Effect of Routine Intensive Care Interactions on Metabolic Rate*

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The alterations in metabolic (oxygen consumption \(\dot{V}_O_2\) and carbon dioxide production \(\dot{V}C_0_2\)) and hemodynamic (heart rate and blood pressure) parameters caused by various common intensive care activities were examined in a group of 23 mechanically-ventilated critically-ill patients. The observed variations in metabolic rate can be classified into four categories as follows: (a) the lowest energy expenditure, which was associated with sleeping in the majority (83 percent) of instances; (b) resting, which was defined as a state where the patient was lying motionless with eyes open and responding to surrounding events, where \(V_O_2\) and \(V_C_0_2\) averaged 9.1±7.5(SD) percent and 7.5±7.3 percent, respectively, above the lowest values; (c) a variety of routine daily care activities (eg, bathing, performing a physical examination) that although not particularly painful, caused arousal from the resting state. During these situations, \(V_O_2\) and \(V_C_0_2\) averaged about 20 percent above lowest values; and (d) chest physical therapy, which was associated with metabolic increases of 35 percent above lowest values as well as increases in both heart rate and blood pressure. This study demonstrates that routine daily ICU activities can significantly alter metabolic rate, and thus, it is important to couple such measurements with astute observations of the patients' activity state. In addition, we have defined an activity state—resting—that can be used in the calculation of energy expenditure as well as for intrapatient and interpatient comparisons.

The intensive care unit is a dynamic setting wherein the severely ill patient receives extensive and constant care. Measurements of oxygen consumption \(\dot{V}O_2\) and carbon dioxide production \(\dot{V}C_0_2\) are frequently performed in such patients to calculate energy (caloric) expenditure using principles of indirect calorimetry. These calculations are used in planning nutritional regimens, as well as to evaluate metabolic state. The intrinsic state of the patient (sleeping, resting, moving, etc) as well as routine daily therapeutic and diagnostic interventions can affect these measurements. This study quantitates the alterations in both metabolic \(\dot{V}_O_2\) and \(\dot{V}C_0_2\) and hemodynamic (blood pressure and heart rate) parameters caused by various common intensive care activities in a group of mechanically-ventilated critically-ill patients. These data can be used to define a baseline metabolic state for use in the calculation of caloric requirements and for use in both intrapatient and interpatient comparisons.

**METHODS**

Twenty-three postoperative patients receiving mechanical ventilatory support were studied on 36 occasions. All patients were hemodynamically stable and not comatose. All were located in the Surgical-Anesthesiology Intensive Care Unit of the Columbia-Presbyterian Medical Center. Metabolic and hemodynamic measurements were performed every 15 minutes during the four to eight hours of each study. If conditions warranted, measurements were made more often. These measurements were correlated with observations of the patient and his or her environment.

**Metabolic Measurements**

The \(\dot{V}_O_2\), \(\dot{V}C_0_2\), and respiratory quotient (RQ) were measured using a Beckman Metabolic Measurement Cart I. The air and oxygen intakes of the Bourns Bear I respirators were provided with gas blended by a single Bennett AO-I air-oxygen mixer to ensure a constant \(F_0_2\). The \(O_2\) and \(C_0_2\) analyzers, as well as the volume transducers, were calibrated before each measurement, then measurements were performed for a period of three minutes. The accuracy of the Beckman Metabolic Measurement Cart was validated as described by Damask et al. The patients in this study were ventilated with inspired oxygen concentration between 0.35 and 0.45.

**Hemodynamic Measurements**

All patients had heart rate and blood pressure monitored continuously using an indwelling 20 g radial artery catheter and Hewlett-Packard pressure amplifier modules. The rate-pressure-product was calculated from the systolic blood pressure and heart rate.†

**Observational Parameters**

The activity state of each patient during each metabolic measurement was evaluated by one of two observers (M. K. or C. W.). Definitions of various events were established as follows to allow for uniformity of reporting.

"Sleeping" was defined as a state where the patient was not aroused by surrounding events.

"Resting" was defined as lying motionless with eyes open responsive to surrounding events.

Other frequently observed daily activities included the movement of body and limbs, chest physical therapy, a physical examination,
Table 1—Metabolic and Hemodynamic Values for Lowest, Resting, and Peak Metabolic States (N = 36; Values are Means ± SD)*

<table>
<thead>
<tr>
<th></th>
<th>(\dot{V}O_2) (ml/min)</th>
<th>(\dot{V}CO_2) (ml/min)</th>
<th>Heart Rate (bpm)</th>
<th>Systolic Blood Pressure (mm Hg)</th>
<th>Rate Pressure Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest</td>
<td>204 ± 57</td>
<td>156 ± 32</td>
<td>95 ± 15</td>
<td>129 ± 22</td>
<td>12966 ± 2958</td>
</tr>
<tr>
<td>Resting</td>
<td>225 ± 55**</td>
<td>166 ± 36**</td>
<td>96 ± 16</td>
<td>129 ± 25</td>
<td>11806 ± 2776</td>
</tr>
<tr>
<td>Peak</td>
<td>285 ± 72**</td>
<td>217 ± 55**</td>
<td>104 ± 16**</td>
<td>130 ± 55**</td>
<td>14233 ± 3605**</td>
</tr>
</tbody>
</table>

*Significantly different than lowest values: (A) p<0.025; (B) p<0.005; and (C) p<0.001. Significantly different than resting values: (D) p<0.025, and (E) p<0.001.

having a bath, having visitors, having an electrocardiogram, undergoing a dressing change, and having a chest roentgenogram taken. Not all of the patients were observed during all of the above activities.

