Evaluation of Resting and Working Postures from the Viewpoint of Local Muscle Energy Metabolic Rate

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According to the prediction method of local muscle energy metabolic rate (Yokoyama, 1980), energy metabolic rates of the seven muscle groups were predicted with simultaneous measurements of total energy metabolic rate and bipolar surface EMG during four resting and four working postures. The subjects were 21 Japanese male volunteers aged 22.5±2.7 years. Four resting postures were relaxed standing, sitting on a chair, supine and prone postures. The present working postures were consisted of standing on tiptoes, half rising with knee extension (at 180°), half rising with knees bending at 120° and deep forward bending postures. The seven muscle groups were the muscles of the anterior abdominal wall (M₁), the erector spinae muscles (M₂), the muscles of the buttock (M₃), the posterior femoral (M₄), the anterior femoral (M₅), the posterior crural (M₆), and the anterior crural muscle group (M₇).

During standing on tiptoes M₇ had the greatest metabolic rate (mean = 21.94 kcal/h) among the seven muscle groups, which was also greater than those of M₆ during the other seven postures. During half rising at 180° it was pointed out through t-test (Student-test) that M₂ and M₄ demanded the greater metabolic rates, of which the mean values (n = 21) were 29.51 and 6.87 kcal/h respectively. M₄ required 45.78 kcal/h during half rising at 120°, which was the greatest mean value in the present study. During deep forward bending posture the greater mean metabolic rates were 11.88 kcal/h in M₆ and 10.45 kcal/h in M₇.

On the other hand, during relaxed standing the metabolic rates were 5.13 in M₃, 7.94 in M₄, 4.88 in M₅, 2.37 in M₆, 5.49 in M₇, 9.61 in M₈ and 0.57 kcal/h in M₉. Since each of the seven muscle groups was near to the minimum metabolic rate during the above four working postures, it was considered that relaxed standing has been adopted to the resting posture in standing. The metabolic rates of the seven muscle groups during sitting on a chair were less than those during relaxed standing. Especially it was shown that the metabolic rates of M₈ and M₇ reduced with the significant level p < 0.001 and that those of M₅ and M₆ reduced with the significant level p < 0.01. During supine and prone postures the mean energy metabolic rates of the seven muscle groups were the least among the present tested postures, therefore it was interpreted to be reasonable that these postures has been adopted the sleeping postures in human daily life.

Key words: Muscular Load; Working Posture; Resting Posture; Local Muscle Energy Metabolic Rate

INTRODUCTION

The quantitative evaluation of postural loads has been done using EMG, ECG, total energy metabolic rate, cardiac output and abdominal pressure (Sato, 1971). Especially, EMG has developed the evaluation of muscular load. Though EMG enables us to evaluate loads in a muscle group among various sustained static postures, it cannot draw the comparison of loads among muscle groups in a posture except by few methods (Sato, 1966; Okada, 1972). Sato (1966) investigated the main muscle supporting a half rising posture by means of the
magnitudes of lowering EMG frequency spectrum. Okada (1972) reported the relative contraction levels of muscles during static postures.

Recently Yokoyama (1980) presented a prediction method of local muscle energy metabolic rate. It requires the measurements of total energy metabolic rate and integrated surface EMGs during different exercise items and the solution of the simultaneous equations. The experimental procedures and the solving procedures of the equations have been improved upon (Yokoyama et al., 1982). The results by the present method have a universal unit [kcal/h] or [W] enabling us to compare the muscular loads regardless of the kinds of postural items and muscle groups. The purpose of this study is to predict energy metabolic rates of seven main muscle groups during four resting and four working postures using 21 healthy Japanese males, of which number is greater than four or seven in the previous papers (Yokoyama, 1982; Yokoyama et al., 1982) and to disclose the difference of local energy metabolic rates between resting and working postures by using statistical analysis.

