A Decision Scheme for Coronary Angiography After Acute Myocardial Infarction

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It is important to select patients in the convalescent phase of acute myocardial infarction in whom knowledge of coronary anatomy may identify those potentially suitable for intervention aimed at improving prognosis. However, differing guidelines have been proposed, and by applying some of these guidelines to our large database of patients after acute myocardial infarction, several problem areas were identified. These include lack of considering patients with resting ischemia beyond day 5 of hospitalization, management of patients with reduced ventricular function or patients not exercise tested, and the role of coronary angiography in the elderly. Based on this experience and further analyses in 1,848 patients surviving beyond day 5 of hospitalization, a modified decision scheme for coronary angiography was developed and then tested in a second population (n=780). In the new scheme, patients over 75 years of age are considered individually. Those under 75 years of age with severe resting ischemia in the hospital at any time beyond the first 24 hours (18% mortality between day 6 and year 1), and hospital survivors with a history of previous myocardial infarction and clinical or radiographic signs of left ventricular failure in the hospital (25% 1-year mortality after discharge), are recommended for coronary angiography. Among the remaining patients, some will perform an exercise test, and those with an ischemic response or poor workload (11% 1-year mortality) are also assigned to coronary angiography. When an exercise test is not performed, a resting radionuclide left ventricular ejection fraction is recommended, and coronary angiography is considered if the value lies between 0.20 and 0.44 (12% 1-year mortality). This relatively simple scheme does not make general recommendations in the elderly, considers patients with in-hospital left ventricular failure or reduced left ventricular function or both, and approaches the problem of patients who do not perform an exercise test. This general approach would avoid early coronary angiography in patients with an average 1-year mortality risk after discharge of 3% and recommend coronary angiography in those at increased risk (average mortality rate, 16%) who make up about 55% of this population under 75 years of age. (Circulation 1989;79:292–303)

After patients are admitted for acute myocardial infarction, mortality decreases over time following a biexponential curve, in which 50% of 1-year mortality occurs by 3 weeks and 75% occurs by 3 months. Therefore, it is important to identify patients at increased risk relatively early so that they can be considered for coronary angiography and revascularization to improve their prognosis. However, the decision process concerning coronary angiography in the convalescent phase of acute myocardial infarction remains controversial, and this procedure can be overused as well as underused. A Joint Task Force of the American College of Cardiology and the American Heart Association has recently published guidelines for selecting patients for coronary angiography, including patients after acute myocardial infarction. Also, a scheme was published, which was derived from a literature review and consensus among a group of cardiologists, that proposed guidelines for distinguishing low- from high-risk patients and for managing patients within the risk groups.

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Application of these two consensus-based guidelines to our large population of patients with acute myocardial infarction identified several problems. Therefore, the goal of this study was to develop a modified scheme to identify in a simple manner patients at high risk of 1-year mortality who survive day 5 of hospitalization, in whom knowledge of coronary anatomy may lead to revascularization and reduced risk of death. The new scheme was developed in one group of patients and then tested in a separate group of patients, both analyses being performed retrospectively.

Methods

Patients and Materials

The study population consisted of 1,848 patients with acute myocardial infarction who survived day 5 of hospitalization, of whom 1,738 were discharged from the hospital and followed until death or for 1 year. Patients were enrolled from January 1, 1979, to August 1, 1984. The mean age was 64±12 years (mean±SD) and ranged from 19 to 95 years. The diagnosis of acute myocardial infarction was established by at least two of the following criteria: characteristic chest pain, evolution of typical electrocardiographic changes, and elevated creatine kinase levels. Diagnosis of non-Q wave infarction required both typical ST segment and T wave changes and elevated creatine kinase levels. Patients were admitted within 24 hours after the onset of symptoms to the University of California San Diego Medical Center (13%), San Diego Veterans Administration Medical Center (13%), Naval Hospital of San Diego (17%), and Vancouver General Hospital, British Columbia, Canada (57%). Data concerning these patients were gathered prospectively and entered into a database supported by the Specialized Center of Research on Ischemic Heart Disease at the University of California San Diego.

Details concerning the exact variables recorded and their definitions are described elsewhere. Resting ischemic pain was defined as persistent chest pain of ischemic type with or without associated electrocardiographic changes. In this study, left ventricular failure was determined to be present if pulmonary edema of grade 2 or higher was observed on the chest radiograph or if the patient had both an apical S3 gallop and pulmonary rales (bibasilar or higher); these findings did not have to be observed simultaneously. This definition was used because the presence of clinical heart failure adds greatly to the predictive power of the left ventricular ejection fraction. In our population, patients with pulmonary edema on the chest radiograph have higher 1-year mortality than those without even if the ejection fraction is 0.51 or greater (13% vs. 5%), a difference that is also present if the ejection fraction is less than 0.40 (35% vs. 15%, p<0.001). Data from the radionuclide left ventricular ejection fraction, left ventriculography at the time of cardiac catheterization, and the exercise test were included if these studies were performed within 6 weeks of hospital discharge.14,18 These studies were optional, and performance of a radionuclide left ventricular ejection fraction or an exercise test required the patient to sign an additional consent form if these tests were not ordered by the attending physician.

