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**Effects of Amrinone on Myocardial Energy Metabolism and Hemodynamics in Patients with Severe Congestive Heart Failure Due to Coronary Artery Disease**

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**SUMMARY** Amrinone has been shown to exhibit a potent inotropic effect in patients with heart failure secondary to congestive cardiomyopathy, but its effects on myocardial oxygen consumption (MVO₂) and coronary blood flow (CBF) are unknown. Accordingly, the hemodynamic, myocardial metabolic and ECG responses to amrinone (2.5 mg/kg i.v. over 1 hour) were measured in nine patients with congestive heart failure secondary to coronary artery disease. Increases were observed in cardiac index (1.3 ± 0.4 to 2.2 ± 0.7 l/min/m²) and left ventricular stroke work (10.6 ± 3.0 to 19.2 ± 6.3 g-m/m²), and decreases in mean pulmonary wedge (31 ± 5 to 26 ± 4 mm Hg), mean pulmonary artery (44 ± 8 to 36 ± 7 mm Hg) and mean right atrial pressures (18 ± 4 to 10 ± 4 mm Hg), myocardial arteriovenous oxygen difference (129 ± 19 to 109 ± 17 ml/l), CBF (215 ± 117 to 178 ± 84 ml/min) and MVO₂ (27 ± 14 to 19 ± 9 ml/min). All changes were significant (p < 0.01). No significant changes occurred in aortic mean pressure, heart rate, myocardial lactate extraction or ECG, and no patient developed angina. In explaining the decline in MVO₂, it is possible that the increase in contractility was more than offset by the reductions in preload and afterload. The amrinone-induced hemodynamic improvement in patients with congestive heart failure secondary to coronary artery disease was associated with reductions in MVO₂ and CBF and no evidence of myocardial ischemia.

**AMRINONE**, a bipyridine derivative, exerts a strongly positive, inotropic action in a variety of in vitro and in vivo preparations.¹ ² In experimental models of congestive heart failure, amrinone consistently elevated cardiac output and lowered ventricular filling pressure.² Amrinone’s mechanism of action has not been established. Its inotropic action is not blocked by propranolol or modified by pretreatment with reserpine. It apparently does not alter adenosine 3'-5'-cyclic monophosphate, phosphodiesterase or Na⁺-K⁺-activated adenosine triphosphatase activity in cardiac muscle.¹ ²

We previously reported the hemodynamic effects of amrinone in a group of patients with nonischemic congestive cardiomyopathy.³ Amrinone consistently raised cardiac output and left ventricular peak dP/dt, while reducing both right and left ventricular filling pressures. Acute intravenous administration of this agent caused no discernible adverse effects. These findings have been corroborated.⁴ A major concern, however, has been that administration of such a potent inotropic agent might be deleterious in patients with congestive heart failure in the setting of extensive coronary artery disease. An increase in contractility, if accompanied by a rise in myocardial oxygen consumption (MVO₂), might precipitate myocardial
ischemia in such patients because the capacity of the
diseased coronary arteries to increase myocardial
blood flow and oxygen delivery is limited. On the
other hand, the overall effect on cardiac metabolism in
the failing heart depends on the interplay of several
factors. The likelihood of increased MVO₂ resulting
from augmented contractility might theoretically be
attenuated or overshadowed by a reduction in left ven-
tricular chamber size and systolic wall tension.
Because systolic wall tension and duration are im-
portant determinants of MVO₂, any reduction in these
variables would be expected to mitigate the stimulat-
ing effect of augmented myocardial contractility on
MVO₂.

In the present study we administered amrinone
acutely to nine patients with severe congestive heart
failure primarily due to extensive coronary artery dis-
ease and prior myocardial infarction. Major hemo-
dynamic improvement was observed without demon-
strable toxicity, and a salutary effect on several mea-
sures of myocardial energy metabolism was also
documented.