Data Analysis

The lowest \(\dot{V}O_2\) and \(\dot{V}CO_2\) observed, the mean resting \(\dot{V}O_2\) and \(\dot{V}CO_2\) and the peak \(\dot{V}O_2\) and \(\dot{V}CO_2\) for each study were examined along with the corresponding heart rate, systolic blood pressure, and rate-pressure-product. The percentage increase above lowest values for both resting and peak was calculated.

The percentage increase above lowest levels of both metabolic (\(\dot{V}O_2\) and \(\dot{V}CO_2\)) and hemodynamic (blood pressure and heart rate) parameters were calculated for each of the various daily activities.

Statistical analysis was performed using analysis of variance and Student's t-test. This study was approved by the Institutional Committee for Human Investigation of Columbia University, Health Sciences.

Results

The lowest oxygen consumption and carbon dioxide production values for each study occurred primarily (83 percent) during sleep. Resting values were significantly greater than the lowest values (Table 1). Mean resting \(\dot{V}O_2\) and \(\dot{V}CO_2\) averaged 9.1 ± 7.5 (SD) percent (p<0.05) and 7.5 ± 3.3 percent (p<0.001) respectively above the lowest values. The peak \(\dot{V}O_2\) values were 32 ± 15 percent above the lowest (p<0.001), while the peak \(\dot{V}CO_2\) values were 32 ± 17 percent above (p<0.001). Hemodynamic data revealed no difference in either heart rate or systolic blood pressure between lowest and resting values (Table 1). During peak oxygen consumption, heart rate, systolic blood pressure, and the rate-pressure-product were significantly greater than both lowest and resting values.

The effect of daily activities on metabolic and hemodynamic variables was also examined. As can be seen in Figure 1, various activities such as dressing changes, visitors, the taking of a chest roentgenogram, etc, result in significant increases (about 20 percent) in both \(\dot{V}O_2\) and \(\dot{V}CO_2\) above both the lowest and resting levels. Significant changes in systolic blood pressure or heart rate were noted only during "moving body or limbs," "visitors" and "physical examination" (Fig 2). Chest physical therapy caused an average of a 38 ± 18
percent increase in $\dot{V}O_2$ and a 35 ± 18 percent increase in $\dot{V}CO_2$ above lowest levels. These values were significantly greater than all other observations. In addition, during chest physical therapy, heart rate and rate-pressure-product were significantly greater than both resting and lowest levels (Fig 2). Throughout the study, the mean respiratory quotients were well within the physiologic range: between 0.75 and 0.85 (Fig 1).

**DISCUSSION**

The results of this study indicate that the daily care of the critically ill patient results in well-defined and predictable alterations in metabolic rate. It should be noted that only hemodynamically stable, noncomatose mechanically ventilated surgical ICU patients were studied. This patient population represents the subset of ICU patients who require mechanical ventilation for a moderate-to-long period of time, and thus, often need either enteral or parenteral nutritional support. These patients often have an acute illness superimposed on a number of preexisting chronic illnesses and are usually of advanced age. The average age of our patients was 68 years. In addition, since these patients were hemodynamically stable, alterations in $\dot{V}O_2$ and $\dot{V}CO_2$ could be ascribed to the observed events, rather than to a pathophysiologic phenomenon.

This group of patients also presents a unique experimental situation, unlike spontaneously breathing patients, since frequent measurements of gas exchange can be performed without interfering with the patient's respiratory system. In spontaneously breathing patients, long-term measurements are difficult since they must be performed with either a mask or mouthpiece plus noseclip or by placing the patient in a canopy.5

The results of this study indicate that the observed variations in metabolic rate can be classified into the four following categories.

(a) The lowest energy expenditure was found to be associated, in the majority (83 percent) of situations, with sleep. The $\dot{V}O_2$ averaged 9.1 ± 7.5 percent below resting values (p<0.001), while $\dot{V}CO_2$ averaged 7.5 ± 7.3 percent below resting values (p<0.001). This is consistent with observations made in healthy individuals that sleep results in an 8 percent to 12 percent decrease in energy expenditure.6,7 It is interesting to note that not all instances of sleep were associated with the lowest $\dot{V}O_2$ and $\dot{V}CO_2$. Others have demonstrated that sudden increases in $\dot{V}O_2$ and $\dot{V}CO_2$ may occur during sleep, especially during rapid eye movement (REM) sleep.4

(b) Resting—This was rigidly defined as a state where the patient was lying motionless with eyes open and responsive to surrounding events. This strict definition was necessary since movement of limbs caused significant increases in both $\dot{V}O_2$ and $\dot{V}CO_2$ above resting. Responsiveness to surrounding events was gauged as eye movements tracking the movements of hospital staff.