**METHODS**

The details of the prediction method of local muscle energy metabolic rate was presented in the previous paper (Yokoyama, 1980). Therefore in the present paper the principle of the method is described briefly.

Though total energy metabolic rate during an exercising item was three times of that during a resting item, the sum of energy metabolic rates of internal organs during an exercising item was the same as that during a resting item (Lehmann, 1953). Jansky (1964) reported that when the maximum metabolic rate occurred in the human body the total energy metabolic rate increased to about ten times of basal metabolic rate (BMR). It was achieved mainly by muscle organs and the sum of metabolic rates except that of muscle increased to only two times of that during BMR at most the same as in many other mammals. By means of the multiple regression analysis it was disclosed that the muscle activities had a significant effect on the total energy metabolic rate in static postures (Yokoyama, 1976). Accordingly under the condition that the metabolic changes are restricted to n muscle groups, total energy metabolic rate during ith item \( H_i \) [kcal/h] can be expressed as equation (1).

\[
H_i = \sum_{j=1}^{n} M_{ij} + B_i
\]

(1)

where \( M_{ij} \): energy metabolic rate in ith muscle group at ith item; \( B_i \): energy metabolic rate in organs other than those in n muscle groups [kcal/h]. Since \( B_i \) was considered to reflect adequately the basal metabolic rate (Yokoyama and Ogino, 1983), it would be called quasi-basal metabolic rate. Local muscle energy metabolic rate \( M_{ij} \) can be expressed by using a linear indicator, for which during human static postures the integrated bipolar surface electromyogram \( (m_{ij}) \) is well adopted.

\[
M_{ij} = c_i m_{ij}
\]

(2)

where \( c_i \) is the coefficient, and this value depends on the electrode condition of individuals. By selecting k (\( \geq n+1 \)) different resting and exercising items in which the total energy metabolic rates are similar, following simultaneous equation (3) can be obtained.

\[
\begin{bmatrix}
H_1 \\
H_2 \\
\vdots \\
H_k \\
H_k
\end{bmatrix} =
\begin{bmatrix}
m_{11} & m_{12} & \cdots & m_{1l} & \cdots & m_{1n} & 1 \\
m_{21} & m_{22} & \cdots & m_{2l} & \cdots & m_{2n} & 1 \\
\vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \vdots \\
m_{k1} & m_{k2} & \cdots & m_{kl} & \cdots & m_{kn} & 1 \\
m_{k1} & m_{k2} & \cdots & m_{kl} & \cdots & m_{kn} & 1
\end{bmatrix}
\begin{bmatrix}
c_1 \\
c_2 \\
\vdots \\
c_k \\
c_k
\end{bmatrix}
\]

(3)

Solving equation (3) for \( c_1, c_k \) and \( B_i \), we can get each local muscle energy metabolic rate by use of equation (2).

The subjects were 21 Japanese male volunteers aged 22.5(mean)±2.7(S.D.) years. Their stature and weight were 170.3±7.6cm and 63.0±7.3kg respectively.

The tested postures were four resting and four working postures. Four resting postures were
relaxed standing (standing at ease), sitting on a chair, supine (lying face upward) and prone (lying face downward) postures. The present working postures were consisted of standing on tiptoes, half rising with knee extension (at 180°), half rising with knees bending at 120° and deep forward bending postures.

As shown in Table 1, the subjected seven muscle groups were the muscles of the anterior abdominal wall (M₁), the erector spinae muscles (M₂), the muscles of the buttock (M₃), the posterior femoral (M₄), the anterior femoral (M₅), the posterior crural (M₆) and the anterior crural muscle group (M₇). In order to solve c₁, c₂ and B₁ in equation (3) easily (Yokoyama, 1980; Yokoyama et al., 1982), another exercising item in addition to the predicted eight postures was measured. The number of additional exercising item was nine or ten in most subjects.