Materials and Methods

Using a protocol approved by the Human Subjects
Committee of the Peter Bent Brigham Hospital, we
studied nine patients with severe heart failure due to
ischemic cardiomyopathy or one or more documented
prior myocardial infarctions. The term ischemic car-
diomyopathy is used to refer to extensive coronary
artery disease, documented by coronary arteriog-
raphy, and extensive segmental left ventricular wall
motion abnormalities, documented by left ventricu-
lography, without a history of documented prior
myocardial infarction. All patients had received con-
ventional therapy with digitalis, diuretics and
afterload-reducing agents before being considered for
the study. They ranged in age from 47–72 years and
had the following characteristics: New York Heart
Association functional class III or IV despite chronic
treatment with digoxin (average daily dose 0.25 mg),
diuretics and vasodilators; multiple-chamber enlarge-
ment on radiographic and echocardiographic ex-
aminations; left ventricular end-diastolic and mean
pulmonary capillary wedge pressures both exceeding
20 mm Hg; right atrial mean pressure exceeding 12
mm Hg; ejection fraction ≤ 0.45, with segmental wall
motion abnormalities on ventriculography; cardiac
index ≤ 2.0 l/min/m²; and the presence of significant
obstruction (luminal narrowing > 50%) of at least two
major coronary arteries documented by angiography.
Before study the patients were maintained on a no-
added-salt diet and continued on essential cardiac
medications (digoxin, diuretics, potassium supple-
ments and various antiarrhythmic agents).

Congestive heart failure was secondary to end-stage
coronary artery disease in eight patients. Four of these
patients had suffered one or more myocardial in-
farctions. In addition, two patients had undergone
previous coronary artery revascularization surgery
with relief of angina but subsequently developed con-
gestive heart failure. One patient had aortic and mitral
valve disease in addition to coronary artery disease,
and underwent concomitant aortic valve replacement
and mitral commissurotomy for rheumatic aortic and
mitral valve disease at the time of coronary artery
revascularization. Clinical characteristics and digoxin
levels at the time of study are presented in table 1.

<table>
<thead>
<tr>
<th>Pt</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Diagnosis</th>
<th>Ejection fraction*</th>
<th>Serum digoxin level (mg/ml)</th>
<th>Total amrinone dose (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>67</td>
<td>M</td>
<td>CHF due to several documented prior myocardial infarctions; 3-vessel CAD</td>
<td>0.13</td>
<td>1.3</td>
<td>2.5</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>F</td>
<td>CHF due to ischemic cardiomyopathy; diabetes mellitus; 3-vessel CAD</td>
<td>0.14</td>
<td>1.1</td>
<td>2.5</td>
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<tr>
<td>3</td>
<td>54</td>
<td>M</td>
<td>CHF due to several documented prior myocardial infarctions; diabetes mellitus; S/P 3-vessel coronary artery bypass surgery and aneurysmectomy in 1975</td>
<td>0.22</td>
<td>1.2</td>
<td>2.5</td>
</tr>
<tr>
<td>4</td>
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<td>0.20</td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>5</td>
<td>64</td>
<td>M</td>
<td>CHF secondary to three documented previous myocardial infarctions; coronary arteriography not performed</td>
<td>0.13</td>
<td>1.0</td>
<td>2.5</td>
</tr>
<tr>
<td>6</td>
<td>47</td>
<td>M</td>
<td>CHF due to ischemic cardiomyopathy; history of hypertension; 2-vessel CAD</td>
<td>0.16</td>
<td>1.3</td>
<td>2.5</td>
</tr>
<tr>
<td>7</td>
<td>68</td>
<td>M</td>
<td>History of RHD with AR and MS; 3-vessel CAD S/P AVR; mitral commissurotomy and saphenous vein bypass to the LAD in 1975; CHF secondary to severe MR</td>
<td>0.45</td>
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<td>1.4</td>
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<tr>
<td>9</td>
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<td>M</td>
<td>CHF due to multiple previous documented myocardial infarctions; 3-vessel CAD</td>
<td>0.21</td>
<td>2.2</td>
<td>2.5</td>
</tr>
</tbody>
</table>

*Measured by contrast ventriculography in patients 1, 2, 4, 5, 6 and 9, and by radionuclide ventriculography in patients 3, 7 and 8.

Abbreviations: CHF = congestive heart failure; CAD = coronary artery disease; RHD = rheumatic heart disease; AR = aortic regurgitation; MS = mitral stenosis; LAD = left anterior descending coronary artery; S/P = status post; AVR = aortic valve replacement.
After informed consent was obtained, patients were premedicated with oral diphenhydramine (25–50 mg) and oral diazepam (5–10 mg). Catheterization of the right heart was done by the brachial or femoral approach under local xylocaine anesthesia. Catheterization of the coronary sinus was accomplished with a \#8F thermodilution coronary sinus flow catheter introduced through a brachial vein. Blood pressure was continuously monitored through a small plastic catheter percutaneously introduced into the right or left femoral artery. All pressures were measured through standard fluid-filled catheters connected to Statham P50 Micron transducers and recorded on an Electronics for Medicine DR8 recorder. Coronary sinus blood flow was measured by the thermodilution technique through a Wheatstone bridge and recorded as described by Ganz et al.  