Among the exercise tests evaluated, 21% were performed with a standard Bruce protocol, 53% with a modified Bruce (Sheffield) protocol, 6% with a modified Balke protocol, and 20% with other protocols selected by the attending physician. Exercise was stopped because of angina in 16% of patients, pronounced ST segment changes (at least 2-mm depression or elevation) in 8%, fatigue in 48%, shortness of breath in 18%, claudication in 5%, severe dysrhythmia in 2%, and attainment of target heart rate in 17%. More than one limiting condition was noted in some patients.

We have previously examined the prognostic value of exercise testing in our database. Because 1 mm ST segment depression was not of prognostic value in our population and because one of the risk stratification schemes we evaluated considered an exercise test positive for ischemia if 2 mm or more ST segment depression occurred, we adopted this criterion. Again, based on our experience, a workload criterion was also used to define a positive test. Patients unable to achieve at least 4 metabolic exercise equivalents (METS) (1 MET = amount of oxygen used at rest) were considered to have a positive test. The number of METS was calculated from the predicted oxygen consumption in the exercise test protocols; oxygen consumption was not measured directly. Only patients able to achieve 4 METS or more without exercise-induced ischemia were considered to have a negative test. Nineteen tests were stopped because of achievement of 70% of maximum heart rate (a target endpoint for one hospital) without reaching 4 METS or experiencing ischemia; these tests were considered indeterminant.

The presence of complex ventricular arrhythmias during 24-hour ambulatory electrocardiographic monitoring was defined as frequent ventricular premature beats (more than 1 beat/min or 30 beats/hr), multiform ventricular premature beats, early ventricular premature beats (R on T phenomenon), or ventricular tachycardia (more than three consecutive ventricular premature beats).

Scheme Development

The new scheme was based on findings in previous analyses of our population, as well as by grouping our population retrospectively into various subsets indicated by a number of previous reports, to identify subgroups at high risk of cardiac death in the 1st year. In patients older than 75 years of age, deaths from hospital day 6 to 1 year after admission were considered, and because of the high mortality observed, these patients were not
followed during the first 5 days. Clinical data gathered excluded those who survived to be discharged from the hospital and who were followed until death or for 1 year. Clinical data gathered within the first 5 days were used for early stratification, as in a recent report, and the exercise test and radionuclide left ventricular ejection fraction were used for stratification close to the time of hospital discharge.

Validation

The scheme derived from the above analysis was then tested in a new series of patients (n = 780) admitted from August 1, 1984, to June 1, 1986, to the original study centers and two additional hospitals: Sharp Memorial Hospital in San Diego, and Hôpital Cantonal in Geneva, Switzerland. The criteria for study entry and data collection protocols were the same as for the original 1,848 patients. The scheme was applied retrospectively to this patient cohort to determine whether or not similar group sizes and mortalities were obtained.

Follow-up

Patient follow-up was performed by telephone at 3, 6, and 12 months after admission. Information concerning deaths was obtained from hospital records and the death certificate in most instances. For some patients, telephone interviews with the personal physician or family members were carried out to clarify details. All data were reviewed by a research physician, and when some doubt occurred as to the cause of death (over 60% of deaths), a committee reviewed available data, obtained additional information when needed, and reached a consensus opinion. Cardiac deaths to 1 year, including new fatal myocardial infarction, congestive heart failure, deaths associated with cardiac procedures or surgery, and sudden deaths, were analyzed. Sudden cardiac death was defined as death caused by documented fatal arrhythmia or an unexpected death that did not have an apparent cause. When sudden death was due to documented fatal arrhythmias, death occurred within minutes. Most of the remaining patients were found dead by relatives, some within minutes after death and others up to a day after death. One-year follow-up of eligible patients was 99% in the original series at the time of this analysis and 95% in the test series.

Statistics

Where appropriate, comparisons of group mortalities were made with the χ² test with Yate's correction. In Figure 2, 95% confidence limits are shown for 1-year mortalities in subgroups. To assess the impact of revascularization, actuarial mortality rates were also computed for each subgroup, with patients who had undergone revascularization withdrawn at the time of their procedure.

Results

Original Population

The proposed scheme, presented in Figure 1, was applied to the original population of 1,848 patients.

Age. In 307 patients over 75 years of age (17% of the population), mortality was 31% from day 6 to year 1 (Figure 2). Among those surviving to hospital discharge, mortality was 22% from time of dis-
charge to year 1. Among 254 patients less than 50 years of age surviving to hospital discharge, 1-year mortality was 2%. These younger patients were not considered separately.