Total energy metabolic rate was determined by the indirect calorimetry method. Expired gas was collected by Douglas bags through a gas mask. The pulmonary volume was measured with a gas meter. The oxygen and carbon dioxide content was determined with an electromagnetic gas analyzer or a micro Scholander gas analyzer. The bipolar surface EMG was led from a pair of silver disc electrodes (10mm in diameter) attached to the skin over the muscle fibers and spaced about 25mm between centers. EMGs were recorded from twelve muscles as seen in the right column of Table 1 with the six muscles in the other muscle groups. Consequently, it was confirmed that a muscle acted with each other in each of seven muscle groups and that muscle groups other than the seven muscle groups were inactive during all tested items. EMG recordings were obtained from the right side of the body.

**RESULTS**

Table 2 summarizes the means, standard deviations and coefficients of variation of energy metabolic rates of seven muscle groups in each posture. Fig. 1 shows the mean values of seven muscle groups and the significant differences of each muscle group between relaxed standing and the other seven postures.

During standing on tiptoes M₆ had the greatest metabolic rate (mean=21.94kcal/h) among the seven muscle groups, which was also greater than those of M₆ during the other postures. During half rising at 180° it was pointed out through t-test (Student-test) that M₂ and M₄ demanded the greater metabolic rates, of which the mean values (n=21) were 29.51 and 6.87kcal/h respectively. M₆ required 45.78kcal/h during half rising at 120°, which was the greatest mean value in the present study. During deep forward bending posture the greater mean metabolic rates were 11.88kcal/h in M₃ and 10.45kcal/h in M₇.

On the other hand, during relaxed standing the metabolic rates were 5.13 in M₁, 7.94 in M₂, 4.88 in M₃, 2.37 in M₄, 5.49 in M₅, 9.61 in M₆ and 0.57kcal/h in M₇. Each of the values in the relaxed standing was near to the minimum metabolic rate during the above four working postures. The metabolic rates of the seven muscle groups during sitting on a chair

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**Table 1.** The selected muscle groups for the prediction of local muscle energy metabolic rate in four working and four resting postures.

<table>
<thead>
<tr>
<th>Muscle group</th>
<th>Muscle</th>
<th>(Local muscle weight/Total muscle weight) %</th>
</tr>
</thead>
<tbody>
<tr>
<td>M₁</td>
<td>M. rectus abdominis*</td>
<td>5.59</td>
</tr>
<tr>
<td>M₂</td>
<td>M. erector spinae*</td>
<td>5.10</td>
</tr>
<tr>
<td>M₃</td>
<td>M. gluteus maximus*</td>
<td>9.24</td>
</tr>
<tr>
<td>M₄</td>
<td>M. semitendinosus*</td>
<td>4.41</td>
</tr>
<tr>
<td>M₅</td>
<td>M. rectus femoral*</td>
<td>13.05</td>
</tr>
<tr>
<td>M₆</td>
<td>M. vastus lateralis*</td>
<td>5.03</td>
</tr>
<tr>
<td>M₇</td>
<td>M. tibialis anterior*</td>
<td>1.80</td>
</tr>
</tbody>
</table>

* Indicator muscle of each muscle group
** After MATSUMISHIMA (1927)
Fig. 1. Predicted energy metabolic rates of seven muscle groups ($M_1$-$M_7$) during four working ($W_1$-$W_4$) and four resting ($R_1$-$R_4$) postures. Symbol (*), (**), and (***), show the significant level of $p<0.05$, 0.01 and 0.001 respectively, when the paired $t$-test (Student-test) was applied to compare the mean of relaxed standing with that of the other seven postures in each muscle group.
Table 2. Mean values, standard deviations (S.D.) (kcal/h) and coefficients of variation (C.V.) [-] of local muscle energy metabolic rate. M1; M. of the anterior abdominal wall. M2; Erector spinae m. M3; M. of the buttock. M4; Posterior femoral m. M5; Anterior femoral m. M6; Posterior crural m. M7; Anterior crural m.

