Clinical, Surgical, and Pathologic Correlation in Patients with Acute Myocardial Infarction and Pump Failure

By Hooshang Bolooki, M.D., F.R.C.S.(C), F.A.C.C., Louis Lemberg, M.D., F.A.C.C., Ali Ghahramani, M.D., Chris Economides, M.D., Thomas Caldwell, M.D., and James R. Jude, M.D., F.A.C.S.

With the assistance of Kathleen Bocacella, R.N.

SUMMARY

A review was made of the entire hospital course of 20 patients aged 44 to 79 years who suddenly developed clinically intractable left-heart pump failure as a result of acute myocardial infarction. They were divided into three groups according to their presenting circulatory state. Thirteen patients were in cardiac arrest (group I), four had cardiogenic shock due to myocardial rupture (group II), and three had severe intractable left-heart failure (group III). Preoperative partial or complete cardiac catheterization was possible in six patients.

Surgical treatment using cardiopulmonary bypass was selectively undertaken as a mode of therapy in 11 of the 20 cases. In 10, the area of infarction was delineated and was resected. Pathologically, the infarcts were from 1 to 14 days old, and in 19 of 20 cases involved the anterior wall. The specimens weighed 25 to 83 g. One patient, who was discharged, had infarctectomy and double coronary vein bypass graft. One patient lived for 3 weeks after infarctectomy and pulmonary embolectomy. Two others survived after surgery for 2 and 36 hours, respectively.

The results of this prospective study suggest that identification of patients possibly amenable to successful treatment of medically irreversible pump failure by surgical means will require earlier recognition of the high-risk group and intensive hemodynamic and radiographic evaluation of the extent of the disease process.

Additional Indexing Words:
Cardiac arrest Cardiac rupture Pulmonary emboli Infarctectomy
Cardiogenic shock Vena cava umbrella Cardiac catheterization
Ventricular function Cardiopulmonary bypass

Since the advent of coronary care units a decade ago, the hospital mortality rate of patients admitted with acute myocardial infarction has significantly decreased to 12-14%.1-4

This decrease in mortality has been due mainly to employment of external cardiac resuscitation and defibrillation; the development of continuous-monitoring equipment, improved nursing

From the Division of Thoracic and Cardiovascular Surgery, Section of Cardiology, and the Department of Anesthesiology, University of Miami School of Medicine, Jackson Memorial Hospital, Miami, Florida 33136.

Supported in part by grants-in-aid from the Florida Heart Association and the Heart Association of Greater Palm Beach, and in part by National Institutes of Health grants 11024-03 and HE-13978-01.

Address for reprints: Hooshang Bolooki, M.D., Division of Thoracic and Cardiovascular Surgery, University of Miami School of Medicine, P. O. Box 875, Biscayne Annex, Miami, Florida 33152.

Received October 29, 1970; revision accepted for publication August 4, 1971.

1034 Circulation, Volume XLIV, December 1971
ACUTE MI AND PUMP FAILURE

care, and the use of antiarrhythmic drugs. Significantly, the mortality rate due to pump failure and cardiogenic shock has not improved. The two principal reasons for lack of success in management of the latter complications are unawareness of the extent of myocardial infarction and unavailability of detailed hemodynamic studies in these seriously ill patients. It is becoming increasingly obvious, however, that clinical judgment based only on physical signs and manifestations cannot predict the irreversible deterioration of myocardial function or contractility. This point, clearly shown in a recent study by Ramo and associates, is to be reemphasized here.

In this report the information obtained during a prospective study of 20 patients who suddenly developed intractable heart pump failure is presented. In accordance with our protocol, an aggressive surgical management of these patients was selectively undertaken only after unresponsiveness to conventional therapy had been established. The results indicated:

1. Most patients who develop severe and intractable heart pump failure harbor large anterior wall infarcts and have severe triple coronary artery disease.

2. The group of patients with acute myocardial infarction whose survival may depend on an aggressive surgical approach must be identified earlier and if possible subjected to a precise hemodynamic evaluation including cardiac and coronary catheterizations.

Methods

During an 18-month period (January 1968 to August 1970), 20 patients who were admitted to our coronary care unit (CCU) were referred for this study. Each patient had a proven diagnosis of acute myocardial infarction based on clinical and electrocardiographic (ECG) findings. Their ages varied between 44 and 79 years; seven were females and 13 were males. Five patients had had previous infarcts 2 months to 2 years earlier.