Resting ischemic pain. Of patients 75 years of age or less, 307 (17% of the total population) had recurrent or persistent ischemic pain beyond the first 24 hours (Figure 1), and their mortality was 18% from day 6 to year 1 (Figure 2).

Hospital survivors. In the remaining patients (n=1,189; Table 1) surviving to hospital discharge, 1-year cardiac mortality after discharge was 9%, and total mortality was 10%. A high-risk subgroup was defined when both a history of previous myocardial infarction was present and in-hospital left ventricular failure occurred at some time during the first 5 days. This group comprised 13% (151 of 1,189) of the patients stratified at discharge, and 25% died within 1 year (Figure 2).

To further stratify patients not in the high-risk group, we evaluated the exercise test and the radionuclide left ventricular ejection fraction, first in patients (n=231) with both studies. In patients with a positive exercise test, 1-year mortality was 13% (9 of 71) compared with 2% (3 of 160) for patients with a negative test (p<0.001). Identical results were achieved with a left ventricular ejection fraction of less than 0.45 used to define high risk. Mortality at year 1 was 13% (2 of 67) for patients with a left ventricular ejection fraction less than 0.45 compared with 2% (3 of 162) for a left ventricular ejection fraction of 0.45 or greater. Following the approach of Fioretti et al,9 the exercise test was used for stratification, and if not performed or if indeterminant, the results of radionuclide left ventricular ejection fractions were evaluated (Figure 1).

Altogether 32% (373 of 1,189) of patients stratified at hospital discharge performed an adequate exercise test. One-year mortality was 16% (5 of 31)

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### Table 1. Subgroup Sizes for Scheme of Figure 1

<table>
<thead>
<tr>
<th>Original population (n=1,848)</th>
<th>Test population (n=780)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age&gt;75 years</td>
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</tr>
<tr>
<td>Resting ischemia</td>
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<td>Remaining patients</td>
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<table>
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<th>Patients stratified at discharge (n=1,189)</th>
<th>(n=469)</th>
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<tr>
<td>Previous MI plus LVF days 1-5</td>
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</tr>
<tr>
<td>Exercise negative</td>
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<tr>
<td>Exercise positive</td>
<td>9</td>
</tr>
<tr>
<td>No exercise test or indeterminant</td>
<td>56</td>
</tr>
</tbody>
</table>

<table>
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<th>Patients eligible for RN ventriculography (n=665)</th>
<th>(n=186)</th>
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<tbody>
<tr>
<td>LVEF≥0.45</td>
<td>36</td>
</tr>
<tr>
<td>LVEF 0.20-0.44</td>
<td>19</td>
</tr>
<tr>
<td>LVEF&lt;0.20</td>
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</tr>
<tr>
<td>No LVEF</td>
<td>44</td>
</tr>
</tbody>
</table>

Data are percentages of number given in the heading immediately above.

LVF, left ventricular failure; LVEF, left ventricular ejection fraction; RN, radionuclide.

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**Figure 2.** Bar graph of 1-year mortality rates for subgroups determined by the scheme in Figure 1. Mortalities are given from day 6 to year 1 after hospital discharge for the groups identified by early period stratification (resting ischemia and age >75 years). For the remaining subgroups, mortalities are given from the time of hospital discharge to 1 year after discharge. Vertical lines show 95% confidence limits for the percent mortalities. Coronary angiography is recommended for groups in stippled boxes. Not shown are patients with a left ventricular ejection fraction less than 0.20 and patients who had neither an exercise test nor left ventricular ejection fraction determination. LVEF, left ventricular ejection fraction; MI, myocardial infarction; LVF, left ventricular failure.
for patients unable to achieve at least 4 METS, 7% (4 of 59) for patients with 2 mm or greater ST segment depression, and 20% (3 of 15) if both criteria were present. By combining these three distinct groups with positive exercise responses, an overall 1-year mortality of 11% (12 of 105) occurred compared with 3% (7 of 268) for patients without criteria \( (p < 0.001) \). The reasons for stopping exercise in the 46 patients unable to achieve 4 METS were angina in 11 patients, ST changes in seven patients, fatigue in 19 patients, shortness of breath in 11 patients, claudication in four patients, and dysrhythmia in two patients. More than one reason was noted for some patients. Mortality for patients not exercised was 7% (48 of 655) compared with 5% (19 of 373) for those exercised.

If an exercise test was not performed or stopped at low workload for any reason not due to ability to exercise further, radionuclide left ventriculography was used to further stratify the patients. Patients with a left ventricular ejection fraction between 0.20 and 0.44 had a 1-year mortality of 12% (15 of 128) compared with 4.6% (11 of 240) in those not exercised with left ventricular ejection fraction 0.45 or greater \( (p < 0.02) \) (Figure 2). Only nine patients had a left ventricular ejection fraction less than 0.20, and three died within 1 year (not shown in Figures 1 and 2).