With the patient in the supine, resting state, baseline pressures, including systemic arterial, pulmonary capillary wedge, pulmonary artery and right atrial pressures, were measured. Myocardial (coronary sinus) blood flow was determined by the thermodilution technique, and cardiac output was measured by the Fick method. Arterial and coronary sinus blood samples were obtained simultaneously for determination of lactate, oxygen and potassium concentrations. Serum lactate and potassium concentrations were determined by standard biochemical methods. Oxygen content was determined using an electrochemical method (Lex-Ox2-Con, Lexington Instruments) that measures molecular oxygen. A 12-lead ECG was recorded. Upon completion of baseline measurements, amrinone was administered intravenously using an infusion pump regulated to deliver 2.5 mg/kg over 60 minutes. Arterial blood pressure, ECG lead II and the patient's clinical condition were continually monitored throughout the infusion period. At 10-minute intervals during the drug infusion, repeat determinations of coronary sinus blood flow were made. At 20-minute intervals arterial and coronary sinus blood specimens were obtained for determination of lactate, oxygen and potassium concentrations. After completion of the amrinone infusion, all pressures, cardiac output and coronary sinus blood flow were again measured. At the same time, repeat arterial and coronary sinus blood specimens were obtained to determine lactate, oxygen and potassium concentrations, and a repeat 12-lead ECG was recorded.

Hemodynamic indexes were calculated from pressure and output data according to standard formulas:

\[
\begin{align*}
SVR &= \frac{MAP - RAP}{CO} \times 80 \\
PVR &= \frac{PAP - PCW}{CO} \times 80 \\
LVSWI &= SI \times (MAP - PCW) \times 0.0136
\end{align*}
\]

where MAP, RAP, PAP and PCW are mean arterial, right atrial, pulmonary arterial and pulmonary capillary wedge pressures (mm Hg), respectively, SI is stroke index, SVR is systemic vascular resistance (dyn-sec-cm⁻²), PVR is pulmonary vascular resistance (dyn-sec-cm⁻²) and LVSWI is left ventricular stroke work index (g-m/m²).

\[
CBF = \frac{T_B - T_I}{T_B - T_M} - 1 \times 1.17 \times 38.2 \text{ ml/min}
\]

where CBF is coronary sinus blood flow (ml/min), \(T_B\), \(T_I\) and \(T_M\) represent the temperatures of blood, indicator and blood-indicator mixture measured by the catheter-mounted thermistors, 1.17 is a constant accounting for specific heat and density of both blood and indicator, and 38.2 ml/min is the injection rate of the indicator (D5W) via the Harvard pump. Lactate extraction ratio was calculated as:

\[
\frac{ART \ [lactate] - CS \ [lactate]}{ART \ [lactate]}
\]

where ART \ [lactate] is the arterial lactate concentration (mEq/l) and CS \ [lactate] is the coronary sinus lactate concentration (mEq/l).

Oxygen extraction ratio was calculated as:

\[
\frac{ART \ [oxygen] - CS \ [oxygen]}{ART \ [oxygen]}
\]

where ART \ [oxygen] is the arterial oxygen content (ml/l) and CS \ [oxygen] is the coronary sinus oxygen content (ml/l).

\[
MVO_2 = CBF \times (ART \ [oxygen] - CS \ [oxygen])
\]

where \(MVO_2\) is oxygen consumption of the myocardium drained by the coronary sinus (predominantly the left ventricular myocardium).

Statistical analysis was done using the \(t\) test for paired determinations, comparing measurements before and after amrinone in each patient.  