Medical Management

In these patients, as for all other patients admitted to the CCU, a routine method of management was employed. This routine included recordings of vital signs, central venous pressure, intake and output, and continuous ECG monitoring by three precordial leads. A daily 12-lead ECG was obtained, and serum enzymes including CPK, SGOT, LDH, and HBD were measured. A chest X-ray was taken on admission, and follow-up films were obtained when deemed necessary. Arterial blood-gas analysis, duplicated with samples of central venous blood, was done in the majority of cases. Frequent daily physical examinations evaluated the cerebral status, the kidney function, and the skin temperature in order to follow the patients' circulatory status.

To combat rhythm disturbances lidocaine, propranolol, or alprenolol was used, and temporary transvenous cardiac pacing was employed whenever indicated. With development of hypotension unresponsive to volume replacement or correction of arrhythmias levartenerol and in some cases isoproterenol or metaraminol were administered intravenously.

The Study Protocol

Regardless of length of stay in the CCU or number of previous infarcts, those patients who developed sudden deterioration of cardiac status unresponsive to medical management were considered for surgical treatment. These patients were categorized into three groups according to their circulatory state at the time of surgical consultation.

Group I (Sudden Cardiac Arrest)

This group consisted of 13 patients who were, by parameters measured, doing well, but who had suddenly developed ventricular fibrillation unresponsive to countershocks and external cardiac massage of 30- to 45-min duration. In this group, therapy with cardiopulmonary bypass was instituted in the CCU, followed by thoracotomy in the operating room to reestablish coronary blood flow, when feasible, and/or to resect the infarct. Cardiopulmonary bypass was established via femoral artery and vein using a portable battery-operated bubble oxygenator* primed with Ringer-lactate solution. Five patients of this group were not felt to be acceptable for surgical therapy because of inadequate response to cardiac massage or because of associated systemic disease. Two other patients were excluded because of difficulty in establishing cardiopulmonary bypass due to femoral arteriosclerosis. Thus, only six patients with intact central nervous system were selected for emergency surgery; among them was one patient who developed cardiac arrest while undergoing cardiac catheterization (E. C.).

*Travenol Laboratories, Morton Grove, Illinois.
Group II (Cardiogenic Shock)

Group II consisted of four patients who were hypotensive (blood pressure less than 80 mm Hg systolic) and had evidence of low tissue perfusion (skin, kidney, and brain) for more than 6 hours, during which time unresponsiveness to appropriate pharmacologic therapy was established. Three patients had suddenly developed a pansystolic precordial murmur due to ventricular septal rupture. All three had bedside right-heart catheterization which confirmed the diagnosis. Two elderly patients (aged 74 and 79 years) in this group, with acute ventricular septal rupture, were not felt to be acceptable for surgery. Of the two patients who were accepted, one had been comatose for a total of 12 hours and the other had had renal shutdown for the preceding 6 hours. Both these patients were transferred to the operating room and were then placed on peripheral partial cardiopulmonary bypass, anesthetized, and thoracotomy was performed.

Group III (Intractable Congestive Failure)

Group III consisted of three patients with moderate but persistent left-heart failure (bilateral pulmonary rales, S_3 and S_4 gallop). They had become unresponsive to medical therapy over a period of 10 or more days after admission. Emergency cardiac catheterization studies were carried out in these patients and followed by immediate surgery.

Results

Clinical Findings

Our overall in-hospital mortality rate for acute myocardial infarction during the period of this study was 16.5% (68 deaths of all causes among 407 patients). The present 20 patients therefore constitute 5% of our total CCU admission. The mean duration of the hospital stay for the group under study had been 6 days (range 1 to 25 days). It was characterized in all cases by mild (groups I and II) to moderate (group III) congestive failure for 1 to 20 days prior to overt irreversibility. Episodes of hypotension (systolic pressure less than 80 mm Hg) had occurred in the course of the hospital stay in seven of the 20 patients. Surprisingly, the incidence of previous ventricular fibrillation or cardiac arrest during the hospital stay was only 10% (two of 20).

Blood-gas analysis was done in 13 of these patients; seven had a base deficit greater than 5 mEq/liter. Evidence of poor tissue perfusion, based on deterioration in cerebral and renal function, was infrequent. ECG signs of conduction defects were noted in eight patients, four of whom were in group I and three in group II. All patients were thought to be responding favorably to conventional management except for those in group III who had intractable congestive failure from the time of admission. In this group multiple episodes of hypotension and recurrent pulmonary emboli in two patients, and 17 incidents of ventricular fibrillation in one, prompted cardiac catheterization and surgical intervention.

