolic pressure, arterial systolic pressure and cardiac index can be related to calculate the mechanical stroke work of the left ventricle. Patients with extreme cardiac impairment and reduced left ventricular stroke work values experience a much higher mortality in the hospital.[28]

In cardiogenic shock, the hemodynamic measurements obtained from the Swan-Ganz catheter have been useful in identifying subsets that may respond differently to various forms of treatment.[29] Cardiogenic shock has been defined as a systolic

pressure less than 90 or greater than 80 mm Hg fall in the systolic pressure in a previously documented hypertensive patient. In addition, there should be evidence of impaired skin, renal and cerebral blood flow as manifest clinically with cold, clammy, cyanotic skin, reduced urine output and alterations in sensorium. As shown in Figure 11, the initial measurements of the left ventricular filling pressure and cardiac index identified four subgroups of mortality for cardiogenic shock after acute infarction.[30] Patients with an initial PAEDP or LVEDP greater than 29 mm Hg had a 100% mortality when managed with available pharmacologic agents. In the second category of patients with a PAEDP greater than 15 mm Hg and a cardiac index less than 2.0 l/min/m^2, the mortality still was extremely high at 92%. The third category of cardiogenic shock patients presented a PAEDP less than 15 mm Hg and a cardiac index less than 2.0 l/min/m^2 with a 60% mortality. These patients present a form of hypovolemic shock with a normal or slightly elevated ventricular filling pressure. Survivors in this category often responded dramatically to volume expansion with dextran or a similar agent. Finally, in the fourth category of patients, the same clinical features of cardiogenic shock were present and the PAEDP was less than 20 mm Hg with a cardiac index less than 2.0 l/min/m^2. These patients experienced only a 13% hospital mortality and probably sustained a smaller area of damaged myocardium when compared to the other three categories. Therefore, from the standpoint of pharmacologic management and consideration for additional studies, such as emergency coronary arteriography and intra-aortic balloon pumping, the initial measurements of left ventricular filling pressure and cardiac index can be useful to the coronary care unit physician.

Fig 11.—The initial hemodynamic measurements for patients with cardiogenic shock and myocardial infarction describe four subsets with mortalities. (Reprinted, with permission, from Rackley, C. E., *et al.*[30])



COMPLICATIONS OF ACUTE MYOCARDIAL INFARCTION

The complications of acute infarction include persistent or recurrent chest pain, rhythm disturbances, heart failure, cardiogenic shock, mitral regurgitation, ruptured papillary muscle, ruptured ventricular septum, rupture of the free left ventricular wall, ventricular aneurysm and systemic emboli from a mural thrombus. Persistent chest pain refractory to analgesics during the initial 24 hours has been associated with an increased incidence of myocardial rupture. Subsequent chest pain often may be caused by pericarditis secondary to the infarction or, in the later stages, the postinfarction syndrome. The incidence of cardiac arrhythmias has been recognized to be far greater than prior to the time of continuous ECG monitoring. ECG monitoring has provided a guideline for the use of intravenous lidocaine to manage and suppress rhythm disturbances early in the phase of acute infarction. The Swan-Ganz catheter has also revealed that depressed left ventricular function and heart failure develop more frequently in acute infarction than has been suspected by clinical examination. In a study of clinically uncomplicated acute infarctions, abnormal elevations of the left ventricular filling pressure measured as PAEDP were recorded in 66% of the patients.[27] Cardiogenic shock, with the attendant mortality, is considered one of the most serious complications of acute myocardial infarction. Rupture of a papillary muscle or chordae often is associated with rapid hemodynamic deterioration. Although this complication may be suspected by physical examination, the precise disorder can be confirmed by the Swan-Ganz catheter. A ruptured ventricular septum can also be definitively diagnosed with a Swan-Ganz catheter by sampling blood in the pulmonary artery and the right atrium and comparing the oxygen content of the two samples. Rupture of the free ventricular wall often is a catastrophic event associated with circulatory collapse and electrical-mechanical dissociation. Although the complications of acute infarction increase the mortality, the early recognition of some of these syndromes may allow the physician sufficient time to utilize beneficial pharmacologic or surgical interventions.