Results

Hemodynamic data before and after completion of the amrinone infusion for each patient are listed in table 2. The onset of hemodynamic response occurred 20–40 minutes after the start of the infusion. In each patient amrinone produced a substantial increase in cardiac output, and the average cardiac index for the entire group rose by 69%. Patients responded with a reduction in pulmonary capillary wedge pressure (average decline 16%) and right atrial pressure (average decline 44%). The decline in pulmonary capillary wedge pressure was accompanied by a similar fall in mean pulmonary artery pressure (average decline 18%). Pulmonary vascular resistance declined in all but one patient in whom it could be
calculated (average decline 50%). These hemodynamic changes were accompanied by a substantial rise (average 81%) in left ventricular stroke work index.

The improvement in cardiac output and left ventricular stroke work and the decline in pulmonary capillary wedge pressure in response to amrinone were accompanied by minor and insignificant changes in heart rate. Systemic arterial mean pressure declined slightly in six patients and rose slightly in three patients; the average change (−3%) was not significant (p > 0.5). Systemic vascular resistance fell substantially (average 40%) in all patients. The hemodynamic changes were accompanied by a slight but not significant rise in total body oxygen consumption (average 9%), accompanied by a 24% decline in arterial lactate concentration.

Significant alterations in several measures of myocardial energy metabolism accompanied these hemodynamic and metabolic changes (table 3). Coronary sinus blood flow (measured in eight patients) declined by an average of 17% (p < 0.01). The arterial–coronary sinus oxygen concentration difference fell by an average of 16% (p < 0.005), accompanied by no change or a slight fall in the myocardial oxygen extraction ratio, with an overall decline of 6%. Myocardial oxygen consumption declined by an average of 30% (p < 0.01). In response to amrinone administration, the myocardial lactate extraction ratio declined by an average of 62%. In all but two patients, however, lactate extraction remained positive in response to amrinone administration.

No patient experienced chest discomfort or other adverse reaction during or after the amrinone infusion. Twelve-lead ECGs taken immediately after completion of amrinone infusion and 45 minutes later showed no changes compared with ECGs recorded on admission or those recorded immediately upon or 12–24 hours after completion of the amrinone infusion. Continual monitoring of ECG lead II during and for 1 hour after the amrinone infusion revealed no evidence of alterations in heart rate or rhythm, ST-segment deviations or T-wave changes. Serum creatine kinase, lactate dehydrogenase and glutamic oxalacetate transaminase levels measured in all patients 12–24 hours after amrinone infusion revealed no evidence of myocardial necrosis.

**Discussion**

All patients studied were extremely ill with chronic biventricular congestive heart failure despite treatment with digoxin, diuretics and vasodilators. All patients had extensive two- or three-vessel coronary disease and segmental wall motion abnormalities on ventriculography; four had a history of one or more previous documented myocardial infarctions. Thus, in all cases the ventricular failure was associated with ischemic heart disease — either ischemic cardiomyopathy or extensive previous myocardial infarction(s). Nonetheless, amrinone administration resulted in marked hemodynamic improvement without demonstrably aggravating myocardial ischemia. Cardiac output, stroke volume and left ventricular stroke work improved, whereas pulmonary capillary wedge, pulmonary arterial and right atrial pressures, as well as the arteriovenous oxygen difference, declined. This combination of hemodynamic findings is consistent with a drug-mediated enhancement of myocardial contractility. However, in this study we did not directly measure parameters of left ventricular contractility. We relied on previous studies by ourselves and others that have shown an increase in indexes of myocardial contractility after administration of amrinone. Although these data suggest that amrinone exerts at least part of its beneficial effect through a potent positive inotropic action, a concomitant vasodilating effect may also be operative. In this study and in previous reports, systemic vascular resistance showed a major decline following amrinone. Although the reduction in calculated systemic vascular resistance may have resulted from a withdrawal of sympathetically mediated peripheral vasoconstriction as a consequence of the rise in cardiac output, as in patients with heart failure treated with digitalis, amrinone may have had a direct vasodilating effect on the systemic resistance vessels. This possibility is supported by the documented hypotensive effects of high doses of amrinone in animals (Rude RE, DeBoer LWV, Maroko PR, Khuri S, Kloner RA, Karoffa S, Braunwald E: unpublished observations) and normal volunteers.

We were concerned that the use of this potent inotropic agent in patients with heart failure from coronary artery disease could precipitate or aggravate existing myocardial ischemia. Augmented myocardial contractility is known to increase MVO₂ and thereby precipitate myocardial infarction. However, amrinone resulted in significant narrowing of the arterial–coronary sinus oxygen difference in patients with ischemic cardiomyopathy. At the same time, coronary blood flow declined, so that MVO₂ for the group fell significantly. The marked increase in left ventricular stroke work (80%) and decline in MVO₂ (30%) indicate that the external efficiency of the heart increased substantially.