In the subgroup of patients not exercise tested with a left ventricular ejection fraction between 0.20 and 0.44, 71% underwent 24-hour ambulatory electrocardiographic monitoring. Although all patients in our population are considered, those with complex ventricular ectopy had a higher 1-year mortality than those without (17% vs. 9%, respectively; \( p < 0.001 \)); in the subgroup being considered, this was not the case. In fact, mortality was slightly lower for patients with complex ventricular ectopy compared with those without (13% vs. 15%, respectively; NS). Therefore, such monitoring was not used to stratify further these selected patients with a depressed ejection fraction.

Of patients without an exercise test, 43% (288 of 665) also did not have a left ventricular ejection fraction; 1-year mortality for this group was 7% (not shown in Figures 1 and 2).

**Validation**

The scheme shown in Figure 1 was also applied in the test population of 780 patients (numbers shown in parentheses, Figure 1). The group sizes (Table 1) and the 1-year mortalities (Figure 2) for most groups agreed reasonably well with those in the original population. In the test population, 14% (110 of 780) of the patients were over 75 years of age, with 28% mortality between day 6 and year 1 (Figure 2) and 20% mortality between hospital discharge and year 1. Patients 75 years of age or less with resting ischemia composed 24% (186 of 780) of the population (Table 1), and 19% died between day 6 and year 1 (Figure 2).

Fourteen percent (67 of 469) of the remaining test population discharged from the hospital had previous myocardial infarction with left ventricular failure on days 1 through 5. One-year mortality was 21% in this group (Figure 2).

Among the patients who could have been considered for exercise testing, 54% (216 of 402) had adequate tests (increased from 32% in the original population). In patients exercise tested who had a negative test, mortality was 1% (1 of 137); of the patients with exercise-induced ischemia or poor workload, 6% died (5 of 79) \( (p < 0.05) \), Figure 2). As observed in the original population, mortality in patients without an exercise test (11%, 20 of 186) was higher than in those with a test (3%, 6 of 216).

Patients in the test population with a left ventricular ejection fraction from 0.20 to 0.44 had a 1-year mortality of 12% (5 of 42) (Figure 2) compared with 6% (3 of 52) for those with left ventricular ejection fraction 0.45 or greater. Only two patients had a left ventricular ejection fraction less than 0.20, one of whom died. In patients with neither an exercise test nor a radionuclide left ventricular ejection fraction (48%, 90 of 186), 1-year mortality was 12% (11 of 90).

**Interventions**

The rates of coronary angiography by 6 weeks and revascularization by 1 year are shown in Table 2 in the subgroups portrayed in Figures 1 and 2 for both the original and test populations. Patients with revascularization by 1 year may not have had coronary angiography within 6 weeks. Also, the decision to perform a given procedure was made by the individual physician and not necessarily according to the scheme proposed. There were no procedures in the acute phase (day 1) of infarction in the original population.

**Yield for revascularization.** In the original and test populations, patients with a positive exercise test tended to have more revascularizations performed beyond the acute phase than those with a negative exercise test (20–24% vs. 9–10%, respectively). Even though the rate of coronary angiography increased to 39% in the test sample for patients with a negative exercise test from 17% in the original population, the rate of nonacute revascularization in both populations remained about the same (9–10%) (Table 2).

In patients with a left ventricular ejection fraction between 0.20 and 0.44, the rate of coronary angiography (9–14%) is lower than for patients with a left ventricular ejection fraction 0.45 or greater (16–17%). Because of the small numbers involved, it is difficult to compare the revascularization rates for these subgroups. However, many of the revascularizations performed were later in the year after the patients had experienced problems, a trend also noted in the subgroup with previous myocardial infarction and left ventricular failure.

The rate of coronary angiography for patients with resting ischemia has increased threefold from
21% to 60% in the original and test populations, respectively. However, the rate of nonacute revascularizations has only increased by about 50% from 21% to 32%. Few acute revascularizations were performed (Table 2).

In patients with neither an exercise test nor a radionuclide left ventricular ejection fraction, the rate of coronary angiography has increased substantially in the test population compared with the original population from 8% to 59%. In the test population, only 8% (34 of 469) of patients eligible for discharge evaluation were not studied (including coronary angiography) compared with 22% (266 of 1,189) in the original population. Presently, many patients have coronary angiography as their first means of evaluation. The rate of revascularization also increased in the test population (Table 2).

**Mortality.** To examine the impact of revascularization on mortality, actuarial 1-year mortality rates were computed for each subgroup depicted in Figures 1 and 2, with patients who had revascularization withdrawn at the time of their procedure. Thus, this analysis assumes that patients with procedures are no longer at risk of cardiac death. If this were the case, the actuarial 1-year mortalities should be somewhat higher than the unadjusted mortalities because the denominator in the mortality computation is decreased while the numerator remains the same. In fact, some deaths were attributed to the revascularization procedures, and some deaths occurred later despite revascularization (Table 2). Because these patients were withdrawn from the analysis at the time of revascularization, the actuarial mortality rates tended to remain the same or to decrease for subgroups with such deaths (compare actuarial with 1-year percent mortality figures, Table 2), especially when the subgroup size was small.