INDICATIONS FOR PACING CATHETER

Various degrees of electrocardiographic conduction disturbances and heart block can occur in patients with acute myocardial infarction. First, second and third degree heart blocks are indicated respectively by prolongation of the PR interval, absence of QRS complexes after P waves and a slow ventricular rhythm without consistent relationship to atrial depolarization. Although patients with inferior wall myocardial infarction on the

electrocardiogram may develop transient complete heart block, some authors have proposed that simple ECG monitoring suffices, since resumption of the sinus mechanism generally occurs within several days. Sinus bradycardia due to inferior or anterior infarction is not an indication for pacemaker insertion and pacing. The development of second degree heart block, either a Mobitz type I (the Wenckebach phenomenon) or Mobitz type II, is considered an indication for insertion of a temporary pacing catheter. These patients may develop ventricular irritability and the antiarrhythmic drugs cannot be used with impunity to suppress the ectopic focus, since suppression of normally conducting pathways may be impaired. Furthermore, clinical or hemodynamic evidence of heart failure may warrant digitalis administration, which can enhance the degree of heart block. Although third degree heart block may be stable hemodynamically, ventricular irritability and heart failure can develop. Pharmacologic interventions with antiarrhythmics or drugs directed at improving the failing ventricle can further suppress conduction and ectopic impulse generation. Finally, the availability of trained personnel and facilities for the insertion of the temporary pacing catheter can be optimally utilized at an elective time rather than during critical deterioration of the patient. These considerations can facilitate the insertion and positioning of the pacing catheter.

TREATMENT OF MYOCARDIAL INFARCTION

Until recently, the treatment and management of patients with acute myocardial infarction had consisted of nursing care and efforts to provide a quiet, stable atmosphere for recovery of the damaged myocardium. The avoidance of stress and increased work loads on the heart were designed to minimize the incidence of arrhythmias and potential extension of the myocardial infarction.

Immediate treatment of acute infarction consists of analgesics for relief from pain. Morphine remains the most effective agent, but the addition of atropine can prevent further slowing of the heart rate if the patient presents with bradycardia. An intravenous route should be established immediately and a solution of lidocaine should be available for prompt infusion if ectopic activity develops. If the pain of acute infarction recurs during the first 12–24 hours, morphine or a similarly potent analgesic should be administered again. A short-acting or long-acting nitrate can be tried for chest pain developing beyond the initial 24 hours. After the severe pain of myocardial infarction has subsided, recurrent chest pain can arise from several sites, including the myocardium, pericardium, lungs and chest wall. The routine use of various cardiac drugs should be avoided. Diuretics should

be used if there is clinical or hemodynamic evidence of heart failure. Digitalis should be withheld, if possible, for the first 48 hours and, if indicated for control of rapid ventricular response to atrial fibrillation, given in half the usual digitalizing amount. The consequences of every pharmacologic agent should be considered carefully before administration to the patient with acute myocardial infarction.

► W. PROCTOR HARVEY: It's still pretty hard to beat morphine when you want to get rid of pain.

The development of a variety of invasive and noninvasive techniques for obtaining physiologic information concerning the heart and circulation has provided recognition of categories of patients with acute infarction who may benefit from currently available cardiac drugs. Physiologic studies on isolated heart muscle and isolated heart preparations have revealed four major determinants of ventricular performance—afterload, contractile state, preload and heart rate. These four determinants of ventricular performance also influence the myocardial oxygen consumption.[31] These determinants of cardiac performance and oxygen consumption can be utilized in the treatment of patients with acute infarction. In addition, the metabolic state of the heart and body in the patient with acute infarction and the size of the myocardial infarction, which determines the additional work load on the noninfarcted myocardium, should be considered. In Table 5, these determinants of left ventricular performance in patients with acute myocardial infarction are delineated. Included are the available clinical techniques that can

TABLE 5.—CARDIAC FUNCTION IN ACUTE MYOCARDIAL INFARCTION

DETERMINANT	METHOD	INTERVENTION	RESULT
1. Afterload	Echocardiogram	Nitroprusside	↓
	Arterial blood pressure	Nitrates	↓
		Antihypertensives	↓
2. Contractile state	Ventricular function curve	Catecholamines	↑
		Digitalis	↑
	Ejection fraction	Propranolol	↓
3. Preload	Echocardiogram	Dextran	↑
	Swan-Ganz catheter	Diuretics	↓
		Nitrates	↓
4. Heart rate	Surface ECG	Pacing	↑
	Catheter electrode	Atropine	↑
		Digitalis	↓
5. Metabolic state	Glucose	Glucose-insulin-potassium	
	Free fatty acids		
6. Myocardial infarction size	Enzymes	Hyaluronidase	↓
	Radionuclides	Glucose-insulin-potassium	↓

provide measurements of these determinants. Currently available pharmacologic interventions that have been shown to influence the various determinants are listed as well as the results from the individual agents.