A potential technical criticism of these results relates to the validity of comparative coronary sinus flow determinations by the thermodilution technique whenever right atrial pressure is altered. In our patients, right atrial pressure and measured coronary sinus flow declined together, and we cannot exclude the possibility that part of the observed decline in coronary sinus blood flow may be artifactual due to right atrial pressure fall. However, arterial–coronary sinus oxygen difference fell in our patients and coronary sinus blood oxygen content rose, indicating that myocardial oxygen extraction was less in response to amrinone administration. Also, a lesser degree of reflux from right atrium to coronary sinus after amrinone would be expected to result in a lower oxygen content of blood sampled from the coronary sinus.
Table 2. Hemodynamic Responses to Amrinone in Patients with Congestive Heart Failure Due to Coronary Artery Disease

<table>
<thead>
<tr>
<th>Pt</th>
<th>Period</th>
<th>CO (l/min)</th>
<th>CI (l/min/m²)</th>
<th>HR (beats/min)</th>
<th>SA (mm Hg)</th>
<th>PCW (mm Hg)</th>
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<tbody>
<tr>
<td>1</td>
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<td>2.3</td>
<td>1.3</td>
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<td>78</td>
<td>33</td>
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<tr>
<td></td>
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<td>4.8</td>
<td>2.7</td>
<td>90</td>
<td>84</td>
<td>27</td>
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<td>2</td>
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<td>1.8</td>
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<tr>
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<td>132</td>
<td>74</td>
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<tr>
<td>3</td>
<td>Before</td>
<td>1.8</td>
<td>1.1</td>
<td>72</td>
<td>76</td>
<td>27</td>
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<tr>
<td></td>
<td>After</td>
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<td>1.1</td>
<td>96</td>
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<td>1.1</td>
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<td>33</td>
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<td>114</td>
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<tr>
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<td>108</td>
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Mean ± SD

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>CI</th>
<th>HR</th>
<th>SA</th>
<th>PCW</th>
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<tbody>
<tr>
<td></td>
<td>2.3 ± 0.7</td>
<td>1.3 ± 0.4</td>
<td>91 ± 16</td>
<td>81 ± 13</td>
<td>31 ± 5</td>
</tr>
<tr>
<td></td>
<td>4.1 ± 1.2</td>
<td>2.2 ± 0.7</td>
<td>91 ± 19</td>
<td>78 ± 14</td>
<td>26 ± 4</td>
</tr>
</tbody>
</table>

*p < 0.001  p < 0.001  NS  NS  p < 0.01

Abbreviations: CO = cardiac output; CI = cardiac index; HR = heart rate; SA = systemic arterial mean pressure; PCW = mean pulmonary capillary wedge pressure; PA = mean pulmonary artery pressure; RA = mean right atrial pressure; SVR = systemic vascular resistance; PVR = pulmonary vascular resistance; LVSWI = left ventricular stroke work index.

and an apparent widening of the arterial–coronary sinus oxygen difference. That the opposite change occurred (a narrowing of the difference) argues against major reflux in these studies. In support of this conclusion is the absence of ischemic change on the ECG or anginal chest discomfort in response to amrinone in any patient. Because amrinone infusion reduced $MVO_2$, any propensity of this positive inotropic agent to stimulate myocardial oxygen demand must therefore have been offset by overall reduction in other determinants of $MVO_2$. Because heart rate and the duration of systole did not change, a fall in mean systolic wall tension presumably accounted for the overall reduction in $MVO_2$ in response to amrinone. This seems likely, because the filling pressures, and therefore presumably the volume of both ventricles and the wall tension, declined.

