Sleeping metabolic rate in relation to body composition and the menstrual cycle\textsuperscript{1,2}

Gerwin AL Meijer, Klaas R Westerterp, Wim HM Saris, and Foppe ten Hoor

**ABSTRACT** The relationship between sleeping metabolic rate (SMR) measured from 0300 to 0600 h in a respiration chamber and body composition was studied in 47 healthy adult subjects (23 men and 24 women). The effect of the menstrual cycle on SMR was examined in 16 of the 24 women. SMR increased in the postovulation phase of the menstrual cycle (estimated as days 18–29 after last menstruation) 7.7% on average ($P < 0.001$). A stepwise regression showed that both fat-free mass (FFM), fat mass (FM), and the phase of the menstrual cycle contributed significantly to SMR. After adjustment for FFM and FM, no sex differences in SMR (men vs. preovulation women) remained. The inclusion of FM in this model is an improvement that eliminates the sex difference in SMR/FFM that is usually found. A prediction equation is given that explains 85% of the variance in SMR among individuals. *Am J Clin Nutr* 1992;55:637–40.

**KEY WORDS** Metabolic rate, body composition, menstrual cycle

**Introduction**

Metabolic rate during rest and sleep is generally believed to represent the cost of maintenance and restoration of body tissue and energy stores. The contribution of resting metabolic rate (RMR) to total daily energy expenditure is generally 65–75% in healthy subjects. Therefore, as proposed by the World Health Organization (1), RMR may be used to estimate the energy requirements of healthy people. Because the assessment of the individual RMR in a large group is labor consuming, predictive equations for RMR may be useful. These equations are based on different measures of body size and/or sex and age. The first equations for predicting RMR date from 1919, when Harris and Benedict (2) presented their material based on 136 men and 103 women. They used sex, age, height, and body mass as independent variables. Since then many studies have examined the relation between different body-size measures and RMR, and today there is general agreement that RMR is best predicted from fat-free mass (FFM) (3–7) because this represents active cell mass. Using FFM as the only variable, RMR of subjects with different physical characteristics may be estimated with an error of $\approx 10\%$ (3, 4, 6).

Despite these unequivocal results there are some indications that other factors, which can be easily assessed, might improve this model. Hoffmans et al (8) showed that adding fat mass (FM) to the model in a multiple regression improved the explained variance in RMR/FFM from 64% to 74% in 28 women, both of normal weight and overweight. Their findings are supported by results of Garby et al (9) and Webb and Sangal (10). Owen et al (11) showed that in a group of 44 obese and nonobese women, RMR was better predicted from body mass (BM) than from FFM. Similar findings were reported recently by Foster et al (12) in obese women. In addition, evidence is now growing that metabolic rate in women fluctuates as a function of the menstrual cycle (13–15). Webb (13) showed that 24-h energy expenditure may increase on average 9% in the postovulation phase. Similarly, Bisdee et al (15) reported an increase of metabolic rate during sleep of 7% in the postovulation phase of the menstrual cycle in eight women.

In this study we analyzed the relationship between BM, FFM, FM, and SMR of 23 men and 24 women. Furthermore, we examined the difference in SMR assessed in the preovulation and postovulation period of the menstrual cycle in 16 women of the 24 mentioned above.

**Methods**

Subjects from two studies were included in this analysis. Subject characteristics are summarized in Table 1. Study 1 was intended to determine differences in metabolic rate and physical activity between lean ($n = 11$) and obese (body mass index, measured in kg/m$^2$, $> 25$, $n = 11$) subjects. Study 2 (16, 17) emphasized the effect of an exercise-training program on body composition and metabolic rate in 13 men and 12 women. From the latter study, measurements carried out before onset of the training program (control measurements) were included. Thus, the total group consisted of 23 men and 24 women, of which 4 and 7 were obese, respectively.

SMR was measured as described elsewhere (16, 17). Briefly, during an overnight stay (1830–0730) in a respiration chamber, SMR was determined from 0300 to 0600 when subjects were asleep. Subjects were not allowed to eat in the chamber; thus, SMR measurement was always $\approx 9$ h after the last meal.