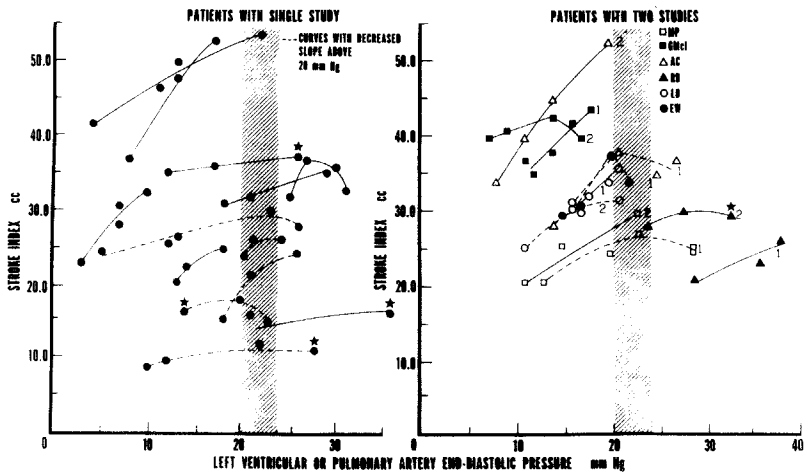
Afterload reduction has received much interest in clinical application in the past several years in patients with acute myocardial infarction complicated by various degrees of heart failure. Although afterload generally is equated with the arterial-systolic blood pressure, this term originated in papillary muscle studies and represents the force resisting shortening of the isolated papillary muscle. This force can be calculated for a cross-sectional area of the ventricular myocardium and expressed as left ventricular wall stress. Dimensions required to calculate ventricular wall stress include not only the systolic blood pressure but also the chamber size and wall thickness of the left ventricle. These measurements can be obtained from the noninvasive determination of systolic blood pressure and the echocardiographic estimation of chamber size and wall thickness.[32] Agents that have been utilized clinically for reduction of afterload include intravenous nitroprusside, phentolamine and the long-acting nitrates. Nitroprusside is used in hypertensive patients following acute infarction or in severe pulmonary edema with elevations of the systemic blood pressure. Nitroprusside requires intravenous administration and careful monitoring of systolic blood pressure. Phentolamine requires similarly careful monitoring under these circumstances. The long-acting nitrates have been shown to exert a slight but measurable reduction in the systolic pressure in patients with coronary artery disease, and these effects can persist for 4 hours.[33] The reduction in the arterial-systolic pressure and afterload permits the left ventricle to eject against reduced resistance or impedance.

Another determinant of the mechanical performance of the left ventricle is the contractile state. The contractile state has been defined as that condition which, if preload and afterload are maintained constant, can be stimulated to improve mechanical performance of the myocardial fiber. These observations on the contractile or inotropic state of the myocardium have evolved from studies on isolated papillary muscle, but determination in the intact heart has been difficult. Nevertheless, two available clinical measurements in patients with acute infarction—ejection fraction and the slope of the ventricular function curve—probably reflect the over-all mechanical performance of the left ventricle.[34] The ejection fraction can be estimated noninvasively using echocardiography or radionuclide scanning.[17, 35] The ventricular function curve can be constructed by relating the changes in the PAEDP and cardiac index before and after the rapid infusion of small amounts of low molecular weight dextran. Drugs that can enhance the contractile state include

digitalis and catecholamines. Propranolol can decrease the force of myocardial contraction. Since digitalis can increase the irritability of the myocardium during the first 48 hours after acute infarction, this drug can be withheld 3 or more days following the acute event. Catecholamines are infused when the arterial blood pressure must be maintained in patients with hypotension or cardiogenic shock. Propranolol can depress the contractile state in patients with myocardial infarction who manifest a hyperdynamic state with an abnormally elevated cardiac output. Such patients often are young men with their first myocardial infarction who exhibit an inappropriate adrenergic stimulation of the heart and circulation.

