Heart Failure Complicating Acute Myocardial Infarction

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SUMMARY
Congestive heart failure (CHF) occurs in about one half of all patients with acute myocardial infarction and is a manifestation of acute alterations in left ventricular function. In the present study CHF is defined on clinical grounds, according to the presence and extent of bilateral pulmonary rales. An accompanying S₃ ventricular gallop was heard in 58% of our patients with heart failure initially, but it disappeared eventually in the majority. Dilatation of pulmonary veins and blurring of pulmonary vascular markings are useful roentgenographic signs which reflect elevations in left heart filling pressure. At times the earliest indicators of heart failure, these findings appear in general to be less sensitive than the physical examination in diagnosing CHF. Although stroke volume is decreased with CHF, cardiac index is generally maintained by increased heart rate. Left ventricular minute work and stroke work are significantly decreased, while left ventricular end-diastolic pressure is significantly increased, in patients with CHF complicating acute myocardial infarction. Arterial hypoxemia is common and the degree of arteriovenous shunting is roughly proportional to the elevation of left ventricular filling pressure. The mortality of patients with CHF is approximately three times that of patients with acute myocardial infarction and no complications. Diuretic therapy is safe and effective. Attention is called to the probability that the use of digitalis preparations in the early hours following myocardial infarction is hazardous. Furthermore, hemodynamic benefit from digitalization in the early postinfarction period remains unproven.

Additional Indexing Words:
Coronary artery disease  Hemodynamics  Left ventricular end-diastolic pressure  Left ventricular function

Cardiac infarction represents an acute insult to myocardial integrity. Since left ventricular damage, old and recent, is often substantial, it is not surprising that clinical evidence of congestive heart failure is frequent in the patient hospitalized with acute myocardial infarction. Recent physiologic studies have demonstrated that abnormalities in left ventricular and pulmonary function after myocardial infarction are common and often more severe than suspected clinically.

Definition
Congestive heart failure (CHF) following acute myocardial infarction is defined as a clinical syndrome manifested by moist rales at the lung bases persisting after vigorous cough, often accompanied by a third heart sound, tachycardia, and tachypnea or dyspnea. Evidence of vascular blurring, dilatation, or parenchymal clouding on a chest roentgenogram is a frequent but not invariable associated finding.

To facilitate the clinical evaluation of patients with acute myocardial infarction we have arbitrarily defined four clinical classes: class I, no signs of heart failure; class II, mild or moderate heart failure, rales over an area of 50% or less of both lung fields; class III,
pulmonary edema, rales over more than half of both lung fields; class IV, cardiogenic shock, blood pressure by cuff of less than 90 mm Hg with signs of inadequate peripheral perfusion including reduced urine flow, cold and clammy skin, cyanosis, and mental obtundation.

Incidence of Heart Failure

Mild or moderate left heart failure was found on physical examination in 48% (range 23–71%) of 1800 hospitalized patients evaluated clinically prior to the development of the Coronary Care Unit (CCU).1–5 Approximately the same incidence, 46% (range 20–68%) of 2300 patients, has been noted in studies reported since 1967.6–16 Severe heart failure or pulmonary edema is less common, occurring in approximately 12% of patients with myocardial infarction.7–8, 10–12, 16–18

Of 112 patients with acute myocardial infarction admitted consecutively to the New York Hospital Coronary Care Unit during 1970–71, 47 (42%) had mild or moderate left heart failure, class II; eight (7%) developed pulmonary edema, class III; 10 (9%) were in cardiogenic shock, class IV; and 47 (42%) had no clinical evidence of heart failure whatever, class I.

The incidence of CHF has been reported to increase with age18 almost doubling after 60 years of age in one study.14 However, our own data and those of Scheinman6 do not support this observation. The mean age of 52 patients (55 admissions) with mild or moderate CHF in our recent series of consecutive CCU admissions was 64 years, compared to 63 years for patients with acute infarction but no CHF. Twenty-six patients with CHF, 50% of the group with heart failure, had prior myocardial infarction. Seventeen (33%) had past hypertension, and 19 (37%) had a history of CHF before the current episode. Others have reported6, 10 that ventricular decompensation is more frequently observed in those with prior history of CHF.

Symptoms and Physical Findings

Dyspnea and orthopnea are common and have been noted in 32–60% of patients with CHF.4, 6, 10 These symptoms are often accompanied by a marked decrease in the 1-sec forced expiratory volume and forced vital capacity20 and correlate well with elevated pulmonary artery diastolic pressure.16

A ventricular gallop or third heart sound has been heard in approximately one third of patients with acute myocardial infarction. The reported incidence ranges from 26 to 65%.9, 16, 21, 22 In our series, an S3 gallop was heard on admission in 20 patients (36%) and developed after admission in 12 additional subjects. Thus a ventricular gallop was identified in 58% of our patients with CHF following acute myocardial infarction.