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TABLE 1
Subject characteristics*

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Height</th>
<th>Body mass</th>
<th>Fat mass</th>
<th>Fat-free mass</th>
<th>Body fat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>cm</td>
<td>kg</td>
<td>kg</td>
<td>kg</td>
<td>%</td>
</tr>
<tr>
<td>Lean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>37 ± 3</td>
<td>177 ± 6</td>
<td>71.9 ± 6.7</td>
<td>13.9 ± 3.4</td>
<td>58.0 ± 6.3</td>
<td>19.3 ± 4.4</td>
</tr>
<tr>
<td>Women</td>
<td>33 ± 6</td>
<td>167 ± 6</td>
<td>60.2 ± 6.2</td>
<td>16.2 ± 4.5</td>
<td>43.9 ± 3.9</td>
<td>26.6 ± 5.5</td>
</tr>
<tr>
<td>Obese</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>37 ± 4</td>
<td>183 ± 6</td>
<td>109.2 ± 20.1</td>
<td>36.1 ± 12.0</td>
<td>73.1 ± 12.7</td>
<td>32.7 ± 6.5</td>
</tr>
<tr>
<td>Women</td>
<td>33 ± 7</td>
<td>166 ± 8</td>
<td>83.0 ± 13.2</td>
<td>35.2 ± 9.5</td>
<td>47.8 ± 4.3</td>
<td>41.8 ± 5.1</td>
</tr>
</tbody>
</table>

* x ± SD.
† Thirteen men and 12 women from reference 16.

Body composition was assessed in the morning immediately after the subjects left the respiration chamber by using hydrostatic weighing with direct assessment of lung volume (16, 17). FFM and FM were calculated using the equations of Siri (18).

Recalling the data of menstruation during the past half year, 16 of the 24 women reported a regular menstrual cycle with a time period of 28-31 d. Data on the last menstruation before the overnight sleep were used to estimate the day of ovulation. First day of menstruation was designated as day 0 in the menstrual cycle. Ovulation was estimated to be on day 15. The preovulation period was designated from days 1 to 12 and the postovulation period, from days 18 to 30. For the women of study 1 SMR was measured again during one night in the opposite phase of the menstrual cycle. The women in study 2 (16) participated in three subsequent measurements; the second and third measurements were after ≈8 and 20 wk, respectively. Their first SMR value was compared with the first one measured in the opposite phase of the menstrual cycle. Three women reported use of oral contraceptives.

Differences between groups (eg, men vs women) were analyzed with standard nonparametric tests (Mann-Whitney U, Wilcoxon signed rank). Simple and stepwise regression equations were calculated with SPSS-X (SPSS Inc, Chicago).

Results

Mean values of SMR, SMR/BM, and SMR/FFM for the different groups are presented in Table 2. SMR expressed in kJ/min was significantly lower in the women than in the men (4.17 ± 0.50 vs 5.10 ± 0.82 kJ/min, P < 0.0001). However, SMR expressed per kg of FFM was significantly higher in the women. SMR per kilogram of BM did not differ between the sexes (63.5 ± 7.2 vs 65.8 ± 6.3 J·min⁻¹·kg⁻¹, NS).

In the postovulation period of the menstrual cycle, SMR was significantly higher compared with the preovulation period. In fact, of the 16 women, only 2 showed a fall in SMR from preto postovulation (Fig 1). Those women were 2 of the 13 who did not use oral contraceptives.

TABLE 2
Sleeping metabolic rate (SMR), SMR/kg body mass (SMR/BM), and SMR/kg fat-free mass (SMR/FFM) of all subjects, men, women, and women in the pre- and postovulation periods of the menstrual cycle*