**Discussion**

The proposed scheme (Figure 1) aims to identify patients at increased risk of cardiac death within 1 year after acute myocardial infarction in whom evaluation by coronary angiography early in the convalescent phase may lead to intervention that could lower this risk. The scheme considers at increased risk 1) patients who have persistent or recurrent early ischemic pain at rest, 2) previous infarction with evidence of left ventricular failure at some time in the early phase, 3) an abnormal exercise test, and 4) those not exercise tested, a reduced ejection fraction from 0.20 to 0.44 (Figures 1 and 2).

**Age**

No general recommendations are made for coronary angiography in patients over 75 years of age, because it is likely that management in this high-risk group will be highly individualized. This approach is not intended to minimize the need for coronary angiography in some of these patients, and further studies in the elderly may identify subgroups that

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**Table 2. Intervention and Impact on 1-Year Mortality**

<table>
<thead>
<tr>
<th>Population</th>
<th>Exercise negative</th>
<th>Exercise positive</th>
<th>LVEF ≥0.45</th>
<th>LVEF 0.20-0.44</th>
<th>Previous MI and LVF days 1-5</th>
<th>Resting ischemia</th>
<th>Age &gt;75 years</th>
<th>No exercise test or LVEF</th>
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<tr>
<td></td>
<td>Orig Test</td>
<td>Orig Test</td>
<td>Orig Test</td>
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<td>Population</td>
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<td>105 79</td>
<td>240 52</td>
<td>128 42</td>
<td>151 67</td>
<td>307 186</td>
<td>307 110</td>
<td>288 90</td>
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<td>Angiograms to 6 weeks</td>
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<td>38 9</td>
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<td>%</td>
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<td>4.6 5.8</td>
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<td>2 2</td>
<td>0 3</td>
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<td>Actuarial death rate</td>
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<td>11.9 4.4</td>
<td>4.3 6.2</td>
<td>10.9 12.0</td>
<td>25.7 20.8</td>
<td>18.1 18.3</td>
<td>31.2 25.5</td>
<td>6.6 12.8</td>
</tr>
</tbody>
</table>

LVEF, left ventricular ejection fraction; MI, myocardial infarction; LVF, left ventricular failure.

*Patients with procedures withdrawn at the time of procedure.
†Includes 2 deaths attributed to coronary angiography.
‡Includes 1 death attributed to coronary angiography.
§Includes 1 death attributed to coronary angiography.
could benefit from further evaluation.\textsuperscript{20} Also, the scheme does not place young patients (less than 50 years of age) in a special group because the issue of whether or not to perform coronary angiography in all young patients after myocardial infarction remains controversial.\textsuperscript{10} Several reports have noted that the yield of multivessel disease is low in patients less than 60 years of age when all such patients undergo coronary angiography.\textsuperscript{4,20,21} In 91 patients under 60 years of age, eight of nine patients with either left main stenosis, three-vessel disease, or disease of the proximal left anterior descending coronary artery had positive treadmill tests, and it was suggested that coronary angiography should be restricted to patients in this age group with positive exercise tests.\textsuperscript{4} In our original population, all young patients who died by 1 year after hospital discharge were included in one of the subgroups for which coronary angiography is recommended, a finding that favors not performing coronary angiography in all young patients after myocardial infarction. However, in young patients, the costs and risks of coronary angiography relative to the potential long-range reduction of mortality and morbidity resulting from subsequent intervention are unknown. The unsettled nature of this issue, as well as that of the general role of coronary angiography after myocardial infarction, is exemplified by our database in which marked variability currently exists in the use of coronary angiography during the convalescent phase, which ranged from 12\% to 52\% among the different hospitals in the test sample.

**Resting Ischemic Pain**

There is wide agreement that patients with ongoing or recurrent ischemic chest pain after acute myocardial infarction should undergo coronary angiography promptly.\textsuperscript{10,11} We found a high mortality rate in this group, as reported by others. Early coronary angiography and revascularization may be beneficial in such patients.\textsuperscript{22}

**Further Stratification**

Among patients without resting ischemic pain, the proposed scheme recognizes that certain patients are at increased risk due to a previous myocardial infarction in combination with early heart failure and should be evaluated further in an effort to reduce their high 1-year mortality. Thus, it seems reasonable to determine whether or not another, often fatal, event may be prevented; such patients composed about 14\% of the group without ischemic pain. This high-risk subgroup was defined to include only those patients well enough to be discharged from the hospital, although it is unlikely that all such patients will be suitable for coronary angiography. In this group, 70\% (79 of 113) of those having a radionuclide left ventriculogram had an ejection fraction less than 0.45, but in only 9\% (12 of 113) was it less than 0.20.