It should be emphasized, however, that the clinical recognition of a gallop may be an inaccurate guide to the presence or absence of ventricular decompensation. Detection of the S3 depends on the skill and motivation of the observer. Unless auscultation is unusually thorough, the true incidence of the gallop is almost certainly underestimated. Frequent examination in a quiet room with the patient on his left side may improve detection.

The rapid-filling sound associated with mitral regurgitation may be erroneously interpreted as evidence for left ventricular failure.23 Mitral regurgitation has been observed in as many as 56% of patients with acute myocardial infarction,9 and a third heart sound is not a reliable sign of myocardial failure in this circumstance.

Peripheral venous congestion is uncommon after acute myocardial infarction, occurring at some time during hospitalization in only 21% of the patients in our series. Rarely, clear evidence of right heart failure occurs with isolated inferior-wall infarction.24, 25 Pathologically, right ventricular infarction is thought to be rare,26 but this view may be a consequence of incomplete examination. With modern techniques of postmortem coronary angiography and topographic mapping of serial sections of ventricular muscle, right ventricular infarction of some degree is encountered frequently in fatal cases of acute myocardial infarction, although the mass of muscle.

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involved is usually small. (Alonso D: Unpublished data).

**Roentgenographic Findings**

Pulmonary venous distension, loss of definition of pulmonary vessels, pulmonary parenchymal clouding, prominent septal lines, pleural effusions, and increased diameter of the right descending pulmonary artery have all been proposed as roentgenographic signs of left ventricular failure. Tattersfield and co-workers\(^{10}\) observed dilatation of upper-lobe pulmonary veins in 76% of patients with acute myocardial infarction. The demonstration by Lassers et al.\(^{24}\) that pulmonary capillary wedge pressures are significantly higher in patients with pulmonary venous dilatation than in those with normal pulmonary vasculature suggests that this roentgenographic sign is a manifestation of left ventricular dysfunction. Sjogren reported that although roentgenographic pulmonary artery congestion was generally associated with elevation of pulmonary artery diastolic pressure, several patients with such pressure elevation were found to have normal chest roentgenograms.\(^{16}\) More recently Harrison et al.\(^{28}\) found pulmonary venous distension to be an unreliable sign of left ventricular failure when chest roentgenograms are obtained with the patient in the semirecumbent position. These authors diagnosed pulmonary congestion by a loss of definition of the borders of the pulmonary vessels. This sign is presumably a manifestation of interstitial or alveolar fluid accumulation.

Pulmonary congestion may sometimes be recognized roentgenographically before rales are clinically apparent. In 38% of Harrison's patients,\(^{28}\) radiographic evidence of pulmonary edema preceded the onset of clinical findings. Although several roentgenographic signs correlate well with clinical or physiologic manifestations of left heart failure, it is not clear at the present time whether subtle roentgenographic findings are sufficiently reliable to permit consistent early or "subclinical" detection of CHF.

**Hemodynamic Changes in Heart Failure**

Ramo et al.\(^{8}\) studied patients shortly after acute myocardial infarction and found that arterial oxyhemoglobin saturation and stroke index were significantly reduced in those with heart failure. Cardiac output was maintained by an increase in heart rate. Although 20 of 31 class II patients had arterial oxygen tension (\(\text{Pa}_o_2\)) less than 70 mm Hg, and 25 of 37 patients had arteriovenous oxygen differences greater than 5 vol %, the incidence of these abnormalities was similar in patients not in failure.

Hamosh and Cohn\(^{29}\) studied 12 patients with CHF and 14 patients with uncomplicated infarction. Stroke volume was significantly reduced and heart rate significantly increased in the patients with CHF. Cardiac index was slightly, but not significantly, lower in the patients with heart failure, averaging 2.6 liters/min/m\(^2\). No differences were observed in central blood volume, mean arterial pressure, or peripheral vascular resistance.