<table>
<thead>
<tr>
<th>Item/Muscle</th>
<th>group</th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
<th>M6</th>
<th>M7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing on tiptoes</td>
<td>Mean</td>
<td>7.66</td>
<td>7.26</td>
<td>3.43</td>
<td>3.79</td>
<td>6.13</td>
<td>21.94</td>
<td>2.58</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>6.49</td>
<td>6.18</td>
<td>3.08</td>
<td>2.73</td>
<td>4.26</td>
<td>13.75</td>
<td>4.74</td>
</tr>
<tr>
<td></td>
<td>C.V.</td>
<td>0.98</td>
<td>0.85</td>
<td>0.90</td>
<td>0.72</td>
<td>0.70</td>
<td>0.63</td>
<td>1.82</td>
</tr>
<tr>
<td>Half rising at 180°</td>
<td>Mean</td>
<td>7.14</td>
<td>29.51</td>
<td>10.13</td>
<td>6.87</td>
<td>4.14</td>
<td>5.65</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>7.69</td>
<td>19.28</td>
<td>9.51</td>
<td>4.47</td>
<td>3.32</td>
<td>4.09</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>C.V.</td>
<td>1.08</td>
<td>0.65</td>
<td>0.94</td>
<td>0.65</td>
<td>0.80</td>
<td>0.72</td>
<td>0.84</td>
</tr>
<tr>
<td>Half rising at 120°</td>
<td>Mean</td>
<td>6.28</td>
<td>13.99</td>
<td>8.04</td>
<td>2.32</td>
<td>45.78</td>
<td>11.55</td>
<td>2.01</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>6.58</td>
<td>9.05</td>
<td>5.98</td>
<td>1.53</td>
<td>19.97</td>
<td>9.68</td>
<td>2.81</td>
</tr>
<tr>
<td></td>
<td>C.V.</td>
<td>1.05</td>
<td>0.65</td>
<td>0.74</td>
<td>0.68</td>
<td>0.44</td>
<td>0.84</td>
<td>1.40</td>
</tr>
<tr>
<td>Deep forward bending</td>
<td>Mean</td>
<td>6.05</td>
<td>4.59</td>
<td>11.88</td>
<td>10.45</td>
<td>4.25</td>
<td>7.66</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>4.39</td>
<td>5.32</td>
<td>11.82</td>
<td>6.13</td>
<td>3.13</td>
<td>4.86</td>
<td>1.12</td>
</tr>
<tr>
<td></td>
<td>C.V.</td>
<td>0.73</td>
<td>1.16</td>
<td>0.99</td>
<td>0.59</td>
<td>0.47</td>
<td>0.63</td>
<td>1.28</td>
</tr>
<tr>
<td>Relaxed</td>
<td>Mean</td>
<td>5.13</td>
<td>7.94</td>
<td>4.88</td>
<td>2.37</td>
<td>5.49</td>
<td>9.61</td>
<td>0.57</td>
</tr>
<tr>
<td>Standing</td>
<td>S.D.</td>
<td>4.87</td>
<td>6.46</td>
<td>3.65</td>
<td>1.88</td>
<td>6.33</td>
<td>6.84</td>
<td>0.64</td>
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<tr>
<td>Sitting on a chair</td>
<td>Mean</td>
<td>4.80</td>
<td>3.42</td>
<td>1.97</td>
<td>0.58</td>
<td>1.70</td>
<td>1.24</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>5.01</td>
<td>2.86</td>
<td>2.18</td>
<td>0.50</td>
<td>1.40</td>
<td>1.50</td>
<td>0.23</td>
</tr>
<tr>
<td></td>
<td>C.V.</td>
<td>1.04</td>
<td>0.84</td>
<td>1.10</td>
<td>0.86</td>
<td>0.82</td>
<td>1.21</td>
<td>0.93</td>
</tr>
<tr>
<td>Supine posture</td>
<td>Mean</td>
<td>2.31</td>
<td>1.40</td>
<td>1.28</td>
<td>0.36</td>
<td>1.50</td>
<td>1.19</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>1.63</td>
<td>0.99</td>
<td>1.33</td>
<td>0.42</td>
<td>0.79</td>
<td>1.05</td>
<td>0.36</td>
</tr>
<tr>
<td></td>
<td>C.V.</td>
<td>0.71</td>
<td>0.71</td>
<td>1.05</td>
<td>0.75</td>
<td>0.78</td>
<td>0.89</td>
<td>0.99</td>
</tr>
<tr>
<td>Prone posture</td>
<td>Mean</td>
<td>2.90</td>
<td>2.97</td>
<td>2.05</td>
<td>0.98</td>
<td>2.40</td>
<td>1.07</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td>2.37</td>
<td>1.97</td>
<td>1.80</td>
<td>0.81</td>
<td>1.59</td>
<td>0.64</td>
<td>0.29</td>
</tr>
<tr>
<td></td>
<td>C.V.</td>
<td>0.82</td>
<td>0.66</td>
<td>0.88</td>
<td>0.83</td>
<td>0.66</td>
<td>0.60</td>
<td>0.86</td>
</tr>
</tbody>
</table>