Surgical Findings

Of the entire group of 20 patients, only 11 were accepted for surgery (table 1). At surgery two hearts in group I were found to have no electrical activity and four were fibrillating. In two patients in group I and one in group II a “single-shot” operative coronary arteriogram was done by injecting 25 ml 50% Hypaque into the root of the aorta with the ascending aorta clamped distally. In two other patients in group I a metal cannula was used for direct coronary artery injection. In these cases only 5 ml of dye was used. In spite of poor quality, in every case the coronary arteriograms showed major proximal obstruction and severe distal disease in all three coronary systems (fig. 1).

In ten patients the area of infarction was delineated and resected. Five of these patients were in group I, two in group II, and three in group III. One patient in group I had left coronary endarterectomy and vein patch graft only. While the extent of the infarcted region was known in all patients in group III and in one in group I who had had previous ventriculograms (fig. 2), it was readily delineated as a black and ecchymotic area in four other patients (two each in groups I and II). In the remaining three patients the size of the infarct was estimated by a variety of gross methods, for example injecting methylene blue or Alpha Zurine 2 G dye into the root of the aorta and observing its appearance within the coronary system at the periphery of the infarct. In two patients the anterior intraventricular septum and the adjacent left and right ventricular walls were resected.
Table 1

Summary of Number of Patients Operated upon, the Procedures Done, and Outcome

<table>
<thead>
<tr>
<th>Group</th>
<th>Patients considered</th>
<th>Patients operated</th>
<th>No. with resection</th>
<th>No. with bypass graft</th>
<th>No. surviving thoracotomy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td>13</td>
<td>6</td>
<td>5</td>
<td>1 (E.C.)</td>
<td>1*</td>
</tr>
<tr>
<td>Group II</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>1†</td>
</tr>
<tr>
<td>Group III</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1 (W.P.)</td>
<td>2‡</td>
</tr>
<tr>
<td>Total</td>
<td>20</td>
<td>11</td>
<td>10</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

*This patient (E. C. on table 2) had resection of infarcts involving the anterior wall of both ventricles and the anterior septum with a right coronary bypass graft. He survived off cardiopulmonary bypass for 2 hours.
†This patient had resection of infarcts involving the posterior wall of both ventricles and the septum. She survived for 36 hours and died of a fresh anterior wall infarct. At autopsy all three coronary vessels had multiple areas of more than 80% luminal obstructions.
‡Both of these patients required insertion of vena cava umbrella (see text and Table 2).

Hemodynamic Findings and Follow-up

The hemodynamic findings in four patients who had preoperative cardiac catheterization are shown in table 2. A complete study, including selective coronary arteriograms and the left ventriculogram, was done in these cases. Hemodynamic data in two other patients who had bedside right-heart catheterization are also given in table 2. In all these patients studied, evidence of cardiac failure prevailed, characterized by high left ventricular end-diastolic pressures (range 28 to 40 mm Hg) and a wide arteriovenous oxygen difference (range 8.5 to 11 volume%).

At the completion of surgery, in only two of the eight patients in groups I and II could a fair attempt be made to resume spontaneous circulation. One of these patients survived for 36 hours, requiring vasopressor drugs intermittently during this time. The other one, in addition to infarctectomy, had an aorta-right coronary saphenous vein bypass graft; he came off bypass but suddenly developed left ventricular (LV) asystole 2 hours later. At autopsy in this case a fresh thrombus was seen in the left circumflex coronary artery.

After surgery, a slight improvement in hemodynamic parameters was evident from

Figure 1

Example of a “single-shot,” on-table coronary arteriogram obtained by injecting 5 ml Hypaque by means of a metal cannula (Ravitch) into the left coronary artery. The left circumflex and the obstructed anterior descending (LAD) coronary arteries with other left ventricular side branches were visualized.
Hemodynamic Findings in Six Patients with Left-Heart Pump Failure*  

<table>
<thead>
<tr>
<th>Patient, age (years), sex group</th>
<th>Diagnosis</th>
<th>Infarct wt (g)</th>
<th>Time of study</th>
<th>Pressures</th>
</tr>
</thead>
<tbody>
<tr>
<td>E.C., 69 M (Group I)</td>
<td>Cardiac arrest in cath. lab.: acute anteroseptal infarct (VSD)</td>
<td>25</td>
<td>Preop.</td>
<td>RA 21, PA 54</td>
</tr>
<tr>
<td>R.R., 74 F (Group II)</td>
<td>Cardiogenic shock, acute anteroseptal infarct, and VSD</td>
<td>48</td>
<td>In CCU</td>
<td>RA 20, PA 40</td>
</tr>
<tr>
<td>M.M., 57 F (Group II)</td>
<td>Cardiogenic shock, acute posteroseptal infarct, and VSD</td>
<td>50</td>
<td>Preop.</td>
<td>RA 22, PA 18</td>
</tr>
<tr>
<td>N.L., 58 M (Group III)</td>
<td>Acute anteroseptal infarct</td>
<td>63</td>
<td>Preop.</td>
<td>RA 24, PA 39</td>
</tr>
<tr>
<td>H.D., 44 M (Group III)</td>
<td>Anterolateral wall infarct, massive pulmonary emboli</td>
<td>30</td>
<td>Preop.</td>
<td>RA 20, PA 50</td>
</tr>
<tr>
<td>W.P., 48 M (Group III)</td>
<td>Anterior wall infarct, multiple pulmonary emboli</td>
<td>30</td>
<td>Preop.</td>
<td>RA 11, PA 48</td>
</tr>
</tbody>
</table>