The purpose of performing coronary angiography in patients with previous myocardial infarction and in-hospital heart failure, and in patients who later have a depressed ejection fraction between 0.20 and 0.44, would be to identify patients who may be candidates for coronary bypass surgery or coronary angioplasty. We have previously shown that a breakpoint at 0.45 provides optimum sensitivity and specificity for prognosis.\textsuperscript{14} In nonrandomized studies of patients with chronic coronary heart disease, those with considerably depressed left ventricular function appear to have increased survival with surgical therapy compared with medical therapy.\textsuperscript{23,24} In one study, preoperative left ventricular ejection fraction values were less than 0.35,\textsuperscript{23} and in another study, values were less than 0.25\textsuperscript{24}; in both reports, most patients who were treated surgically had significant chronic angina pectoris or unstable angina and differed from the postinfarction population under discussion. These studies, however, do suggest the possibility of successful treatment by surgery (or angioplasty) in patients with poor ventricular function associated with regions of the left ventricle at risk.\textsuperscript{23,24} In the proposed scheme, we do not recommend coronary angiography in patients with a left ventricular ejection fraction less than 0.20.

In the postinfarction population, as well as in chronic coronary heart disease, there is increasing interest in identifying patients at high risk because of left ventricular dysfunction who may have potentially reversible areas of dysfunction due to hypoperfusion or to stunning, with or without silent ischemia.\textsuperscript{25} Electrocardiographic and thallium exercise testing or radionuclide ejection fraction studies during exercise in some patients may detect the presence or effects of ischemia distant from the site of infarction.\textsuperscript{10} In those unable to exercise, a dipyridamole thallium test may prove useful.\textsuperscript{26} Metabolic studies at rest by positron emission tomography with \textsuperscript{18}F-labeled 2-fluoro-2-deoxyglucose to identify increased glucose metabolism and N-13 ammonia to assess myocardial perfusion\textsuperscript{27} may identify areas of dysfunctional but perfused (stunned or "hibernating")\textsuperscript{25,26} myocardium in which the dysfunction is potentially reversible.\textsuperscript{29} However, coronary angiography and left ventriculography will be required for definitive assessment of the potential for revascularization in such patients.

**Exercise testing.** In both the original and test populations, exercise testing identified a very low-risk group (1–3\% 1-year mortality) in patients achieving at least 4 METS without evidence of ischemia. In both populations, a positive exercise test (either 2 mm ST segment depression or failure to achieve 4 METS) identified a relatively high-risk group (6–11\% 1-year mortality) (Figure 2). In a recent study, "meta-analytic" techniques showed that workload variables more consistently predicted outcome than criteria based on ST segment depression in the 23 centers surveyed.\textsuperscript{30} Therefore, in the new scheme, workload and ischemic criteria are combined.
In our population, not all patients eligible for exercise testing performed an exercise test; these patients were evaluated further by the results of the radionuclide left ventricular ejection fraction. Patients with a left ventricular ejection fraction 0.45 or greater were not recommended for coronary angiography. However, if there is no reason that an exercise test cannot be performed, even if the ejection fraction exceeds 0.45, every effort should be made to obtain one. Among the patients who had a positive exercise test, 54% of those who also had a radionuclide left ventricular ejection fraction (70% of that subgroup) had an ejection fraction 0.45 or greater, thus indicating that some patients at potentially increased risk can remain in that subgroup (exercise-positive, Figure 2).

Impact of Intervention

Because the recommendations we have proposed were not applied prospectively, it is difficult to evaluate the impact of coronary angiography in the subgroups for which this procedure is recommended. The retrospective data in Table 2 suggest that the impact of revascularization on 1-year cardiac mortality in our population is slight. Further studies are planned to investigate this issue.

Management patterns are rapidly changing as reflected by the increased rates of coronary angiography in the test compared with the original population (Table 2). Despite these increases, the rates of nonacute revascularization in some categories have remained the same because not all patients undergoing coronary angiography have indications for revascularization or are suitable candidates. For example, among the 13 patients undergoing coronary angiography in the test sample who had previous myocardial infarction and left ventricular failure on days 1–5 (Table 2), one had acute angioplasty, one died early (day 19), four had coronary artery bypass grafting, and seven were not revascularized. Of these seven, four had three-vessel disease, two of whom were not revascularized because of depressed left ventricular ejection fraction (0.15 and 0.20) and two because they had no angina. In the three remaining patients, two had one-vessel disease and one had two-vessel disease that the attending physician did not consider extensive enough to warrant revascularization.