The preload of the ventricle represents the distending force acting on the relaxed myocardial fiber. Although the left ventricular filling pressure recorded as the pulmonary-capillary wedge pressure or the pulmonary artery end-diastolic pressure generally is designated as preload, the precise determination requires dimensions of chamber size, wall thickness and filling pressure. The left ventricular filling pressure can be obtained from the Swan-Ganz catheter, and chamber dimensions and wall thickness are available from the echocardiogram. Pharmacologic agents are available that can both increase and decrease the preload of the left ventricle. Preload can be increased with a volume expander such as low molecular weight dextran. Agents that can decrease the left ventricular filling pressure include diuretics and long-acting nitrates.[36] Figure 12 illustrates the

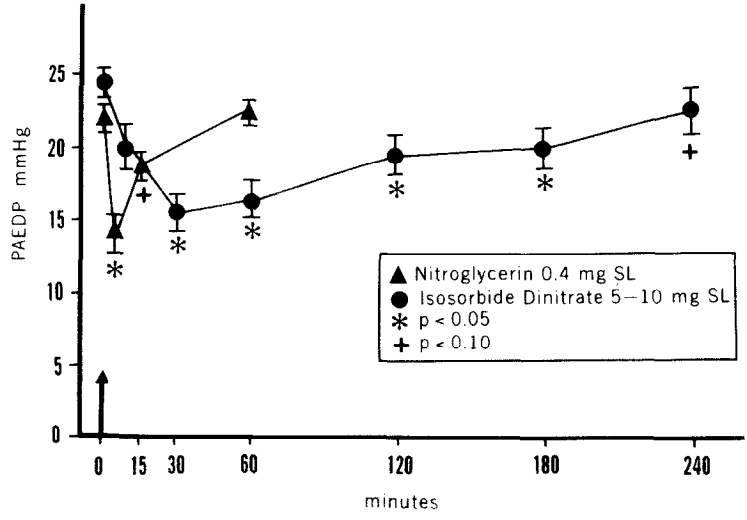
Fig 12.—Left ventricular function curves in patients with acute myocardial infarction demonstrated a critical range for left ventricular or pulmonary artery end-diastolic pressure between 20 and 24 mm Hg. The highest stroke index was attained in this range and above 24 mm Hg the function curves remained depressed or exhibited a descending limb. (Reprinted, with permission, from Russell, R. O., Jr., *et al.*[21])



optimal left ventricular filling pressure that has been documented in patients with acute myocardial infarction. The normal left ventricular filling pressure is less than 12 mm Hg and pulmonary edema can develop when the filling pressure exceeds 25 mm Hg. As shown in the illustration, the peak systolic performance of the infarcted left ventricle developed when the filling pressure ranged between 20 and 24 mm Hg. Therefore, this optimal left ventricular filling pressure could be produced by available agents to increase or decrease the preload of the left ventricle. As shown in Figure 13, the left ventricular filling pressure or PAEDP in patients with congestive heart failure in acute myocardial infarction can be lowered significantly with either nitroglycerin or isosorbide dinitrate.[37] However, the long-acting nitrate isosorbide dinitrate produced a significant reduction in the PAEDP that persisted 4 hours. This reduction in the filling pressure, displayed in Figure 14, was accompanied by a slight increase in the cardiac index and provided further evidence for the optimal range of the filling pressure in patients with acute myocardial infarction and left ventricular failure.

Heart rate is another factor in determining the mechanical performance of the left ventricle. The modification of the Swan-Ganz catheter described by Mantle and colleagues[15] can provide a source of a noise-free atrial signal that can be computerized to provide continuous monitoring of heart rate changes with acute infarction. A rapid ventricular rate can be slowed by digitalis,

Fig 13.—The abnormally elevated pulmonary artery end-diastolic pressure (PAEDP) was reduced to a similar extent by sublingual nitroglycerin and isosorbide dinitrate. The reduction in PAEDP persisted for 4 hours after the isosorbide dinitrate in patients with congestive heart failure (CHF) secondary to myocardial infarction (MI). (Reprinted, with permission, from Mantle, J. A., *et al.*[37])



