Indirect Calorimetry Measurement of Energy Expenditure Related to Body Position Changes in Healthy Adults

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Early mobilization is advocated to prevent intensive care unit-acquired physical weakness, but the patient’s workload and its changes in response to body position changes have not been established. We used indirect calorimetry to determine the energy expenditure (EE) in response to body position changes, and we assessed EE’s correlation with respiratory parameters in healthy volunteers: 8 males and 8 females, mean age 23.4 ± 1.3 years. The subjects started in the resting supine position followed by a 30° head-up position, a 60° head-up position, an upright sitting position, a standing position, and the resting supine position. EE was determined in real time by indirect calorimetry monitoring the subject’s respiratory rate, tidal volume (VT), and minute volume (MV). The highest values were observed immediately after the subjects transitioned from standing to supine, and this was significantly higher compared to the original supine position (1,450 ± 285 vs. 2,004 ± 519 kcal/day, \( p < 0.01 \)). Moderate correlations were observed between VT and EE (\( r = 0.609, \ p < 0.001 \)) and between MV and EE (\( r = 0.576, \ p < 0.001 \)). Increasing VT or MV indicates an increasing patient workload during mobilization. Monitoring these parameters may contribute to safe rehabilitation. Further studies should assess EE in critically ill patients.

Key words: early mobilization, energy expenditure, indirect calorimetry, rehabilitation, body position

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nurses), was shown to be one of the major barriers to the early mobilization of patients in an ICU [9]. However, the timing and body positions that are involved in the development of clinical instability during rehabilitation have not been described.

In this study, we used indirect calorimetry to determine (1) our subjects’ energy expenditure (EE) depending on their body positions and its changes and (2) the correlation between EE and physiological parameters.

**Subjects and Methods**

**Study population.** This study was approved by the Research Ethics Committee of the Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences (approval no. 1198) and was conducted in accord with the Declaration of Helsinki. All subjects provided written informed consent. Healthy subjects including 8 males and 8 females who were ≥ 20 years old were eligible for participation in the study. We enrolled 8 males and 8 females: mean age, 23.4 ± 1.3 years; mean body mass index [BMI], 22.0 ± 2.3 kg/m². Of the 16 subjects, 13 were categorized as normal weight (BMI 18.5-24.9) according to the World Health Organization guidelines [10]. The mean ± standard deviation (SD) BMI of all the 16 subjects in the study was 22.0 ± 2.3 kg/m², the variability of which is considered valid [11, 12].

**Calculation of energy expenditure (EE).** An indirect calorimetry monitor (S/5 Compact Critical Care Monitor™, GE Healthcare, Milwaukee, WI, USA) was used. This monitor measures EE in real time by extracting the consumed oxygen and produced carbon dioxide values from expired gas.

With the indirect calorimetry, we measured the subjects’ oxygen consumption (VO₂) (ml/min), carbon dioxide production (VCO₂) (ml/min), respiratory quotient (RQ), respiratory rate (RR) (breaths/min), tidal volume (Vₜ) (ml), minute volume (MV) (ml/min), and EE (kcal/day). The Weir equation was used to make these calculations, as follows [8].

\[
EE \ (\text{kcal/day}) = 3.941 \times VO₂ \ (\text{ml/min}) + 1.11 \times VCO₂ \ (\text{ml/min}) \times 1.440
\]

Respiratory parameters including RR, Vₜ, and MV are used as physiological parameters for safety considerations during patient mobilization, as their measurement allows real-time monitoring [8]. All of the above-described parameters were recorded every 10 sec over a 35-min period in each subject. Recordings were started 30 sec after the initiation of the measurement.

**Measurement protocol.** The measurements were performed in a calm environment. An oxygen mask was fitted to the subject with 2 belts to ensure that there were no air leaks. The indirect calorimetry device was connected to the mask via a heat and moisture exchange filter (Covidien DAR™ filter, Medtronic, Minneapolis, MN, USA), because the indirect calorimetry monitor is designed to connect directly to the circuit of a mechanical ventilator.

The measurement protocol involved mainly the body positions that are used for patient mobilization. The subject started in the resting supine position for 5 min, then shifted without assistance to a 30° head-up position supported by the adjustable hospital bed (hereinafter, “30° position”) for 7 min, and a then 60° head-up position supported by the bed (hereinafter, “60° position”) for 7 min. The subject then transitioned to an upright sitting position for 6 min and a standing position for 5 min. Finally, the subject returned to the resting supine position (hereinafter, “supine position”) for 5 min (Fig.1). Thus, the position order was: supine, 30° position, 60° position, upright sitting, standing, return to supine. The subject accomplished all of these position changes without assistance.