Assessment of Two Other Schemes in This Population

The rationale for the proposed scheme was derived from a preliminary analysis of our population with guidelines proposed in two recent consensus-based reports.10,11 discussed below, together with features suggested by our own and other studies concerned with risk stratification after acute myocardial infarction.2–9,13,14,16

Joint Task Force. A subcommittee of the Task Force on Cardiovascular Procedures and Therapy of the American College of Cardiology and the American Heart Association has provided guide-

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Percentage of original population</th>
<th>Percent 1-year mortality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ischemic pain</td>
<td>7</td>
<td>15</td>
</tr>
<tr>
<td>Clinical heart failure</td>
<td>42</td>
<td>17</td>
</tr>
<tr>
<td>Left ventricular ejection fraction &lt;0.45</td>
<td>25</td>
<td>19</td>
</tr>
<tr>
<td>Exercise-induced ischemia</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Non-Q wave myocardial infarction</td>
<td>22</td>
<td>14</td>
</tr>
<tr>
<td>Any of the above</td>
<td>65</td>
<td>14</td>
</tr>
<tr>
<td>None of the above</td>
<td>35</td>
<td>5</td>
</tr>
</tbody>
</table>

lines on which general agreement exists that coronary angiography is appropriate for certain subgroups in the convalescent phase of acute myocardial infarction.10 No age criteria were suggested in that report. Table 3 shows the Task Force criteria applied to our original population of 1,738 patients of all ages who survived hospitalization. Resting ischemic pain was one criterion, especially in the early convalescent phase (day 7 or later), and mortality was 15% (Table 3). This finding prompted the recommendation of coronary angiography in our scheme for patients with recurrent resting ischemia at any time in the hospital after day 1 (Figure 1), which differs from the 2–5-day period in the other consensus-based scheme11 (see below).

In the Task Force report, clinical heart failure was another criterion, and 42% of our patients had early (day 1–5) clinical signs of left ventricular failure with 17% mortality (Table 3). However, some were elderly and suffering from recurrent infarction. Therefore, in the new scheme, we grouped the elderly separately, and among the remaining patients, we identified a high-risk group by the presence of previous myocardial infarction together with clinical signs of early left ventricular failure (Figure 1).

According to the Task Force guidelines, patients with reduced left ventricular ejection fraction (<0.45), particularly those with severe ventricular arrhythmias, should undergo coronary angiography. In our population, 1-year mortality in patients with reduced left ventricular ejection fraction was 19% (Table 3). Although the presence of advanced ventricular ectopy is highly associated with 1-year mortality in our population as a whole,14 as in other studies,17,31,32 this factor carried the same mortality in patients with or without ventricular ectopy when patients with an exercise test were eliminated. Therefore, in the new scheme, ambulatory electrocardiographic monitoring is not routinely recommended to further define risk in the subgroup with depressed ejection fraction.

Patients with non–Q wave myocardial infarction were recommended for coronary angiography by
the Task Force. In our population (without age restriction), 1-year mortality for this group was 14% (Table 3). However, most nonsurvivors could also be identified by other conventional factors such as advanced age or the presence of previous myocardial infarction, which tend to be more prevalent in patients with non–Q wave infarction. One-year mortality after hospital discharge was the same in patients under 70 years of age with a first myocardial infarction for patients with Q wave (4.4%) and non–Q wave (5.3%) infarction. Therefore, we have not recommended in the new scheme that this subgroup as a whole undergo coronary angiography. The question of whether or not all patients with non–Q wave myocardial infarction may benefit over the longer term (beyond 1 year) from coronary angiography because of increased risk of reinfarction could not be answered in our database and remains unsettled.

Combining all of the Task Force guidelines for coronary angiography (Table 3) yielded a group composing 65% of our population with 14% average 1-year mortality. Mortality in the remaining patients was 5%. Although there was significant overlap among the groups, collectively the Task Force guidelines performed well in our entire population, supporting their usefulness.

Consensus scheme. According to another consensus-based scheme (Figure 3), patients surviving until hospital discharge are divided into three groups based on observations during the first 5 days after admission. Those with ongoing severe myocardial ischemia are considered to be at very high risk, and early coronary angiography is recommended. Among the remaining patients, those with severe “pump failure” (Killip Class III or IV) are also identified as being at very high risk, and medical therapy is recommended. Other patients are assessed near the time of hospital discharge, and those with an infarction estimated to be more than 35% of the left ventricle or with a radionuclide left ventricular ejection fraction less than 0.35 are also considered to be at very high risk, and medical therapy is recommended. In the remaining patients, a submaximal exercise test is recommended before discharge (days 7–14), and coronary angiography is recommended if the test is positive for ischemia (≥2 mm ST segment depression or failure of systolic blood pressure to rise at least 10 mm Hg). A second, symptom-limited maximal test is recommended at days 21–24, and patients who show ischemia are advised to undergo coronary angiography (not shown in Figure 3).