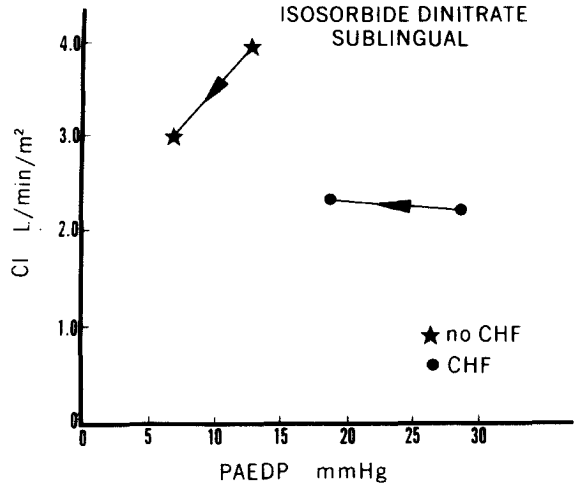


Fig 14.—In a patient with acute infarction and no congestive heart failure (CHF), isosorbide dinitrate produced a decline in both pulmonary artery end-diastolic pressure (PAEDP) and cardiac index (CI). In the presence of heart failure, the reduction in PAEDP was accompanied by a slight increase in CI. (Reprinted, with permission, from Rackley, C. E., *et al.*[27])

which decreases AV nodal conduction. However, during the first 48 hours after acute infarction, digitalis can increase ventricular irritability. In patients who develop atrial fibrillation with a rapid ventricular response but no evidence of hemodynamic deterioration, digitalis still can be administered in acute infarction, but half the usual digitalizing dose should be given. If the patient deteriorates, with hypotension, development of ischemic pain or left ventricular failure with atrial fibrillation, cardioversion is indicated. Heart rate can be increased in patients with acute infarction by the vagolytic effect of atropine. In patients with either second or third degree heart block, a temporary pacing catheter should be inserted.

The metabolic state in patients after acute myocardial infarction has received attention in recent years based on earlier observations that the myocardium generates its biochemical energy from the metabolism of free fatty acids and glucose.[38, 39] Glucose and free fatty acids can be measured with appropriate laboratory techniques. Under fasting conditions, the heart utilizes predominantly free fatty acids for generation of ATP. However, studies have suggested that free fatty acids may be detrimental to the ischemic myocardium by producing arrhythmias and depressing ventricular function.[40, 41] Although these experimental studies remain controversial, the clinical administration of glucose-insulin-potassium (GIK) has been shown to inhibit the release of free fatty acids as well as to provide an increased concentration of glucose.[42] As shown in Figure 15, patients with

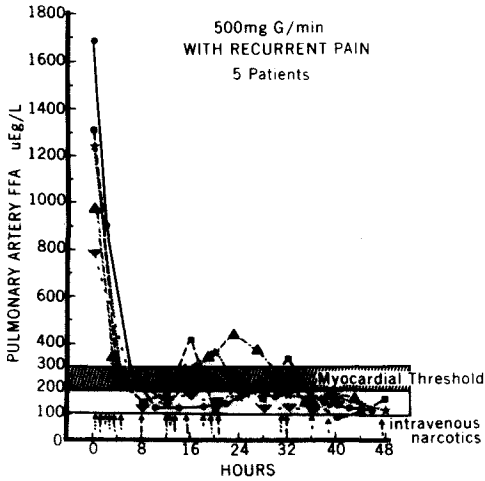
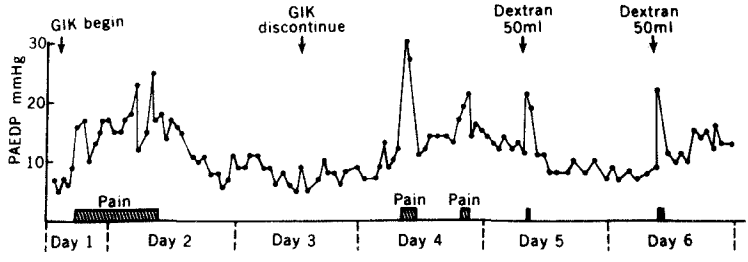