The maximum value of EE for each body position was defined as the 2-min mean value immediately after a position change. The stable value of EE was defined as the 2-min mean value immediately before a position change.

**Statistical analysis.** Continuous variables are presented as mean and SD. For the statistical analysis, we used Dunnett’s method for multiple comparisons to compare changes from the supine position to each other body position. The Pearson product-moment correlation coefficient was used for the statistical analysis regarding the correlations of changes in the EE during mobilization with the other measurements (RR, Vₜ, and MV). P-values < 0.05 were accepted as significant. All analyses were performed using JMP 11.0 software.

**Results**

**Changes in EE between positions.** The changes in EE depending on the subjects’ body positions are shown...
in Fig. 2. Immediately after a position change, the EE gradually increased and then peaked, returning to a value close to the supine value after approx. 2 min. The highest values were observed immediately after the transition from standing back to the resting supine position. The stable EE value after the 60° position was approximately equal to the supine value. When we assessed the differences in the EE between the supine position and each position by using a multiple comparison, significant changes were observed in the EE maximum values for the upright sitting (1,450 ± 285 vs. 1,682 ± 346 kcal/day, \( p < 0.01 \)), standing (1,450 ± 285 vs. 1,624 ± 347 kcal/day, \( p < 0.01 \)), and supine positions (1,450 ± 285 vs. 2,004 ± 519 kcal/day, \( p < 0.01 \)) (Fig. 2).

![Diagram of position changes](image)

**Fig. 1** Measurement protocol. The subject started in the resting supine position for 5 min and then shifted to a 30° head-up position for 7 min, then a 60° head-up position for 7 min, an upright sitting position for 6 min, a standing position for 5 min, and finally returned to the resting supine position for 5 min.

![Graph of energy expenditure](image)

**Fig. 2** Changes of EE every 30 sec in response to body position changes (mean ± SD). The maximum values of EE in the upright sitting, standing, and supine position from standing were significantly higher compared to the supine position at the beginning \(( p < 0.01)\). EE, energy expenditure.
No significant changes were observed in any other EE maximum values or in any stable EE values.

**Correlations of changes in EE with the respiratory parameters.** The correlations among the RR, \( V_T \), and MV values and the EE are shown in Table 1 and Fig. 3. Table 1 summarizes the correlations among the RR, \( V_T \), MV, and the EE for each subject, and in Fig. 3, all 16 subjects are represented. Although no correlation was observed between the RR values and the EE (\( r = -0.119, \ p < 0.001 \)), moderate correlations were observed between \( V_T \) values and the EE (\( r = 0.609, \ p < 0.001 \)) as well as between the MV values and the EE (\( r = 0.576, \ p < 0.001 \)) (Fig. 3). Although the RR remained nearly unchanged, the \( V_T \) and MV showed their highest peak after the transition from standing back to the supine position, which was in line with the changes in the EE (Fig. 4).

**Discussion**

This is the first study to use indirect calorimetry to examine the EE associated with body position changes in healthy subjects. We observed that the peak of EE occurred after the subjects transitioned from standing back to the supine position. Our findings also indicate that monitoring the \( V_T \) or MV in real time may reflect

<table>
<thead>
<tr>
<th>No.</th>
<th>RR ( r )</th>
<th>P value</th>
<th>( V_T ) ( r )</th>
<th>P value</th>
<th>MV ( r )</th>
<th>P value</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>0.16</td>
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<td>n.s.</td>
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<td>3</td>
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<td>0.008</td>
<td>0.295</td>
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<tr>
<td>4</td>
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<td>0.48</td>
<td>0.002</td>
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<td>&lt;0.001</td>
</tr>
<tr>
<td>6</td>
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<td>&lt;0.001</td>
<td>0.588</td>
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<td>&lt;0.001</td>
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<td>0.528</td>
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<td>&lt;0.001</td>
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<td>&lt;0.001</td>
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<td>&lt;0.001</td>
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<td>0.192</td>
<td>n.s.</td>
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<td>0.602</td>
<td>&lt;0.001</td>
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<tr>
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<td>&lt;0.001</td>
<td>0.663</td>
<td>&lt;0.001</td>
<td>0.821</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

RR, respiratory rate; \( V_T \), tidal volume; MV, minute volume; EE, energy expenditure.
patients’ actual workload during rehabilitation.

