Measurement of Oxygen Consumption After Uncomplicated Acute Myocardial Infarction*

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**Background:** Oxygen consumption (VO₂) has been shown to be decreased after acute myocardial infarction (AMI) complicated by cardiogenic shock.

**Study Objective:** To evaluate early measurement of VO₂ by indirect calorimetry after an uncomplicated AMI (UAMI).

**Study Design:** Prospective nonrandomized case study.

**Setting:** Emergency department of a large urban hospital.

**Participants and Interventions:** Twenty-six consecutive patients presenting with confirmed UAMI. VO₂ was measured by indirect calorimetry (Deletrac, Datex Ins.) which is noninvasive. All patients received buccal or intravenous nitroglycerin and thrombolytic therapy, and none received opiates before VO₂ measurement.

**Results:** Two groups of patients were identified by subsequent development of cardiogenic shock. Group 1 did not develop cardiogenic shock, and group 2 developed shock within 24 h of admission. Group 1 (n = 22) had a significantly higher VO₂ compared to group 2 (n = 4), mean 154(SD 25) vs mean 100(SD 13) ml/min/m², p<0.002. Group 1 had a significantly higher increase in basal metabolic rate than group 2, mean 30 percent (SD 11) vs mean 10(SD 15) percent, p<0.007. There was no significant difference in age, heart rate (HR), shock index (SI), or rate-pressure product (RPP) between groups 1 and 2. All patients in group 2 developed cardiogenic shock despite thrombolytic therapy, and two died within 24 h of admission.

**Conclusion:** VO₂ is increased in UAMI and represents increased metabolic demands of peripheral tissues and not cardiac oxygen uptake. A reduction in VO₂ (<100 ml/min/m²) after AMI may be an early predictor of subsequent development of cardiogenic shock. Measurement of VO₂ in UAMI by indirect calorimetry in the emergency department may be of value to identify patients at high risk and could influence their management.

*(Chest 1993; 104:930-34)*

**AMO** = acute myocardial infarction; **Do₂** = systemic oxygen delivery; **MAP** = mean arterial pressure; **RPP** = rate-pressure product; **SI** = shock index; **UAMI** = uncomplicated AMI; **Vo₂** = oxygen consumption.

**Patients and Methods**

The study was approved by the Institutional Review Board for Human Research, and verbal consent from enrolled patients was obtained. Twenty-six consecutive patients who presented with a confirmed diagnosis of UAMI were included in the study. The initial diagnosis and inclusion criteria were made by the following typical chest pain, serial 12-lead ECGs (development of new ST elevation >1.5 mm and Q wave >2 mm), and later supported by cardiac creatine phosphokinase isoenzyme (CPK-MB index ratio >5) measured on admission, and at 12 and 24 h. The UAMI hemodynamic stability was defined as: heart rate (HR) <120 and >60 beats/min, mean arterial pressure (MAP) >70 and <120 mm Hg (measured noninvasively), and respiratory rate >12 and <25 per min. Left and right ventricular failure were excluded by clinical examination and chest radiography. All patients were normothermic (temperature 36 to 37.5°C) on admission.

The VO₂ was measured by indirect calorimetry using the Deletrac (Datex Instrument Corp., Helsinki, Finland) in the canopy mode, and patients were spontaneously breathing on room air (FiO₂ = 0.21). The Deletrac was calibrated with a standard gas mixture of 4 percent carbon dioxide and 96 percent oxygen before each study. The VO₂ was measured at 1-min intervals and calculated as an average of ten successive readings within 5 percent standard deviation. The paramagnetic oxygen electrode measures oxygen concentration in the inspired and expired gas and computes total oxygen uptake from the gas flow rate. The drift in the electrode calibration is less than 5 percent over 12 h. Using the Harrison-
Table 1—Characteristics of Group 1 and 2 Patients Presenting With UAMI Within 24 h*