Several problems with this scheme were encountered in applying it in our population. Again, no age criteria were suggested, and the scheme was applied in the 1,738 patients of all ages who survived hospitalization. Mortality was high (29%) in our population with early severe pump failure (30% expected, Figure 3), but 23% of the patients in this group were exercise tested, and 8% underwent coronary bypass surgery. Also, 23% of patients with left ventricular ejection fraction less than 0.35 on predischARGE evaluation (severe left ventricular dysfunction, Figure 3) were exercise tested, and in 11%, coronary bypass surgery was performed. Neither of these subgroups was recommended for further evaluation in the consensus scheme, but because nearly one quarter of these patients in our population were considered suitable for exercise testing by the attending physician, they are not automatically excluded from further evaluation in the new scheme (Figure 1).
Another significant issue arises from applying this scheme to our database concerning the capability of patients to perform an exercise test (no severe left ventricular dysfunction, Figure 3). As noted earlier and observed in our database, as well as by others in which 32–78% of the population were exercise tested,7–9,30,35–37 patients not performing an exercise test appear to be older, more ill, and to exhibit a worse prognosis. Several other studies on risk stratification have recognized that not all patients will be capable of performing an exercise test.7–9 A recent study (n = 706) found 1-year mortality to be 22% in patients ineligible for exercise testing, and it was recommended that such patients be evaluated further by radionuclide ventriculography and 24-hour ambulatory electrocardiographic monitoring.9 Our scheme adopts this strategy, but as mentioned earlier, the ambulatory electrocardiographic monitoring did not provide further risk discrimination in the subgroup not exercise tested (Figure 1).

Because not all eligible patients in our population performed an exercise test, evaluating the consensus scheme further is difficult. If all eligible patients could be exercise tested in the hypothetical population used to develop the scheme in Figure 3,11 coronary angiography would be recommended in about 30% of the population who are at moderately increased risk (15–20% 1-year mortality), whereas patients at low (<5%) or high risk (>25%) would not undergo angiography.

Implications

The present study targets patients for coronary angiography relatively early after acute myocardial infarction who are predicted to be at moderate-to-high risk of death (average 1-year mortality rate, 16%; range, 6–25%, including both original and test populations) and who may benefit from revascularization procedures.20–22,38–42 Also, its goal is to avoid coronary angiography in low-risk patients (1-year mortality average, 3%). With this scheme, coronary angiography would be recommended in approximately 55% of the patients in our entire population who are 75 years of age or younger surviving through day 5 or in about 45% of the entire population of all ages (n = 2,628). Thus, in our population, the new scheme identifies a somewhat smaller group recommended for coronary angiography than does the Task Force; also, in the new scheme, a slightly wider spread in mortality occurs between patients recommended and not recommended for coronary angiography. Thus, the new scheme supplements the general guidelines provided by the Task Force. Determination of whether or not the scheme we propose is more cost effective than the Task Force’s guidelines,10 the consensus scheme,11 or other possible alternative approaches such as those delineated by Dittus et al,43 will require further studies.

The percentage of patients recommended for coronary angiography under any scheme will depend on population characteristics that, in turn, can be influenced by such factors as the hospital (community vs. referral center) and the geographic setting. Also, with any scheme, individual exceptions will occur, and other factors such as occupation, family setting, lifestyle, and results of any additionally performed tests will probably influence decision making. Ongoing studies will assess whether or not the proposed scheme and other published approaches will be applicable in patients who have had early intravenous thrombolysis. Many of these patients have residual coronary artery lesions, and it is likely that an even higher proportion will be recommended for coronary angiography.10

Despite the increasing use of early intervention in some centers, the proposed scheme and the general guidelines of the Task Force should be applicable to many populations in the United States and elsewhere in which the incidence of early intervention remains low. Thus, this scheme and the Task Force guidelines are necessarily based primarily on data gathered before the widespread application of thrombolysis and percutaneous transluminal coronary angioplasty. Only 19% of general medical care hospitals in the United States have cardiac catheterization facilities,44 so use of intravenous thrombolysis will likely become more widespread than coronary angioplasty in the acute phase, and in the majority of patients, performance of coronary angiography in the acute or the convalescent phase will require transfer to a tertiary care center.44 In the best of circumstances, intravenous thrombolysis has been unsuccessful in opening the occluded artery in approximately 30% of individuals.45 In the remaining patients, there is often some myocardial damage which is probably less extensive than if the patient had not undergone medical therapy, and if so, such patients may avoid falling into one of the high-risk subgroups. On the other hand, the coronary lesion might have been made less stable and more susceptible to later occlusion. The late results of the GISSI (Gruppo Italiano per lo Studio della Streptochinasi nell’Infarto Miocardico) study showed a small increase in reinfarction rate but without a significant long-term increase in mortality in patients treated with thrombolysis.46 Thus, in a population with a high rate of thrombolytic therapy, the subgroup sizes would probably change, but subgroup mortalities should remain close to those observed in the present study.

It remains to be established whether or not the recently reported trend of a reduction in 1-year mortality after myocardial infarction47 can be ascribed to improved medical therapy such as β-adrenergic blockade. Future studies will determine to what degree application of early intravenous thrombolysis48 in the general population and increased use of coronary angiography in the convalescent phase will further reduce the high 1-year mortality rate from acute myocardial infarction.
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