were less than those during relaxed standing. Especially it was shown that the metabolic rates of M4 and M6 reduced with the significant level \( p < 0.001 \) and that those of M5 and M7 reduced with the significant level \( p < 0.01 \). During lying postures, supine and prone posture, each of the mean energy metabolic rates of the seven muscle groups was less than that of relaxed standing. Especially, during supine posture each of them was the least among the present tested postures (see Table 2 and Fig. 1).

**DISCUSSION**

The evaluation of muscular load by our method has several points of advancements by comparison with the other methods. One of most important aspects considered is that the results by the present method has a universal unit [kcal/h] or [W] enabling us to compare the muscular loads regardless of the kind of postural items and muscle groups. Secondly it is pointed out that the present method demands no surgical operation for the subject by using integrated surface EMG as linear indicator of muscle energy metabolic rate.

There are a few reports concerning evaluation of muscular load from the viewpoints of local muscle energy metabolic rate (Yokoyama, 1982; Yokoyama et al., 1982). In the previous papers the number of subjects was four or seven. It was too small to apply sufficient statistical analysis. In the present study the number of subjects increased to 21.

The energy metabolic rate of M1 and M7 did not remarkably change throughout the present four working and four resting postures, which agreed with the previous results (Yokoyama et al., 1982). In four working postures the present quantitative results showed that the activities of dominant muscle groups suggested from the view points of EMG. For example, Carlsson (1961) suggested that M6 acted strongly in standing on tiptoes. The present energy metabolic rate of M6 in standing on tiptoes showed to be significantly greater than those of the other muscle groups and than those of M6 in the other present working postures. In half rising posture with knees bent it was shown that M6 acted dominantly (Sato, 1966). The corresponding energy metabolic rate of M6 was the greatest in the present study.

Since each of the seven muscle groups during relaxed standing was near to the minimum metabolic rate during the present four working postures, it was considered that relaxed standing has been adopted the resting posture in standing (Sato, 1971). In sitting on a chair the energy metabolic rates of seven muscle groups were less than those in relaxed standing. It was shown that the significant reduction was detected in M2, M3, M4 and M6, which is called
the anti-gravity muscles.

As seen in Fig. 1, during supine and prone postures the mean energy metabolic rates of the seven muscle groups were less than those in relaxed standing. Especially in supine posture, each of them was the least among the present tested postures, therefore it was interpreted to be reasonable that these postures has been adopted the sleeping postures in human daily life (Sato, 1971).

Local muscle energy metabolic rate can quantitatively evaluate muscular loads not only among different postures in a muscle group but also among different muscle groups during a posture. On the other hand, the value is useful to construct a human thermoregulation model, because it gives the main source of heat production in the human body (Yokoyama and Ogino, 1984).

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