We have obtained hemodynamic data from 60 patients with and without CHF within 4–304 hours (median 34 hours) after the clinical onset of definite acute myocardial infarction. Right and left heart catheterization were performed with small flexible nylon catheters. Cardiac output was calculated by standard methods from indicator-dilution curves obtained following injection of indocyanine green into the pulmonary artery or right atrium and sampling from the aortic root or left ventricle. Left ventricular work in kg-m/min was calculated from the formula:

\[
\text{LV work} = (\text{LVM sys} - \text{LVEDP}) \times \text{CO} \times 1.055 \times 13.6/1000
\]

where LVM sys and LVEDP represent mean systolic and end-diastolic pressures in the left ventricle in millimeters of mercury; CO, cardiac output in liters/minute; 1.055, the specific gravity of blood; and 13.6, the mercury conversion factor to allow expression of the result in metric units. Stroke work in gram-meters/minute was calculated as left ventricular work times 1000 divided by heart rate.
Table 1

Measurements of Cardiovascular Performance in Patients with and without Heart Failure following Acute Myocardial Infarction*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>No complications, class I</th>
<th>CHF, class II</th>
<th>P†</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>23</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>89 ± 19</td>
<td>96 ± 20</td>
<td>NS</td>
</tr>
<tr>
<td>Stroke-volume index (ml/beat/m²)</td>
<td>31 ± 10</td>
<td>25 ± 12</td>
<td>NS</td>
</tr>
<tr>
<td>Cardiac index (liters/min/m²)</td>
<td>2.5 ± 0.6</td>
<td>2.2 ± 0.6</td>
<td>NS</td>
</tr>
<tr>
<td>Peripheral vascular resistance (dynes-sec-cm⁻³)</td>
<td>1620 ± 400</td>
<td>1750 ± 600</td>
<td>NS</td>
</tr>
<tr>
<td>Cardiac-work index† (kg-m/min/m²)</td>
<td>3.0 ± 1.1</td>
<td>1.9 ± 0.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Stroke-work index† (g-m/beat/m²)</td>
<td>38 ± 17</td>
<td>22 ± 12</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Arterial pressure, s/d, mean (mm Hg)</td>
<td>119/70, 88</td>
<td>111/68, 82</td>
<td>NS</td>
</tr>
<tr>
<td>Pulmonary arterial pressure, s/d, mean (mm Hg)</td>
<td>23/11, 15</td>
<td>39/21, 27</td>
<td>All</td>
</tr>
<tr>
<td>Left ventricular end-diastolic pressure (mm Hg)</td>
<td>16 ± 9</td>
<td>25 ± 7</td>
<td>&lt;0.02</td>
</tr>
<tr>
<td>Right atrial pressure (mm Hg)</td>
<td>5 ± 2</td>
<td>8 ± 4</td>
<td>&lt;0.005</td>
</tr>
</tbody>
</table>

Abbreviations: CHF = congestive heart failure; NS = not significant; s/d = systolic/diastolic.
*Results expressed as mean ± standard deviation of the mean.
†P values calculated by Student’s unpaired t test.
†Cardiac and stroke work are expressed per square meter of body surface area in this table, but not in figure 1.

Table 1 and figure 1 summarize our observations. Hemodynamic findings in patients with acute myocardial infarction generally correlate well with the clinical severity of heart failure. Cardiac and stroke-volume index decrease, and heart rate and total peripheral resistance increase in patients who develop CHF (class II). Differences in these variables are small and not statistically significant. However, significantly higher pulmonary artery and left ventricular end-diastolic pressures were observed in the patients with left ventricular failure. Left ventricular minute work and stroke work, derived measurements which combine pressure and flow data, are markedly reduced in patients with heart failure.

Pulmonary Edema

Physiologic observations when acute infarction is complicated by overt pulmonary edema are scant since the clinical state is usually unstable and subject to rapid change. Furthermore, available data have been obtained at varying intervals after the initiation of therapy. Ramo noted lower stroke indices, higher right atrial pressures, and reduced Pao₂ for class III as compared to class II patients. Cardiac index in pulmonary edema was 1.9 liters/min/m², significantly decreased from the mean of 2.7 liters/min/m² observed in class II subjects. Peripheral vascular resistance, arterial pressure, and arteriovenous oxygen difference were similar in both groups. Recently Scheinman et al. evaluated seven patients with pulmonary edema and acute myocardial infarction. All still had orthopnea, dyspnea, and rales when studied 11 hours after admission. Cardiac output was reduced and pulmonary artery pressure markedly elevated, averaging 50/25 mm Hg. Mean arterial Pao₂ was low (64 mm Hg) while arterial pH was normal. Cardiac index was within the normal range in only one report, i.e., in a group of patients studied 7 hours after admission for acute pulmonary edema.

Left Ventricular Diastolic Pressure

Cohn and co-workers first called attention to the high incidence of abnormal left ventricular filling pressure after acute myocardial infarction. More recently his group recorded LVEDP averaging 30 mm Hg in patients with failure as compared to 15 mm
HEART FAILURE IN MI

ACUTE MYOCARDIAL INFARCTION
HEMODYNAMICS & CLINICAL STATUS

HEART RATE
beats/min

CARDIAC INDEX
l/min/M²

STROKE VOLUME INDEX
ml/beat/M²

PERIPHERAL VASCULAR RESISTANCE
dynes/sec/cm⁻⁵

LVEDP
mm Hg

CARDIAC WORK
kg/M/min

Figure 1

Hemodynamic measurements according to clinical status in patients studied shortly after acute myocardial infarction. Mean values for heart rate, cardiac and stroke volume indices, and peripheral vascular resistance do not differ between class II (CHF) and class I (no CHF) patients. LVEDP is significantly higher and external left ventricular work (“cardiac work”) significantly lower in patients with heart failure.