Fig 15.—The initial values for free fatty acids (FFA) were elevated above the normal range of 300–800 mEq/l in patients with acute myocardial infarction. The infusion of glucose-insulin-potassium (GIK) at a rate that provided 500 mg glucose/minute reduced the FFA below the myocardial threshold. (Reprinted, with permission, from Russell, R. O., Jr., *et al.*[43])

acute infarction presented abnormal elevations of free fatty acids, and the mechanism is presumed to be the influence of circulating catecholamines on lipoprotein lipase, which splits triglycerides into glycerol and free fatty acids.[43] The provision of GIK produced a prompt fall in plasma free fatty acids, which remained at or below the myocardial threshold even during the recurrence of ischemic pain. The infusion of GIK is one intervention that might alter the substrate availability and metabolism of marginal ischemic tissue in patients with acute myocardial infarction. Figure 16 illustrates continuous hemodynamic monitoring for 6 days in a patient with acute myocardial infarction.[44] The patient received the GIK solution the first 48 hours after the infarction, and serial measurements of PAEDP and cardiac

Fig 16.—During the first 48 hours of glucose-insulin-potassium (GIK) infusion the pulmonary artery end-diastolic pressure slowly declined. Chest pain recurred after the GIK was discontinued and was accompanied by an increase in the PAEDP. (Reprinted, with permission, from Rackley, C. E., *et al.*[44])



index reflected the alterations in ventricular performance. With recurrent chest pain there were abnormal elevations of the left ventricular filling pressure. Initial studies on the effects of GIK infusion during the early phase of myocardial infarction appear encouraging, with beneficial influence on mortality,[45] left ventricular mechanical performance[46] and incidence of cardiac arrhythmias.[47]

A final consideration of cardiac performance in acute infarction is the size of the myocardial infarction. Several methods have been developed for estimating the size of the myocardial infarction and include the serial assay of CPK enzymes,[10] precordial mapping with quantitation of the ST segments[41] and, finally, measurement of the size of radionuclide scans.[12] These methods require further testing and calibration with independent techniques in order to define the accuracy and reproducibility of each technique. Available clinical interventions that may alter or influence the ultimate size of the myocardial infarction include the metabolic intervention of the GIK solution, hyaluronidase, propranolol and steroids. The initial studies of the influence of GIK on the course of acute infarction are encouraging, but evidence for reduction of infarct size remains to be provided. Maroko and associates[48] have reported that hyaluronidase given in the early stage of infarction can reduce infarct size as estimated by the precordial mapping technique. Initial reports suggest that propranolol administration in the early phase of infarction may alter the release of CPK-MB isoenzymes and possibly reduce infarct size.[49] Conflicting reports have appeared regarding the influence of large dosage of steroids on myocardial infarct size. One experience has shown an increase in infarct size whereas another report has provided evidence that infarct size can be reduced with steroids.

Clinical experience with the Swan-Ganz catheter in hemodynamic monitoring in patients with acute infarction not only has shown that there often is disparity between clinical signs and hemodynamic measurements of ventricular function but also has revealed that patients could be managed according to the measurements of left ventricular filling pressure, PAEDP and cardiac index.[27] As shown in the flow diagram in Figure 17, the initial measurement of the PAEDP could identify patients whose initial values were above or below the optimal range of 20–24 mm Hg. The addition of cardiac index to the PAEDP identifies several subsets of patients who are candidates for different forms of treatment. The patient presenting with a PAEDP less than 20 mm Hg and a normal cardiac index, if stable, might simply be observed for several days. If clinical complications did not develop, the patient could be a candidate for early ambulation and hospital discharge. In a patient with similar hemodynamic measurements of a PAEDP less than 20 mm Hg