The fall in coronary blood flow was associated with little or no change in the pressure gradient across the coronary vascular bed. Because coronary blood flow fell, calculated coronary vascular resistance increased by an average of 18%, but this change was not significant. Because the coronary arteriovenous oxygen difference fell and coronary sinus oxygen content rose as a result of amrinone, the elevation of coronary vascular resistance was presumably mediated by autoregulation in response to a reduction in myocardial oxygen requirements,¹⁵ rather than by a coronary vasoconstrictor effect. Total body oxygen consumption rose and arterial lactate concentration declined after amrinone. It is possible that as a result of the improved cardiac output, intermediary metabolism became more aerobic, lactic acid production by skeletal muscle and gut declined, hepatic lactate clearance increased and arterial lactate concentration fell.¹⁴ A rise in total body oxygen consumption coincident with an increase in cardiac output in patients with very low initial cardiac output is consistent with the observations of Bauman et al.¹⁷ Though our data show that amrinone is of significant hemodynamic benefit and is well-tolerated acute-
Our studies provide information about coronary artery chronic ATPase as tensify acute disease, myocardial reduce at ure, observations).

Thus, amrinone may reduce myocardial oxygen requirements in patients with chronic coronary artery disease and severe heart failure, it probably should not be used in patients with acute myocardial infarction or any other acute ischemic syndrome in the absence of heart failure.

Several important questions concerning amrinone are unanswered. We do not know whether tachyphylaxis to the inotropic effect of amrinone occurs. Our studies were designed to examine the acute hemodynamic and cardiac metabolic effects, and do not provide information about amrinone’s duration of action or possible tachyphylaxis, although preliminary observations at this institution suggest that responsiveness to the drug persists. A second question relates to amrinone’s mechanism of action. Amrinone does not act through inhibition of sodium-potassium ATPase as cardiac glycosides do, and does not depend on cardiac release of catecholamines or histamine or an alteration of myocardial cyclic 3′-5′ adenosine monophosphate levels. Its positive inotropic action is not blocked by propranolol or modified by pretreatment with reserpine. Its effect may be exerted directly on the contractile mechanism and appears to be additive to the inotropic effect of digoxin or catecholamines. Elucidation of the fundamental mechanism of action of amrinone should increase understanding of the mechanism of myocardial contraction.

Amrinone has exciting therapeutic potential as an inotropic agent that is effective when administered intravenously or orally. While we hope that ongoing investigations will establish its usefulness in the acute and chronic management of patients with congestive heart failure from a variety of causes, caution must be exercised, and critical appraisal of all data regarding amrinone’s efficacy is mandatory at the outset. It must be anticipated that chronic therapy with amrinone, an agent with such a potent inotropic effect through an as yet unknown mechanism of action, will not be without adverse effects, cardiovascular or otherwise.

In summary, amrinone effectively increased cardiac output and decreased left and right ventricular filling pressures in patients with advanced coronary artery
### TABLE 3. Myocardial Metabolic Responses to Amrinone in Patients with Congestive Heart Failure Due to Coronary Artery Disease

<table>
<thead>
<tr>
<th>Pt</th>
<th>Period</th>
<th>ART-CS [O₂ difference] (m/l)</th>
<th>CBF (ml/min)</th>
<th>MVO₂ (ml/min)</th>
<th>CVR (mm Hg/ml/min)</th>
<th>O₂ extraction ratio</th>
<th>ART [lactate] (mEq/l)</th>
<th>CS [lactate] (mEq/l)</th>
<th>Lactate extraction ratio</th>
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<tbody>
<tr>
<td>1</td>
<td>Before</td>
<td>112</td>
<td>277</td>
<td>31</td>
<td>0.22</td>
<td>0.59</td>
<td>0.40</td>
<td>0.2</td>
<td>0.38</td>
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<tr>
<td></td>
<td>After</td>
<td>113</td>
<td>177</td>
<td>20</td>
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<td>0.61</td>
<td>0.5</td>
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<td>97</td>
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<td>1.9</td>
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Abbreviations: ART-CS [O₂ difference] = difference in oxygen concentration between systemic arterial and coronary sinus blood; CBF = coronary blood flow; CVR = coronary vascular resistance; ART [lactate] = arterial lactate concentration; CS [lactate] = coronary sinus lactate concentration; MVO₂ = myocardial oxygen consumption.

Disease and severe biventricular failure. These salutary hemodynamic changes were associated with a reduction in MVO₂ and no clinical or electrocardiographic evidence of myocardial ischemia. It is possible that the amrinone-induced increased contractility was more than offset by the decline in ventricular tension development in the reduction of MVO₂.

### References

Effects of amrinone on myocardial energy metabolism and hemodynamics in patients with severe congestive heart failure due to coronary artery disease.
J R Benotti, W Grossman, E Braunwald and B A Carabello

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