Hg in those without failure. Mean ventricular diastolic pressures were lower, averaging 20 mm Hg for class II and 11 mm Hg for class I patients, respectively.

We have measured ventricular filling pressures within a short time after myocardial infarction in 22 patients with clinical evidence of CHF, in three patients with pulmonary edema, and in 14 patients with uncomplicated infarction. A wide range of values was observed (fig. 2). Left ventricular end-diastolic pressure averaged 16 mm Hg and ranged from 4 to 31 mm Hg in patients without CHF. Seven of 13 patients without clinical evidence of failure had abnormal LVEDP (>12 mm Hg). In class II patients with mild or moderate CHF, LVEDP averaged 25 mm Hg, but values as low as 16 mm Hg and as high as 43 mm Hg were observed. No patient with clinical evidence of heart failure had a normal LVEDP, and in about half the level was in the range where pulmonary interstitial fluid accumulation should occur (>25 mm Hg). LVEDP was markedly elevated in three patients with pulmonary edema, ranging from 32 to 42 mm Hg.

Correlation of clinical findings with left ventricular diastolic pressure in patients with acute infarction is poor. Sixteen patients in our group had LVEDP greater than 25 mm Hg. Three were in pulmonary edema, but 10 had rales covering less than 50% of the lungs (class II), and three actually demonstrated no clinical evidence of pulmonary congestion whatever! In another study only one of seven patients with LVEDP between 25 and 40 mm Hg had clinical pulmonary edema. Lassers et al. reported poor correlation...
between mean pulmonary capillary wedge pressure and diastolic heart sounds, dyspnea, or persistent basilar rales. Only when pulmonary capillary pressure exceeded 20 mm Hg was a ventricular gallop invariably present. Many patients with normal wedge pressures also had ventricular gallops. Rales were present when pulmonary capillary pressure exceeded 25 mm Hg but were also heard with normal or only slightly increased wedge pressures.24

Figure 2

Left ventricular end-diastolic pressure measured shortly after acute myocardial infarction. Note the variation in patients with and without failure. No patient with CHF (class II or III) had a normal LVEDP (<12 mm Hg). LVEDP exceeding pulmonary capillary oncotic pressure (about 25 mm Hg) was commonly recorded, yet most patients with such striking elevations had only moderate clinical failure.

Sjogren,16 however, found a moderate correlation between pulmonary arterial diastolic pressure and increasing rales, dyspnea, tachycardia, and X-ray evidence of pulmonary congestion in 50 patients with acute myocardial infarction. Furthermore, elevation of pulmonary arterial diastolic pressure correlated well with low cardiac output and infarct size as estimated by the maximum elevation of serum glutamic oxaloacetic transaminase activity.

Reasons for caution in evaluating ventricular end-diastolic pressure have been discussed.33 Due to the shape of the ventricular pressure-volume curve, small changes in ventricular volume may result in large changes in diastolic pressure in patients with high filling pressures, as in myocardial infarction. Experimental studies have demonstrated increased stiffness or decreased compliance in an infarcted area.34 Since end-diastolic pressure is influenced by factors other than the functional state of the myocardium, this measurement alone cannot be decisive in evaluating the presence or absence of ventricular failure.

End-diastolic pressure may be affected to a greater degree by changes in ventricular compliance than mean ventricular filling pressure. In our study of patients with acute myocardial infarction the left ventricular pre-a pressure closely approximated mean ventricular filling pressure (r = 0.98). The contribution of atrial systole to ventricular diastolic pressure, measured as the height of the a wave above the pre-a level, averaged 8 mm in class I, 9 mm in class II, and 14 mm Hg in class IV (cardiogenic shock). The post-a (or end-diastolic) pressure was always higher than the mean filling pressure, often to a considerable degree.35 Though ventricular pressure at the end of diastole may transiently exceed pulmonary transcapillary oncotic pressure, the mean hydrostatic pressure transmitted via a fronte from the left ventricle through the left atrium and pulmonary veins to the pulmonary capillary bed is often substantially lower and may not reach that level at which transudation of fluid into pulmonary alveoli occurs.