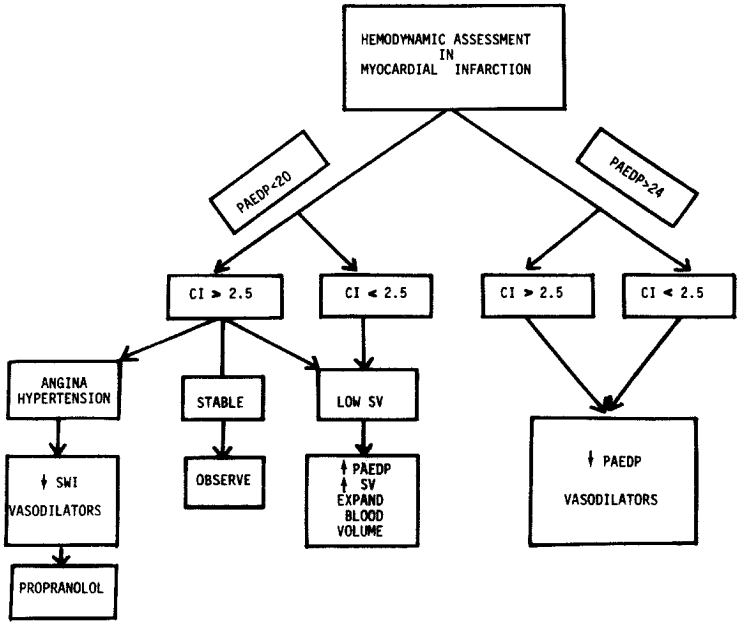


Fig 17.

and a normal cardiac index but with recurrent ischemic pain or elevated blood pressure, long-acting nitrates could be administered to lower the blood pressure and reduce the afterload. In the occasional hyperdynamic condition with tachycardia and a high cardiac output, propranolol can be beneficial. If the PAEDP is less than 20 mm Hg and the cardiac index normal or reduced, the patient could benefit from volume expansion with an infusion of dextran to elevate the PAEDP to the optimal range of 20–24 mm Hg. If tachycardia has been present, the increased cardiac output after the dextran infusion will produce slowing of the heart rate. The patient whose initial PAEDP exceeded 24 mm Hg is likely to have symptoms of pulmonary congestion and failure. Whether the cardiac index is normal or reduced, lowering of the left ventricular filling pressure is indicated. Therapy available for reduction of the elevated PAEDP includes nitroprusside, long-acting nitrates, diuretics and phlebotomy. In this manner, the initial measurement of the PAEDP and cardiac index can assist the physician in the optimal management of the patient in any of these hemodynamic categories.

When the acute infarction is complicated by cardiogenic shock, ruptured ventricular septum or mitral regurgitation due to disruption of the valve apparatus, pharmacologic agents may fail to support the circulation. Mechanical assist devices such as the intra-aortic balloon can maintain the arterial blood pressure

and augment the cardiac output. However, this form of support usually is temporary and plans should be made for cardiac catheterization and surgery. Catheterization is necessary to delineate the anatomic coronary artery disease and to document the impairment of left ventricular function. Emergency surgery has been most successful in rupture of the ventricular septum and severe mitral regurgitation. If the damage to the myocardium is extensive, surgery is attended by a high mortality. Patients developing these complications are candidates for transfer to institutions with the necessary facilities.

CONVALESCENCE

The availability of the noninvasive and invasive techniques to obtain physiologic information in the patient with acute infarction can also be utilized to identify candidates for early discharge from the hospital as soon as 7–10 days. Other patients with evidence of impaired cardiac performance or recurrent chest pain might require slightly prolonged hospitalizations and definitive studies such as coronary arteriography and left ventricular angiography. Hemodynamic monitoring with the Swan-Ganz catheter requires that the patient remain in bed. However, after stabilization of the electrical and hemodynamic functions of the heart and removal of the catheter, the patient can be rapidly ambulated and often transferred out of the coronary care unit to a ward for progressive activity. When ventricular irritability persists, Holter monitoring can be useful during the early ambulatory phase. Recent studies have shown that continued ventricular irritability is associated with extensive two- and three-vessel coronary artery disease.[50] The general course of activity after transfer from the coronary care unit involves increasing daily activities in the room and ambulation in the hallway. In the absence of ventricular dysfunction, recurrent arrhythmia or ischemic pain, the patient usually is a candidate for discharge after 2–3 weeks in the hospital.

► W. PROCTOR HARVEY: In the usual uncomplicated course after an acute myocardial infarction, I still prefer 3 weeks in the hospital and approximately 3 months total convalescence after the initial episode before the patient returns to work.