*Preoperative data are from cardiac catheterization studies. Postoperative data were obtained by direct measurements in the operating room or in the recovery room area.

Abbreviations: VSD = acquired ventricular septal defect; RC and LAD = right and left anterior descending coronary arteries; RA = mean right atrial, PA = mean pulmonary artery, BP = mean radial, and LV = left ventricular pressures in mm Hg; CI = cardiac index in liters/min/m²; dp/dt = first derivative of the left ventricular pressure in mm Hg/sec; CCU = coronary care unit; A-VO₂ = arteriovenous oxygen difference.

Figure 2

Left ventricular angiogram of W. P. during systole (upper) and diastole (lower) taken at right anterior oblique view. The akinetic area of the anterior wall is marked between two arrows. This area was resected and the right coronary as well as the anterior descending coronary arteries were bypassed with saphenous vein grafts.

the pressure measurements taken during and after surgery (table 2). An improvement in cardiac function (an increase in cardiac index and calculated LV stroke work associated with a decrease in LV end-diastolic pressure) was noted during the 2 days following surgery in two patients (H. D. and W. P.). On the third day after infarct resection both these patients developed severe and frequent ventricular premature dysrhythmias which were controlled by lidocaine drip for 12 hours. Also, both these patients required additional procedures for treatment of multiple pulmonary emboli. Patient H. D. required pulmonary embolectomy and umbrella insertion via the right atrium simultaneously with the infarctectomy. In this case an increase in right-heart pressures occurred postoperatively due to new episodes of pulmonary emboli in spite of anticoagulant therapy with heparin; these emboli proved at autopsy to have originated from the right atrium. This patient lived for 3 weeks and
died of cardiac failure associated with gram-negative septicemia originating from a pulmonary abscess.

Patient W. P. required interruption of the inferior vena cava by an umbrella device on the fifth postoperative day. He is the only long-term survivor and is functional class II at the present time (16-month follow-up).

Pathologic Findings

Of 19 in-hospital deaths, autopsy permission was obtained in 16 cases. In 15 the infarction involved the anterior wall. Seven hearts had ruptured (table 3). The average weight of the infarcted area in 16 patients was 50 g, ranging from 25 to 85 g. The infarct size averaged 6.8 by 4.8 by 1.4 cm, or 45 cm³. Group I had the largest infarct (55.3 cm³) and group III the smallest (29.2 cm³).

Microscopically, the age of the infarct was determined by Mallory’s criteria. In five hearts, after surgical removal of the infarct, pathologic studies showed the presence of further areas of infarct extending beyond the suture line. In three hearts the age of the infarcted specimens ranged from 24 hours to 7 days, all within the same specimen (fig. 3). The anterior descending coronary artery was totally occluded in 15 of 16 patients. Also, multiple areas of occlusion were found in the main left and right coronary artery trunks, averaging 60% of the diameter of each vessel. Except in three patients (W. P., H. D., and E. C.), most branches to these vessels were totally obstructed distally.

Discussion

Recent attempts to improve the survival rate from complications of acute myocardial infarction have met with considerable success in the treatment of dysrythmias and control of ventricular irritability. Our report, however, as well as one by others, stresses the inadequacy of present clinical methods to predict future irreversible cardiac failure. In group I, for example, all 13 patients were apparently awake and had satisfactory blood pressure up to the time when intractable ventricular fibrillation—"total pump failure"—ensued.

In our previous studies on patients developing cardiac arrest in a well-controlled situation such as the operating room, we had found that more than 90% of the patients who eventually recovered from circulatory arrest did so within the first 10 minutes after initiation of external or open cardiac massage. Therefore, in patients in group I, it was thought that if...
adequate cardiac massage were promptly instituted, with the use of emergency cardiopulmonary bypass as an assist device, a substantial chance for return of the prearrest cardiac function would be present. However, because of very large areas of infarct and severe triple coronary artery disease the odds for recovery of cardiac function were nil.