<table>
<thead>
<tr>
<th></th>
<th>Group 1</th>
<th>Group 2</th>
<th>p-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>22</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Age, yr</td>
<td>61 (11)</td>
<td>74 (4)</td>
<td>NS</td>
</tr>
<tr>
<td>VO₂</td>
<td>286 (53)</td>
<td>191 (24)</td>
<td>&lt;0.007</td>
</tr>
<tr>
<td>VO₂ index</td>
<td>154 (25)</td>
<td>100 (13)</td>
<td>&lt;0.002</td>
</tr>
<tr>
<td>Percent of BMR</td>
<td>30 (11)</td>
<td>10 (15)</td>
<td>&lt;0.007</td>
</tr>
<tr>
<td>Infer AMI</td>
<td>9</td>
<td>2</td>
<td>NS</td>
</tr>
<tr>
<td>Anter AMI</td>
<td>13</td>
<td>2</td>
<td>NS</td>
</tr>
<tr>
<td>MAP</td>
<td>96 (14)</td>
<td>79 (4)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>HR</td>
<td>82 (13)</td>
<td>91 (21)</td>
<td>NS</td>
</tr>
<tr>
<td>SI</td>
<td>0.66 (0.14)</td>
<td>0.93 (0.27)</td>
<td>NS</td>
</tr>
<tr>
<td>RPP</td>
<td>10,458 (2,770)</td>
<td>9,013 (1,790)</td>
<td>NS</td>
</tr>
</tbody>
</table>

*Values are mean (± SD). VO₂ = oxygen consumption (ml/min); VO₂ index = oxygen consumption per body surface area (ml/min·m²); percent of BMR = percentage difference from basal metabolic rate; MAP = mean arterial pressure (mm Hg); HR = heart rate (beats/minute); SI = shock index; RPP = rate pressure product.

p values calculated using Fisher's exact test.

Benedict equation, the basal metabolic rate (BMR) was calculated for individual patients adjusting for age, sex, weight, and height. Percent increase in BMR was calculated from the actual energy expenditure and BMR. Shock index (SI) and rate-pressure product (RPP) were calculated (SI = heart rate/systolic arterial pressure and RPP = heart rate multiplied by systemic systolic arterial pressure) to indicate cardiac mechanical work and indirectly, myocardial VO₂.*

All patients were spontaneously breathing, and initial therapy included administration of high flow oxygen to maintain peripheral pulse oximetry (SaO₂>96 percent) and buccal nitroglycerin (1 to 2 mg) to relieve ischemic pain. No opiates or thrombolytic therapy was given before initial VO₂ measurement. All patients received thrombolytic therapy as soon as the diagnosis of AMI was made and were monitored in the cardiac intensive care unit. Patients were grouped by the incidence of cardiogenic shock developing within 24 h of admission to hospital. This was defined as the administration of inotropic drugs (dopamine or dopamine) to reverse hypotension (MAP<60 mm Hg) and requirement of mechanical ventilation for pulmonary edema. Survival was defined as hospital discharge.

The differences in measured variables between groups were compared using Mann-Whitney test, and correlation between VO₂ and RPP was analyzed using Pearson's correlation coefficients. The distribution of anterior vs inferior AMI in groups 1 and 2 was compared with Fisher's two-tailed exact test. Statistical significance was accepted at p<0.05.

RESULTS

Twenty-four patients were studied within 6 h and two within 24 h of onset of symptoms. Fifteen patients had electrocardiographic evidence of anterior AMI, and 11 had inferior AMI (Table 1). There were 9 female and 17 male subjects. There was no age difference between group 1 and group 2 patients (Table 1). All patients in group 2 were studied within 6 h, and in group 1, 20 patients were studied within 6 h and 2 patients within 24 h of onset of symptoms.

Although both groups had similar HR, SI, and RPP, group 2 was normotensive and group 1 had raised initial MAP. Group 2 patients, who later progressed to cardiogenic shock within 24 h of hospital admission, had significantly lower VO₂, VO₂ index, and percent increase in BMR than group 1. The mean VO₂ index was 100 ml/min·m² in group 2 (normal range 120 to 140 ml/min·m²). All patients in group 1 had VO₂ index greater than 100 ml/min·m². There was no significant difference in the distribution of anterior and inferior AMI between groups 1 and 2 (p>0.9). There were no
significant correlations between RPP vs \( \text{VO}_2 \), SI vs \( \text{VO}_2 \), RPP vs percent increase in BMR, or SI vs percent increase in BMR (Fig 1-4).

Within 24 h of admission, all patients in group 2 developed clinical features, and two died of cardiogenic shock in the cardiac intensive care unit (Table 2). The patients in group 1 had uncomplicated recoveries from AMI and were hospital survivors.