POSTINFARCTION CORONARY ARTERIOGRAPHY AND VENTRICULOGRAPHY

Recent experience has revealed that patients can be safely studied with coronary arteriography and left ventricular angiography 3–4 weeks after the acute myocardial infarction.[51] Infor-

mation available from cardiac catheterization includes the extent of anatomic disease in the coronary arterial tree, the size of the residual scar from the infarcted myocardium and mechanical function of the left ventricle. Such studies may be particularly beneficial in the patient less than 50 years of age who has a strong desire to return to his normal physical and professional activities. Furthermore, the findings can assist the physician in recognizing the prognosis of the patient and the likelihood of future events. As shown in Table 6, the size of the residual scar or abnormally contracting segment after a previous myocardial infarction reveals a linear relationship between specific parameters of left ventricular function, clinical symptoms and extreme impairment of left ventricular function. The earliest abnormality in the postinfarction ventricle appears to be a decrease in diastolic distensibility, which occurs with an infarct that involves only 8% of the over-all size of the left ventricle. The ejection fraction is measurably reduced below normal when the abnormally contracting segment is greater than 10%. At 15% and 17% scar sizes, elevations in the left ventricular end-diastolic pressure, dilatation and hypertrophy occur. When the area of abnormal contraction is greater than 23% the patient often presents symptoms and signs of heart failure. Finally, loss of more than 40% of the left ventricular myocardium usually produces cardiogenic shock, and there are few survivors from this extensive loss of muscle. Young men and women in their third or fourth decade who have documented transmural infarction by electrocardiogram may reveal normal coronary arteries in follow-up studies.[52] Such information is extremely helpful in selection of medical or surgical interventions, the design of postinfarction activities and reassurance to both patient and physician.

A major clinical challenge in the follow-up of patients with a previous myocardial infarction is clinically recognizing deterioration of cardiac function. Coronary arteriography and left ventricular angiography have demonstrated significant abnormalities in cardiac performance before development of clinical

TABLE 6.–ABNORMALLY CONTRACTING SEGMENTS IN POSTMYOCARDIAL INFARCTION

SIZE OF ACS	VENTRICULAR FUNCTION	RESULT
> 8%	Compliance	↓
>10%	Ejection fraction	↓
>15%	LVEDP	↑
>17%	End-diastolic volume	↑
>17%	Left ventricular mass	↑
>23%	Clinical heart failure	
>40%	Cardiogenic shock	

symptoms. Heart size traditionally has been estimated from the standard chest x-ray by comparing the cardiac and thoracic diameters (CT ratio). Examination of the radiographic CT ratio in patients within 1 year of infarction revealed a wide range of ejection fraction values from normal to severely reduced without a detectable increase in the cardiothoracic ratio.[53] Comparison of the left ventricular end-diastolic volume to the chest film indicated that the ventricle can dilate as much as 25% before cardiomegaly is apparent radiographically. If the physician waits until there is radiographic evidence of cardiac enlargement with an abnormal CT ratio, significant dilatation of the left ventricle and depression of the ejection fraction already will have developed. These observations may provide an explanation for the dyspnea in postinfarction patients with a normal size heart, which may be heart failure and not merely anxiety. Therefore, the physician should be alerted to the limitations of standard techniques for assessing postinfarction ventricular function and be knowledgeable of the contributions from the noninvasive studies of echocardiography and radionuclide scanning as well as the invasive procedures of coronary arteriography and left ventricular angiography.

SUMMARY

This presentation has described the modern approach to the patient presenting with chest pain suspected as acute myocardial infarction. Noninvasive and invasive methods have been applied to estimate the extent of the myocardial damage and to monitor the electrical, hemodynamic and metabolic changes during the acute phase. In addition to the use of standard analgesics and antiarrhythmics, measurement of the determinants of left ventricular function by noninvasive and invasive techniques provides a physiologic basis for administration of available pharmacologic agents that can alter the afterload, contractile state, preload, heart rate, metabolic state and infarct size. Information from the Swan-Ganz catheter can describe hemodynamic categories that can be optimally managed by regulation of the left ventricular filling pressure. Patients managed in this manner can be identified for early hospital discharge at 7–10 days. Other patients less than 50 years of age or those experiencing recurrent arrhythmias, ischemic pain or evidence of left ventricular dysfunction may be candidates for coronary arteriography and left ventricular angiography before hospital discharge.

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SELF-ASSESSMENT ANSWERS

1. Stimulation of the adrenergic nervous system can generate a state of anxiety and apprehension, which often expresses itself clinically as fright or fear.