<table>
<thead>
<tr>
<th></th>
<th>SMR</th>
<th>SMR/BM</th>
<th>SMR/FFM</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>kJ/min</td>
<td>J·min⁻¹·kg⁻¹</td>
<td>J·min⁻¹·kg⁻¹</td>
</tr>
<tr>
<td>All subjects</td>
<td>4.62 ± 0.82</td>
<td>64.6 ± 6.8</td>
<td>88.4 ± 7.6</td>
</tr>
<tr>
<td>(n = 47)</td>
<td>(1.10 ± 0.20)</td>
<td>(15.4 ± 1.6)</td>
<td>(21.1 ± 1.8)</td>
</tr>
<tr>
<td>Men</td>
<td>5.10 ± 0.82</td>
<td>65.8 ± 6.3</td>
<td>84.2 ± 6.8</td>
</tr>
<tr>
<td>(n = 23)</td>
<td>(1.21 ± 0.20)</td>
<td>(15.7 ± 1.5)</td>
<td>(20.1 ± 1.6)</td>
</tr>
<tr>
<td>Women</td>
<td>4.17 ± 0.50‡</td>
<td>63.5 ± 7.2</td>
<td>92.4 ± 6.1‡</td>
</tr>
<tr>
<td>(n = 24)</td>
<td>(1.00 ± 0.12)</td>
<td>(15.2 ± 1.7)</td>
<td>(22.1 ± 1.5)</td>
</tr>
<tr>
<td>Preovulation</td>
<td>4.02 ± 0.43‡</td>
<td>61.2 ± 8.2</td>
<td>88.3 ± 5.3</td>
</tr>
<tr>
<td>(n = 16)</td>
<td>(0.96 ± 0.10)</td>
<td>(14.6 ± 2.0)</td>
<td>(21.1 ± 1.3)</td>
</tr>
<tr>
<td>Postovulation</td>
<td>4.33 ± 0.45§</td>
<td>65.7 ± 9.8§</td>
<td>94.7 ± 7.1§</td>
</tr>
<tr>
<td>(n = 16)</td>
<td>(1.03 ± 0.11)</td>
<td>(15.7 ± 2.3)</td>
<td>(22.6 ± 1.7)</td>
</tr>
</tbody>
</table>

* x ± SD.
† Values in parentheses are kcal equivalents.
‡ Significantly different from the value for men, P < 0.0001 (Mann-Whitney U).
§ Significantly different from the preovulation period; §P < 0.001; ||P < 0.01 (Wilcoxon signed-rank).

FIG 1. Change in sleeping metabolic rate per kilogram of fat-free mass (SMR/kg FFM) in 16 women from the preovulation (pre-O) to the postovulation (post-O) period of the menstrual cycle. (P < 0.01, Wilcoxon signed rank).
FIG 2. Relationship between sleeping metabolic rate (SMR) and fat-free mass, (FFM) \times [SMR (kJ/min) = 1.018 + 0.068 \times FFM (kg); n = 47, r^2 = 0.80, S_{xy} = 0.37 (P < 0.0001).

SMR was strongly related to FFM in our group (Fig 2) and was the best single predictor of SMR (Table 3). A stepwise regression was conducted with FFM, FM, sex, and phase of the menstrual cycle as independent variables to see which other parameters might influence SMR. From this it appeared that both FM and menstrual-cycle phase improved the model significantly (Table 4). After adjustment of SMR for FFM and FM, no significant sex difference in SMR remained. However, the women in the postovulation period of the menstrual cycle had a significantly higher SMR. Thus, SMR in our population is best described as:

\[
SMR (kJ/min) = 0.51 + 0.070 \times FFM + 0.016 \times FM \\
+ 0.253 \times MC \quad (r^2 = 0.85, S_{xy} = 0.31, P < 0.0001)
\]

where FFM and FM are in kg, MC is 0 for men and for preovulation women and 1 for postovulation women, and S_{xy} is the SEE of the regression equation.

**Discussion**

FFM assessed by using hydrostatic weighing is generally believed to represent active cell mass (19). It has been reported frequently that FFM is the best single predictor of RMR, SMR, or 24-h energy expenditure (3–7), as it was in this study. However, results from the current analysis indicate that FM significantly contributes to SMR, supporting the findings of Hoffmans et al (8), Garby et al (9), and Webb and Sangal (10). Because all measures of body composition are interrelated, it is not possible to determine whether this statistical contribution of FM to the model represents a true physical contribution of FM to active cell mass.