**DISCUSSION**

Several indices have been used to assess the prognosis in AMI. Surface electrocardiographic changes in 12-lead recordings are useful to localize the site and extent of myocardial infarction but do not indicate the degree of impairment of cardiac function.\(^{10,11}\) Enzymes released from injured myofibers, e.g., creatine phosphokinase isoenzyme, can indicate the size of myocardial damage but cannot predict short-term complications.\(^{12}\) Two-dimensional echocardiography has been used to detect regional and global wall motion abnormalities of cardiac chambers and to measure ventricular ejection fraction in AMI.\(^{13,14}\) These changes may correlate with the severity of AMI and its morbidity and mortality. However, the measurements obtained by echocardiography are operator-dependent, and this technique requires extensive training to be utilized as a bedside diagnostic modality in the emergency department.\(^{15}\) Forrester et al.\(^{15}\) utilized invasive monitoring of pulmonary capillary wedge pressure and its relationship to cardiac output to predict the severity and prognosis in AMI. Unfortunately, with early administration of intravenous thrombolytic agents, invasive hemodynamic monitoring can be hazardous in AMI.\(^{16}\) Other investigators have questioned the benefit and risks of such invasive monitoring in patients with uncomplicated AMI.\(^{17,18}\) Lactic acid concentration in AMI complicated by cardiogenic shock was shown to correlate with mortality.\(^{19}\) Hyperlactemia indicated low cardiac output and oxygen delivery (\( \text{DO}_2 \)) to meet tissue oxygen requirement and the accumulation of an oxygen debt.\(^{6}\) The critical \( \text{DO}_2 \) (i.e., lowest possible \( \text{DO}_2 \) to satisfy aerobic tissue requirements) was estimated at 330 ml/min\( \cdot \)m\(^2\) in anesthetized man\(^{20}\) and was reduced to 270 ml/min\( \cdot \)m\(^2\) in cardiogenic shock.\(^{21}\) The left shift or decrease in critical \( \text{DO}_2 \) can delay the onset of anaerobic metabolism and hyperlactemia in cardiogenic shock. An “alactic” oxygen debt may accumulate before any significant rise in lactic acid concentrations, and its increase is a late manifestation of deterioration in cardiac output, \( \text{DO}_2 \), and global tissue ischemia.\(^{22}\)

Alternatively, the measurement of \( \text{VO}_2 \) may provide a direct assessment of global tissue oxygen demand and an early warning of deterioration in systemic oxygen uptake and onset of global ischemia in AMI.

Previous studies observed that \( \text{VO}_2 \) was reduced below normal (less than 120 ml/min\( \cdot \)m\(^2\)) in AMI complicated by cardiogenic shock or left ventricular failure.\(^{1,4,23,24}\) However, \( \text{VO}_2 \) was measured by indirect Fick method which required pulmonary artery catheterization. Patients were mechanically ventilated and receiving exogenous catecholamines as inotropes and/or vasopressors. The infusion of exogenous catecholamines was shown to increase systemic metabolic demands and \( \text{VO}_2 \) in cardiogenic shock.\(^{25,26}\) In this study, \( \text{VO}_2 \) was measured by indirect calorimetry in spontaneously breathing patients in the absence of pharmacologic intervention with inotropes or vasopressor therapy soon after AMI. Indirect calorimetry is the gold standard and most accurate method to measure \( \text{VO}_2 \), especially at low inspired oxygen concentration (FIO\(_2\) = 0.21). This method is noninvasive and has minimal risks to the patient. The Deltrac metabolic computer was used because it is easy to use, oxygen electrode calibration is stable over time, and the values obtained are reliable and reproducible. This \( \text{VO}_2 \) measurement can be easily done at any time of day, and nursing staff can be trained to use the Deltrac computer with minimal operator-related error.

The \( \text{VO}_2 \) was increased in group 1 (mean 154 ml/min\( \cdot \)m\(^2\)) patients who made uncomplicated recovery and survived the AMI. Could the rise in systemic \( \text{VO}_2 \)

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**Table 2—Short-Term Outcome (Within 24 h of Admission) Following UAMI in Group 1 (Raised \( \text{VO}_2 \)) and Group 2 (Low \( \text{VO}_2 \))**

<table>
<thead>
<tr>
<th>Admission Criteria</th>
<th>Incidence of Cardiogenic Shock*</th>
<th>Hospital Survivors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Shock</td>
<td>Shock</td>
</tr>
<tr>
<td>Group 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(↑ ( \text{VO}_2 )) n = 22</td>
<td>22</td>
<td>0</td>
</tr>
<tr>
<td>Group 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(↓ ( \text{VO}_2 )) n = 4</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

*Hemodynamic collapse requiring therapy with mechanical ventilation, inotropic and vasoactive drugs or LV mechanical assist device.