Right Ventricular Failure

The influence of left ventricular failure on right ventricular filling pressure has been investigated extensively in patients with acute myocardial infarction. Right atrial pressures within the normal range were found in 29% of
patients with CHF and 20% of patients with overt pulmonary edema in one study.\(^8\) Forrester and co-workers found no consistent relationship between central venous pressure and pulmonary capillary wedge pressure.\(^2\) Furthermore, even the direction of changes in pulmonary capillary wedge pressure during expansion or contraction of intravascular volume was not accurately assessed by central venous pressure. Hamosh observed similar discrepancies between left ventricular and right atrial pressures in patients with acute myocardial infarction.\(^29\)

It is apparent that the right ventricle may remain competent despite gross left ventricular dysfunction after acute myocardial infarction. Although readily measured at the bedside with suitable techniques, right atrial or central venous pressures are, unfortunately, unreliable guides to the state of left ventricular compensation.

**Hypoxemia**

Arterial hypoxemia is common after acute myocardial infarction\(^20,\) \(^37\) and the degree of hypoxemia correlates roughly with the severity of left ventricular dysfunction. Fillmore et al.\(^38\) studied patients with acute infarction and found that \(\text{PaO}_2\) averaged 86 mm Hg in patients without heart failure, 71 mm Hg with moderate failure, 60 mm Hg with pulmonary edema, and 57 mm Hg with cardiogenic shock. As the degree of pulmonary congestion increased, administration of 100% oxygen was less effective in raising \(\text{PaO}_2\).

Hypoxemia can be partially or wholly corrected with increased concentrations of inspired oxygen in patients with mild CHF, but even 100% oxygen may not be sufficient to overcome arterial desaturation in patients with pulmonary edema or cardiogenic shock. One potential adverse effect of oxygen therapy is an increase in ventricular afterload as a result of oxygen-induced peripheral vasoconstriction.\(^37,\) \(^39\) Sukumalchantra et al.\(^39\) demonstrated a significant increase of oxygen transport to the tissues (calculated as oxygen content multiplied by cardiac output) only in severely hypoxemic patients (\(\text{SaO}_2 < 90\%\)).

The hypoxemia of acute infarction is not due to alveolar hypoventilation since arterial \(\text{pCO}_2\) is usually below normal. Diffusion capacity is probably also normal.\(^40\) Data from several sources support the view that perfusion of poorly ventilated alveoli with consequent increased pulmonary arteriovenous shunting accounts for a major portion of the arterial desaturation.\(^20,\) \(^37–42\) We have evaluated the effects on arterial oxygen tensions of 100% oxygen administered by mask and have demonstrated that significant right-to-left intrapulmonary shunting or venous admixture is common after acute myocardial infarction.\(^42\) The magnitude of the arteriovenous shunt increases as clinical heart failure worsens. The degree of arteriovenous shunting correlates reasonably well with the elevation of pulmonary arterial diastolic pressure.

**Course**

Clinical evidence of CHF is usually transient after acute myocardial infarction. In our group of consecutive CCU admissions all clinical evidence of CHF had disappeared within 7 days of infarction in 13 patients (24%), within 14 days in 27 (49%), and within 21 days in 34 patients (62%). In 20 (36%) evidence of CHF persisted for more than 3 weeks, to discharge or death.

The \(S_3\) ventricular gallop disappeared in 22 of the 32 patients within 7 days of infarction. It persisted to discharge or death in only five patients. Other investigators report disappearance of the \(S_3\) during hospitalization in 60% of patients.\(^21\)

The natural history of the hemodynamic abnormalities after myocardial infarction has not been extensively evaluated. Broder, Rodriguez, and Cohn studied the evolution of hemodynamic abnormalities over a 3-week period in 12 patients with acute myocardial infarction and left ventricular failure.\(^43\) Cardiac index rose and right atrial pressure fell significantly, while heart rate, mean arterial pressure, LVEDP, and LVEDP-stroke index ventricular function curves (constructed after acute volume reduction or expansion) did not change in the 3 weeks following infarction.
Persistent elevation of LVEDP occurred in the face of normal left ventricular end-diastolic volume derived from ultrasoundcardiography. These data suggest that left ventricular compliance remains abnormal at least over a period of several weeks after acute myocardial infarction.