In the study of Ravussin et al (4) FM had no significant effect on RMR adjusted for FFM. However, in their study, body composition was assessed by using skinfold thickness, which may not be accurate enough to detect the small contribution of FM to RMR. This might also explain the difference in explained variance of RMR from FFM in their study (68%) compared with the 80% we found. Recalculating from the data of Ravussin et al (4) it can be shown that the women had a significantly higher RMR per kg of FFM than did the men (89.0 ± 11.4 vs 81.7 ± 9.4 J·min^{-1}·kg^{-1}, P < 0.05, Mann-Whitney U), as was the case in our study. In a more recent paper Ravussin and Bogardus (19) attribute this discrepancy to a mathematical problem. The x and y intercept of the regression equation of RMR on FFM should be taken into account when comparing RMR/FFM of groups or individuals differing in FFM. However, the positive y intercept of the regression of RMR on FFM is not concordant with their assumption that FFM overestimates body cell mass. It is tempting to suggest that the difference in RMR/FFM between men and women is due to the higher FM in women compared with men.

Women are known to have a higher energy intake and a higher body mass during the postovulation period of the menstrual cycle (20–23). The increase is thought to be due to increased concentrations of progesterone during this period. Despite this, the results of different studies on the influence of the menstrual cycle on RMR or SMR are conflicting (13–15; JA Weststrate, P Deurenberg, and JGAJ Hautvast, unpublished observations, 1989). Webb (13) concluded that methodological factors may be responsible for these different findings. He suggested that SMR should be assessed because this measurement may be more reproducible than RMR, due to the fact that the subjects are asleep during a whole night, whereas before measurement of RMR, different behaviors may have occurred that influence subsequent metabolic rate. Our data, which were gathered under this strict protocol, confirm the finding of Bisdee (15) that SMR during the postovulation period is increased ≈8% on average. To the contrary, Weststrate et al (unpublished observations, 1989), who

| TABLE 3 | Cross-correlation matrix of Pearson product-moment coefficients based on 63 observations |
| --- | --- | --- | --- | --- | --- |
| Body mass | Fat-free mass | F. ass | Sex | Sleeping metabolic rate |
| Body mass | — | 0.756* | — | — | — |
| Fat-free mass | 0.786* | — | 0.192 | — | — |
| Fat mass | — | — | 0.672* | 0.161 | — |
| Sex | — | — | — | — | — |
| Sleeping metabolic rate | — | — | — | — | — |

* P < 0.0001.
† P < 0.05.
‡ P < 0.01.
measured RMR in the early morning on subjects who had just woken up, were not able to reproduce these findings. In their study, 14 women showed increases and 9 showed decreases in postovulation RMR. However, both in the study of Webb (13) and in ours, some women did not show the postovulation increase in metabolic rate; the reason for this was unclear. Webb (13) showed that use of oral contraceptives may inhibit the metabolic response usually found after ovulation. However, this was not the case in our study. The three women who reported use of oral contraceptives showed a similar increase in SMR during the second half of the menstrual cycle as the other women as well as similar pre- and postovulation SMR adjusted for FFM and FM. This may be because contraceptives with low estrogen content are very popular in our country. Because we could not discriminate the three women using oral contraceptives from the other women by their SMR values and because the number of subjects was relatively small, we included them in the present analysis. Excluding the three women mentioned does not substantially change the model presented here.

The data on SMR and menstrual cycle in study 2 were gathered during different stages of exercise training. Thus, changes in SMR in response to training status may have influenced or obscured the effect of the menstrual phase. However, in this study (16) SMR was measured ≥3 h after the last training session and we were not able to detect any significant chronic effect of exercise training on SMR either in the men or in the women (16, 17, 24).

In summary, we found that 85% of variance in SMR, between individuals of both sexes and of normal-weight as well as obese subjects, was explained in a model comprising FFM, FM, and phase of the menstrual cycle. SMR adjusted for FFM, and FM of women in the preovulation period of the menstrual cycle did not differ from that of the men. Postovulation SMR increased 7.7% on average (P < 0.001).

We thank Paul Webb for his helpful criticism during the preparation of the manuscript.

**References**