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in group 1 be related to an increased myocardial Vo2?
Left ventricular and cardiac mechanical work as
indicated by the SI and RPP were similar in patients
with high (group 1) and low (group 2) Vo2.8,9 There
were no significant correlations between systemic Vo2
or percent increase in basal metabolic rate and the
RPP after UAMI. Therefore, the increase in Vo2 was
not related to an increased myocardial Vo2 but raised
systemic metabolic demands of extracardiac tissues.8,7
The increase in metabolic demands and Vo2 was
independent of the site of AMI, ie, anterior or inferior
and may be related to raised plasma catecholamines
and possibly cytokines which can increase basal met-
abolic demands.4,5 Alternatively, the rise in Vo2 in
group 1 may reflect a repayment of an already existing
systemic oxygen debt. Lactic acid concentration was
not measured in this study, however, its normality
might not necessarily exclude "lactic" oxygen debt.
A rise in Vo2 was reported in AMI and was associated
with agitation and skeletal muscle activity and could
be reversed with sedative drugs.26

The Vo2 was decreased (mean 100 ml/min·m2)
in group 2 presenting with normal MAP and HR and
apparent hemodynamic stability and progressed later
to cardiogenic shock. The stroke volume, cardiac
output, and Do2 may be reduced after UAMI.1,9 When
Vo2 is reduced, this usually indicates a Do2 reduced
below its critical value and onset of global tissue
ischemia. Anaerobic metabolism and hyperlactemia
can develop later after the decrease in Vo2.6,22 Previous
studies in AMI patients showed that subnormal Vo2
was related to low cardiac output and Do2 below their
critical level even at normal MAP.2 The sympathoadre-
nal and humoral mechanisms activated during low
cardiac output can increase systemic vascular resis-
tance, and therefore, maintain systemic MAP and
hemodynamic stability.23,29,30 This is consistent with the
original Shoemaker23 observation that Vo2 was reduced
in shock states before hemodynamic collapse
manifested. Group 1 tended to have a raised MAP,
potentially due to similar systemic vasoconstriction
response to a reduction in cardiac output.
Previous work has demonstrated that when Vo2 was
increased at low cardiac output and Do2 by exogenous
catecholamine infusion, global tissue ischemia and
hyperlactemia were exacerbated and this was associ-
ated with poor outcome in AMI.31,32 Inotropic drugs
were used to maintain cardiac output, and no attempts
were made to recanalize the infarct zone coronary
artery with either thrombolytic therapy or angioplasty.
The poor cardiac response and reduced Do2 in the
face of increased Vo2 can be detrimental in AMI. In
this study, group 2 patients with low Vo2, progressed
to cardiogenic shock after thrombolytic therapy. Per-
haps this group of patients should have had more
invasive hemodynamic monitoring and aggressive
means of myocardial revascularization, eg, translumi-
nal coronary balloon angioplasty or coronary artery
grafting to improve outcome.33,34 Early evaluation of
Vo2 by indirect calorimetry may provide early identi-
fication of UAMI patients who are normotensive and
hemodynamically compensated but still at risk of
progressing to shock. This subset of patients may
require aggressive therapy early in their hospitaliza-
tion.

There are limitations in the present study. Although
the number of patients included in the study was
small, the difference in Vo2 between groups 1 and 2
was highly significant. Lactic acid concentration was
not measured in this study, however, this was likely
to be raised in group 2 as a later manifestation of an
earlier reduction in Vo2 and global tissue ischemia.
Certain conditions, eg, hypothermia, old age, may be
associated with low BMR and Vo2.35,36 When AMI
occurs in such states, the reliability of Vo2 to predict
subsequent shock may be affected.

CONCLUSIONS
The Vo2 is increased in UAMI and represents
increased peripheral tissue metabolic demands and
not increased myocardial Vo2. When Vo2 is reduced
(<100 ml/min·m2) after AMI, this may be an early
indication of progressive cardiac failure. Early meas-
urement of Vo2 by indirect calorimetry is a simple
noninvasive method to identify UAMI patients with
severe cardiac dysfunction and poor prognosis who
may benefit from early aggressive means of myocardial
revascularization.

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