Our group II patients were those whom we categorize as having cardiogenic shock or "severe pump failure." In our institution the incidence of this complication is very low (4.4%). This is because we define "cardiogenic shock" as a hypotensive state accompanied by clinical evidence of poor tissue perfusion, providing all correctable causes of shock such as hypovolemia, arrhythmias, and electrolyte imbalance have been eliminated. Therefore, it should not be surprising that in this study all the patients regarded as having "cardiogenic shock" were eventually found to have cardiac rupture, although this category of patients, in the minds of many, may represent only one end of this spectrum. Here again our findings reveal that surgical attempts to combat sudden and severe pump failure due to cardiac rupture meet with little success.

One main objective of this study was to evaluate the extent of reversibility of cardiac function in a patient with acute myocardial infarction after failure of medical therapy had been established. Although the number of patients within each group is small, it seems justifiable to conclude that group III patients, who obviously had a more satisfactory cardiac function and the status of whose coronary arteries was known preoperatively, had better results. The reason for our failure in treating group I and group II patients, we believe, was that the extensive myocardial and coronary artery involvement precluded any attempt at myocardial revascularization. These findings made us wonder what useful role other aggressive means of therapy, such as cardiac assist devices, can play in the treatment of pump failure,\textsuperscript{9-11} the myocardium must receive blood if an adequate cardiac function is to be expected.\textsuperscript{12}

From this study and those of others it is concluded that patients who have anterior wall infarcts with associated septal involvement and conduction defects should, in terms of eventual pump failure, be considered a "highly susceptible group."\textsuperscript{13, 14} Initial isolation of this group and an attempt at their categorization based on the hemodynamic findings, the extent of myocardial involvement, and the coronary artery pathology could lead to a better method of selection with an eventually improved survival rate from aggressive methods of therapy.  

**Addendum**

Since submission of this paper, six other patients with moderate to severe pump failure at varying peri-

### Table 3

**Summary of Pathologic Findings in Sixteen Autopsied Cases**

<table>
<thead>
<tr>
<th>Group</th>
<th>No. autopsied</th>
<th>Location of infarct</th>
<th>Age of infarct and other pathology</th>
<th>Average % occlusion of coronary arteries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td>10</td>
<td>All anterior wall</td>
<td>7 to 10 days</td>
<td>Apical rupture in 2, Septal rupture in 1</td>
</tr>
<tr>
<td>(13 patients)</td>
<td></td>
<td></td>
<td></td>
<td>4 to 6 days</td>
</tr>
<tr>
<td>Group II</td>
<td>4</td>
<td>3 anteroseptal, 1 posteroseptal</td>
<td>Over 2 weeks</td>
<td>Wall rupture in 1</td>
</tr>
<tr>
<td>(4 patients)</td>
<td></td>
<td></td>
<td></td>
<td>LV aneurysm in 1</td>
</tr>
<tr>
<td>Group III</td>
<td>2</td>
<td>All anterior wall</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(3 patients)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*The location of the infarct was verified at surgery or at autopsy. All patients with cardiac rupture had confirmation of the diagnosis at autopsy.

Abbreviations: LC = left coronary artery; RC and LAD = right and left anterior descending coronary arteries; LV = left ventricular.
ACUTE MI AND PUMP FAILURE

Figure 3
Microscopic appearance of infarcts with pathologic age of 12 hours (upper left), 24 hours (upper right), 2 weeks (lower left), and more than 4 weeks (lower right), all within the same heart in a patient in group I who on the third day in the coronary care unit suddenly developed multiple episodes of ventricular fibrillation and cardiac arrest. (Hematoxylin and eosin, × 60.)

Acknowledgment
The authors wish to thank the entire nursing staff of the coronary care unit and the operating room and the surgical and anesthesia residents at the Jackson Memorial Hospital, who made this study possible. We
are also grateful for the efforts of Mr. Cliff Senecal and Mr. Sam Fisher, the cardiopulmonary bypass technicians in charge of this study.

References
Clinical, Surgical, and Pathologic Correlation in Patients with Acute Myocardial Infarction and Pump Failure

HOOSHANG BOLOOKI, LOUIS LEMBERG, ALI GHAHRAMANI, CHRIS ECONOMIDES, THOMAS CALDWELL, JAMES R. JUDE and Kathleen Bocchella

Circulation. 1971;44:1034-1042
doi: 10.1161/01.CIR.44.6.1034

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1971 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/44/6/1034

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/