In another study, pulmonary artery systolic and right ventricular end-diastolic pressures fell to within the normal range in most patients within a week following myocardial infarction.12 The normalization of pressures usually preceded clearing of radiologic evidence of pulmonary venous hypertension by approximately 24 hours. Patients with pulmonary edema, reevaluated 1 week after the acute episode, had decreased heart rate and arterial pressure, increased stroke volume, and unchanged cardiac output as compared to earlier studies.30

Pathogenesis

Although the data are far from complete it is tempting to speculate that in the patient with coronary artery disease there is a direct relationship between the mass of injured or destroyed myocardium and the impairment of left ventricular performance. The greater the damage the poorer is cardiac function. Recent pathologic studies by our group demonstrated an average of 23% of left ventricular mass destroyed by old, intermediate, or recent infarction in a group of patients dying suddenly of arrhythmias after hospitalization for infarction. By comparison, in patients dying from cardiogenic shock, 51% of the left ventricle had been destroyed. Patients with mild or moderate cardiac failure but not the gross dysfunction of cardiogenic shock may have an intermediate degree of injured or destroyed myocardium.

Other factors of variable importance which may contribute to the syndrome of heart failure include alterations of heart rate and rhythm, the myocardial consequences of arterial hypoxemia, acidosis or electrolyte imbalance, abnormalities of ventricular geometry or sequence of contraction, valvular dysfunction, and associated disease states. Although one might suspect that the anatomic location of an area of infarction within the left ventricle would be of functional significance, aside from direct injury to the papillary muscles with resultant mitral valve dysfunction, there is little support for this concept. We have previously noted no difference in electrocardiographic locations of infarction in patients with and without shock.44 While some observers feel this is also true for patients with CHF,3 others have reported a higher rate of left heart failure in anterior as opposed to diaphragmatic infarction.16

Prognosis

The prognosis of acute myocardial infarction is clearly related to the presence or absence of complications. Hospitalized patients without complications (class I) have an excellent prognosis. In earlier studies at The New York Hospital,45 hospital mortality was 6% for class I, 17% for class II, and 38% for class III patients. These figures are in accord with reports from others2, 3, 6, 7, 16, 18, 46 in which mortality averages 8% (range 4–10%) for class I, 30.5% (range 15–43%) for class II, and 44% (range 17–68%) for class III.

In our recent survey of 112 consecutive patients with acute myocardial infarction, eight of the 55 with CHF died, a mortality rate of 15%. The cause of death was pulmonary edema or cardiogenic shock in six of eight who died. Mortality in patients who remained in class II or improved during hospitalization was 5%, a rate essentially similar to that in patients who never had clinical evidence of CHF (table 2).

We have demonstrated hemodynamic differences between those patients with CHF who remain class II or subsequently improve, and those whose clinical status deteriorates (fig. 3). Left ventricular end-diastolic pressure averaged 26 mm Hg in patients with CHF who subsequently developed pulmonary edema or shock compared to 22 mm Hg in those who did not develop further complications. Similarly, left ventricular work averaged 2.5 kg-m/min in patients whose clinical status later worsened as opposed to 4.3 kg-m/min for those who remained class II or improved (P < 0.01). Significantly, there is little overlap
Table 2
Prognosis of Heart Failure Complicating Acute Myocardial Infarction (Data from 112 Consecutive Admissions to the Coronary Care Unit)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Total</th>
<th>Lived</th>
<th>Died</th>
<th>Mortality (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild or moderate CHF only (class II throughout or</td>
<td>42</td>
<td>40</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>improved)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulmonary edema (class III) at some time during</td>
<td>8</td>
<td>7</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>hospitalization</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CHF initially, later developed cardiogenic shock</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>All patients with CHF at some time after acute</td>
<td>55</td>
<td>47</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td>myocardial infarction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3
Hemodynamic measurements in patients with heart failure according to subsequent clinical course. Mean heart rate, arterial pressure, cardiac index, and LVEDP of patients who improve and those who remain class II throughout hospitalization do not differ significantly from values observed in patients whose clinical status worsens. The group mean as well as most individual patient measurements of cardiac work was lower in those patients whose status worsened. The data suggest that marked depression of cardiac work may be a clinically useful indicator of poor prognosis.

of individual values for left ventricular work between the two groups, so that calculation of this parameter may allow identification of those patients with poor prognosis. Cardiac
work less than 3.8 kg-m/min is usually associated with clinical deterioration. We have previously reported that most patients with cardiac work less than 3.0 kg-m/min will not survive hospitalization. Rutherford and co-workers also related prognosis to degree of left ventricular dysfunction. They observed that patients with mean pressure in the pulmonary artery greater than 20 mm Hg demonstrated clinical evidence of heart failure, had major arrhythmias, and a mortality of 25%.48