An earlier study used indirect calorimetry to investigate the correlation between the degree of exercise intensity and the EE in both critically ill patients and healthy volunteers [13]. In that study, the EE induced by exercise in the critically ill patients was confirmed to be higher compared to that in the healthy volunteers, and no adverse events occurred among the patients. In another study assessing oxygen consumption in critically ill patients undergoing rehabilitation, sitting on the edge of the bed was found to be associated with a significant increase in oxygen consumption compared to passive chair transfer [14].

Berney et al. showed that among critically ill patients, the changes in body position from supine to side lying caused a transient 39% increase in oxygen consumption [14]. In the present study, we determined the detailed time-course changes of the EE in response to body position changes in healthy subjects, and the results revealed that the upright sitting position induced a 16% increase in the EE from the basal values in the supine position. Transitioning from standing back to the supine position surprisingly led to a 38% increase in the EE in comparison to the basal values in the original supine position. The EE after the transition to a 30° or 60° position from the supine position did not change, which may be attributed to passive movement. We also observed that the peak in EE associated with the position changes did not occur immediately after any position change, but rather took approx. Thirty sec to 1 min and subsequently decreased to a value nearly equivalent to the original supine value within 2 min, which is consistent with previous data [15].

These results may be explained by the fact that the standing position increases the body’s metabolic rate due to the antigravitational muscle tone, and this slight delay may have occurred because carbon dioxide is not produced until slightly after the muscles metabolize energy [16]. In addition, the supine position is associated with increased metabolism by minimizing the tidal volume due to an elevated diaphragm [17]. Changes in posture can significantly affect respiratory patterns in patients with chronic obstructive pulmonary disease or chronic heart failure [18,19]. Our present findings suggest that physical therapists and nurses in rehabilitation settings should be aware that the peak in EE is reached after a patient changes from the upright or standing position to the supine position.

Fig. 4 Changes of RR, Vt and MV every 1 min in response to body position changes (mean ± SD). The Vt and MV showed their maximum values after the transition from standing back to the supine position. A, RR; B, Vt; C, MV. The subject started in the resting supine position for 5 min followed by a 30° head-up position (from 5 to 12 min), a 60° head-up position (from 12 to 19 min), an upright sitting position (from 19 to 25 min), a standing position (from 25 to 30 min), and the resting supine position (from 30 to 35 min).

RR, respiratory rate; Vt, tidal volume; MV, minute volume.
In the absence of indirect calorimetry settings, Mehta et al. suggested that monitoring carbon dioxide elimination values might be sufficient to obtain the EE [20,21]. Osuka et al. proposed that in patients with severe head injuries, the EE may be estimated from the patient's age, body height, body weight, heart rate and MV [22]. Our present findings demonstrated that VT and MV were moderately correlated with the EE measured by indirect calorimetry in healthy subjects, indicating that the continuous monitoring of VT or MV can guide healthcare professionals in their goal to provide proper and safe rehabilitation. Since the VT and MV demonstrated their highest peak after the transition back to the supine position, monitoring these parameters can be helpful for measuring patients' workload.

There are several limitations to our study. We investigated the EE in response to position changes only in healthy young subjects, and the EE during active motion in critically ill patients seems to differ from that in healthy subjects [13]. We were also unable to examine hemodynamic parameters that are generally observed in daily clinical practice, including heart rate and blood pressure. In addition, clinical information including the diagnosis, severity of disease, comorbidities, and medications should be taken into consideration in critical care settings. Thus, our findings cannot be generalized to mechanically ventilated patients in an ICU.

Despite these limitations, this is the first study using indirect calorimetry to examine the EE in response to position changes in healthy subjects. The maximum value of EE was observed after the subjects transitioned from standing back to the supine position, and the implication of this finding in clinical practice is that patients should be watched carefully for a while even after they have returned from rehabilitation and resumed the supine position in bed. Our study also showed that monitoring the VT and MV may contribute to patients' safe rehabilitation. Further investigations are needed to assess the EE in critically ill patients.

In conclusion, we reported the detailed time-course changes of EE associated with body position changes revealed by indirect calorimetry, based on the concept of active rehabilitation in healthy subjects. The peak in EE was observed after the transition from standing back to the supine position. Fluctuations in VT or MV may be useful as a risk management indicator during mobilization, contributing to patients' safe rehabilitation.