(c) A variety of situations (Fig 1) was associated with oxygen consumption and carbon dioxide production levels that were about 20 percent greater than the lowest values. These situations were routine daily care activities that although not painful, involved arousal from the resting state, external stimulation, and both active and passive limb movement. In fact, voluntary movements of the patients’ bodies and limbs produced increases in $\dot{V}O_2$ and $\dot{V}CO_2$ of similar magnitude (Fig 1).

(d) Chest physical therapy—This patient care activity was associated with the greatest metabolic stimulus and was associated with significant increases in heart rate as well as rate-pressure-product. Increases greater than 20 percent in both metabolic and hemodynamic parameters were not observed since blood pressure and heart rate were continuously monitored during this procedure, and the nursing staff discontinued the therapy when either blood pressure or heart rate increases greater than 20 percent of the resting values were observed. The increases in both $\dot{V}O_2$ and $\dot{V}CO_2$ observed during this procedure are probably due to a variety of factors including pain, movement, and muscular tension in both the chest and abdomen. This procedure is both a major hemodynamic and metabolic stress and caution should be exercised while performing it, especially in patients with underlying cardiovascular disease.

These results appear to have both clinical and scientific importance. They indicate the extent of both the metabolic and hemodynamic stress that is associated with the various routine daily activities of the ICU patient. It is interesting to note that increases in metabolic rate of up to 25 percent above the lowest energy expenditure were not accompanied by consistent alterations in hemodynamic parameters. There, thus, appears to be a threshold above which increases in metabolic rate are accompanied by consistent increases in heart rate and blood pressure.

In addition, these results allow for the definition of the resting state. Measurements of energy expenditure are traditionally performed in the “basal” state. This is defined as the minimal energy expenditure of a subject lying down and resting in a thermoneutral environment having fasted for the previous 12 hours.8,9 Such conditions are extremely rare in the critically-ill patient since such a patient is receiving some form of continuous nutrition, whether it be 5 percent dextrose or enteral or parenteral nutrition. Measurements made during rest in patients receiving total parenteral nutrition are described as measurements of resting energy expenditure (REE) and are usually about 10 percent above basal since they include the specific dynamic action of foods.10 Such measurements are performed with the patients supine, resting, and
awake; three to five such measurements each of 40- to 60-minute duration are performed over a 24-hour period.18

Measuring energy expenditure in critically ill patients receiving mechanical ventilation poses a variety of problems. The initial problem is defining a reference state from which to calculate energy expenditure for use in the formulation of caloric intake. This is especially crucial since these patients may be comatose, may have received narcotics or muscle relaxants (both of which can alter metabolic rate), or may be disoriented, and thus, be unable to follow verbal commands to remain at rest, not sleep and not thrash about. In addition, these patients receive intensive and often continuous nursing and medical care.

In this study, we have defined such a reference state and have named it "resting" since it appears to correspond to the resting state found in spontaneously breathing patients. However, it is important to remember that, due to the oxygen cost of breathing, REE is greater during spontaneous breathing than during mechanical ventilation.19 It should also be noted that the patients in this study were hemodynamically stable and were not comatose. Further investigation is required to define a reference state for the comatose patient.

While performing this study, a number of important practical observations were made. It was noted in one patient that VO₂ and VCO₂ were lower when he was sedated heavily with narcotics (morphine) than when he was unversed. This is consistent with observations20 that narcotics decrease metabolic rate when given in moderate-to-large doses. Also, it is very important to be aware that after stimulation, (whether it be a bath, chest physical therapy, or some other procedure, such as connecting the instrumentation used to measure VO₂ and VCO₂) metabolic rate may be elevated for a period of time up to 45 minutes. Damask et al21 observed that after a painful procedure such as a muscle biopsy, normal subjects had increases in VO₂ and VCO₂, at least 15 percent above baseline for an average of 11 minutes. It is thus important to wait a while after stimulation before attempting to measure a resting metabolic rate. In addition, multiple and frequent measurements should be made to ensure that the patient is truly resting. Fluctuations in the measurement (it is important to make sure they are not due to technical problems) may indicate that the patient has yet to return to baseline or is experiencing stimulation such as pain or anxiety. Thus, the mere observation of a motionless patient with his eyes open responding to his surroundings in and of itself is insufficient to be labelled resting, but coupled with stable measurements over a 15 to 30 minute period can be considered to represent resting. Confirmation is most reliably obtained by repeating the resting measurements at some later time. In addition, monitoring of heart rate and blood pressure is useful since increases may indicate that the patient is in an unstable metabolic situation.22

In summary, this study demonstrates that the various routine daily ICU activities can significantly alter metabolic rate. It is important to couple metabolic measurements with astute observations of the patient's activity state. In addition, we have defined an activity state in the group of subjects we have studied that appears to be similar to the resting state of spontaneously breathing subjects. This activity state can be used in the calculation of the caloric requirements of such patients. This rigidly defined activity state can also be used to make both intrapatient as well as interpatient comparisons.

Finally, it must be emphasized that measurement of resting energy expenditure is a complex and exacting task that requires an astute observer and much patience.

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