Therapy

The general principles for therapy of acute myocardial infarction apply equally to patients with and without heart failure. Myocardial oxygen demand and cardiac work are minimized by restriction of activity, usually bed rest for several days, relief of pain and anxiety, and dependency of the lower extremities to minimize venous return. Small, easily digested meals, a low-bulk diet, and the use of stool softeners and bedside commode to reduce effort of defecation are usually indicated. Sedation when required and control of body and ambient temperature to reduce metabolic needs are helpful. Correction of hypoxemia, acidosis, and electrolyte abnormalities inhibit adverse cardiac effects. Serious arrhythmias are prevented whenever possible by aggressive treatment of premonitory signs (such as ventricular premature contractions) or otherwise controlled immediately after recognition by appropriate therapy. The potential hazard of venous thromboembolism is reduced by the use of elastic stockings, exercise of lower extremities, and perhaps short-term anticoagulation. In view of the higher incidence of pulmonary emboli in patients with heart failure, anticoagulation should be seriously considered when CHF complicates acute myocardial infarction. Unfortunately, however, hepatic dysfunction associated with CHF may make regulation of dosage of the coumarin derivatives more difficult.

Diuretics

Retention of salt and water in patients following acute myocardial infarction is usually effectively and safely treated with diuretics. In one study, 20 of 25 patients with CHF and myocardial infarction were successfully treated with intravenous furosemide alone, while the remaining five patients responded to subsequent digitalization.15 Sjogren demonstrated a decrease in pulmonary diastolic pressure in each of eight patients receiving furosemide. This was associated with a small but insignificant reduction of cardiac output, mean aortic pressure, and left ventricular stroke work.16

In patients with pulmonary edema following myocardial infarction, cardiac output, stroke volume, and Pao2 rose while heart rate, oxygen consumption, pulmonary artery systolic and diastolic pressures, and serum potassium fell after administration of diuretics.30 Changes were small, however, and not statistically significant.

Although vigorous therapy with potent diuretics may lead to excessive plasma water loss, decreased blood volume, low central venous pressure, and hypotension or shock, these effects of diuretic therapy are uncommon.15,16 Such complications, however, are particularly hazardous in the patient with recent myocardial infarction, and use of the potent diuretics should be closely monitored.

Digitalis

The role of the digitalis glycosides following acute myocardial infarction has been extensively discussed elsewhere in this symposium (see p 891). The administration of digitalis to the patient with recent myocardial infarction has been the subject of both concern about enhanced toxicity and debate regarding effectiveness for many years. One study reported a satisfactory response to digitalis alone in 78% of patients with acute myocardial infarction in whom diuretics were not subsequently needed.7 However, Malmerona et al.,49 Balcon and co-workers,50 and Sjogren16 were unable to show any significant improvement in cardiac output following digitalization in patients with acute myocardial infarction. In unanesthetized dogs digitalis has little effect on ventricular performance in the first few hours.
after acute myocardial infarction but increases cardiac output and lowers LVEDP when administered 1 week after injury.51

The toxic threshold to digitalis decreases in experimental animals after myocardial infarction.52, 53 In man, Morrison and Killip54 noted normal serum glycoside levels in the presence of arrhythmia consistent with digitalis toxicity within the first 24 hours after infarction. After 24 hours, arrhythmias presumed due to digitalis intoxication were associated with serum levels in the generally accepted toxic range. These observations suggest that the patient with acute myocardial infarction may have increased sensitivity to the toxic effects of digitalis in the immediate postinfarction period.

We currently recommend the following schedule for digitalization soon after acute myocardial infarction: digoxin 0.5 mg intravenously administered over 3–5 min as an initial dose, followed by 0.25 mg in 6 hours, followed by 0.125 or 0.25 mg in another 6 hours. Thereafter the patient is maintained on a daily dose of 0.25–0.375 mg/day depending upon response, blood level, renal function, and body size. The intravenous route of administration is preferred in the acutely ill patient, in our opinion, because of uncertainty about retention or absorption of drugs given orally.

Although the use of ouabain has been advocated by some,7 digoxin and ouabain have a similar physiologic and biologic half-life. Since the earlier onset of action of ouabain is seldom of value clinically and maintenance with ouabain is difficult it seems reasonable to use a single drug, digoxin, both for initial and maintenance therapy.

It is useful to monitor the blood level of the digitalis preparation, especially when renal function is abnormal or serious ventricular arrhythmias develop. Serum level is best maintained for digoxin between 0.7 and 1.4 ng/ml and for digitoxin between 15 and 30 ng/ml for reasonable effectiveness and minimal toxic risk.

Oxygen

Our current practice is to administer oxygen by nasal prongs or face mask at flow rates of 4–6 liters/min for the first 2–3 days after acute myocardial infarction. This modest increase in inspired oxygen aids in keeping arterial oxygen tension in the normal range or slightly above in the patient with mild or moderate CHF. Patients with pulmonary edema or cardiogenic shock may require higher concentrations of inspired oxygen (e.g. venturi mask or even 100% oxygen by respirator) and even then it is often impossible to achieve normal arterial oxygen tension in the most critically ill patients. Even though arterial desaturation may be improved by oxygen administration, dyspnea or tachypnea, perhaps more related to changes in lung compliance, is seldom relieved in patients with CHF.59

Alterations in Ventricular Preload

It has been suggested that myocardial performance could be optimized in critical clinical situations by adjusting blood volume and thereby regulating ventricular filling pressure.55 There is some evidence that following acute myocardial infarction the peak of the ventricular length-tension curve occurs with left ventricular filling pressures in the range of 20 to 24 mm Hg and that when filling pressures exceed this level there is little improvement in ventricular performance.55

The potential for improving myocardial function by increasing volume and utilizing the Frank-Starling mechanism appears limited in patients with acute myocardial infarction, since none of our patients with CHF had LVEDP below 16 mm Hg and only six of 22 patients had LVEDP 20 mm Hg or less when first studied.

Treatment of Pulmonary Edema

When pulmonary edema complicates acute myocardial infarction, left ventricular diastolic pressure is usually 30 mm Hg or more. Hypoxemia, tachycardia, and occasionally acute respiratory acidosis further compromise cardiac function.56 Progressive clinical deterioration is frequent unless left ventricular filling pressure is reduced as quickly and effectively as possible.

Intravenous morphine sulfate (5–10 mg) decreases venous return, lowers pulmonary
capillary pressures, and relieves anxiety. The drug usually produces considerable clinical improvement within 15–30 min. Rotating tourniquets also decrease venous return and pulmonary capillary pressure. In dire circumstances, or when all else fails, rapid phlebotomy of 250–500 cc of blood may be the most effective way to reduce intravascular volume and venous return. Intravenous administration of a potent diuretic such as furosemide 40–50 mg or ethacrynic acid 50–100 mg generally results in significant diuresis within 30–60 min, although the usefulness of these agents in the treatment of acute pulmonary edema is controversial.\textsuperscript{57} Increased concentration of inspired oxygen may improve arterial oxygen saturation, and where possible intermittent or continuous positive pressure respiration may aid in reducing venous return. While digitalis preparations are helpful in controlling the rapid ventricular response of atrial tachycardia, flutter, or fibrillation, the positive inotropic effects of even the most rapid acting digitalis preparations are much less dramatic in relieving signs and symptoms of pulmonary edema than are morphine, oxygen, and tourniquets. More cautious use of digitalis after the acute emergency is past is frequently indicated; careful and deliberate usage will greatly lower the incidence of toxic reactions to digitalis.

Conclusion

Although descriptions of clinical and hemodynamic abnormalities in the patient with CHF and acute myocardial infarction are now available, important questions remain unanswered.

The pathogenesis of heart failure is not yet fully explained. It is probable that the extent of damage to left ventricular myocardium, both acute and chronic, is paramount. Post-mortem studies confirm a relationship between size of infarction and death from cardiogenic shock, but direct confirmation of the postulate that patients with CHF have more myocardial injury than those without failure is lacking. Quantification of myocardial damage and correlation with clinical and hemodynamic events during life are needed.

The role of alterations in ventricular geometry in the genesis of CHF is unclear. Localized or generalized abnormalities of ventricular contraction are common after acute infarction, but the functional consequences and natural history of such abnormalities remain to be elucidated.

Recent observations from many laboratories indicate that ventricular dysfunction is common after myocardial infarction, whether or not clinical evidence of CHF is noted. Of particular interest is the extraordinary frequency of elevated left ventricular filling pressure, regardless of clinical status. There are indications, both experimental and clinical, that alteration of ventricular compliance plays a significant role in the genesis of abnormal filling pressure associated with recent infarction of the ventricle. The cause, however, remains a subject of considerable interest and debate. Further resolution of this problem awaits safe, accurate, and reproducible measurement of ventricular volume in the acutely ill patient.

Many important questions remain unanswered regarding effectiveness of various modes of therapy for CHF. The potent diuretics appear to be safe and effective when used with care. Digitalis is useful but serial studies of ventricular hemodynamics and metabolism are needed to clarify indications for administration. Preliminary data from animals and man suggest increased sensitivity to toxic effects of digitalis soon after myocardial infarction. Confirmation and extension of these observations will be awaited with interest.

Prognosis of patients with CHF is less favorable than for those with uncomplicated myocardial infarction. Recent studies suggest that patients with a high risk of developing more severe CHF, pulmonary edema, or cardiogenic shock can be identified from an analysis of ventricular performance, especially cardiac work. Early identification of the patient whose condition is likely to deteriorate and the application of more aggressive therapy such as intraaortic balloon counterpulsation might prevent serious complications and
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reduce morbidity and mortality associated with this common condition.

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