Energy expenditure by indirect calorimetry in premenopausal women: variation within one menstrual cycle

Juliette C. Howe, William V. Rumpler, and James L. Seale

United States Department of Agriculture, Agricultural Research Service, Beltsville Human Nutrition Research Center, Energy and Protein Nutrition Laboratory, Beltsville, MD, USA

Energy expenditure in relation to the menstrual cycle was determined by indirect calorimetry in premenopausal women. For each subject, three measurements were made within a single menstrual cycle. Energy expenditure measurements coincided with the subject's expected hormonal fluxes of estradiol and progesterone: menstrual phase–both hormones at basal levels; follicular phase–elevated estradiol; and luteal phase–elevated progesterone. In experiment 1, resting energy expenditure of 14 women was determined for 1 hour using a canopy system for calorimetry; in experiment 2, 24-hour energy expenditures of 12 subjects were measured in a room-size calorimeter. Blood from fasted (12 hours) subjects was collected following measurements of energy expenditure and analyzed for serum estradiol-17B and progesterone by radioimmunoassay. In experiment 1, resting energy expenditure did not differ within one menstrual cycle; neither estradiol nor progesterone affected resting energy expenditure. In experiment 2, 24-hour energy expenditure was significantly lower ($P < 0.013$) during the follicular phase when compared with the menstrual (−3.8%) and luteal (−4.9%) phases. Lowered 24-hour energy expenditure during the follicular phase may in part be due to a decrease in spontaneous activity and exercise. Energy expenditure during sleep, an indicator of metabolic energy expenditure, was significantly greater ($P < 0.0001$) during the luteal phase than during the menstrual (+6.7%) and follicular (+5.4%) phases; this was a reflection of increased progesterone ($P < 0.0001$). Twenty-four hour energy expenditure (mean ± SEM) during the menstrual, follicular, and luteal phases was 8.86 ± 0.26, 8.52 ± 0.22, and 8.96 ± 0.21 MJ/d, respectively. Corresponding values for energy expenditure during sleep were 5.49 ± 0.09, 5.56 ± 0.10, and 5.86 ± 0.11 MJ/d. The menstrual cycle is a significant contributor to variation in energy expenditure through progesterone-mediated increases in metabolic rate. Variation in metabolic energy expenditure was detectable when the contributory components of 24-hour energy expenditure were measured.

Keywords: energy expenditure; estrogen; progesterone

Introduction

Measurements of energy expenditure are confounded by factors that lend variability to the estimates. Factors that influence inter-subject variation in energy expenditure include body size, age, sex, nutritional status, and activity such as work, play, and fidgeting. Stress, changes in nutritional status, changes in weight, physical activity during the previous 24 hours, and seasonal changes are known to contribute to intra-subject variation in resting energy expenditure.[1]

One factor that has been suggested as a source of

Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture, and does not imply its approval to the exclusion of other products that may also be suitable.

Address reprint requests to Dr. Juliette C. Howe at the U.S. Department of Agriculture, Beltsville Human Nutrition Research Center, Energy and Protein Nutrition Laboratory, Room 213, Bldg. 308, BARC-East, Beltsville, MD 20705 USA.

Received February 18, accepted October 12, 1992.

Preliminary reports have been presented at the meetings of the Federation of American Societies for Experimental Biology; New Orleans, LA, March 1989 and Atlanta, GA, April, 1991. *The FASEB Journal* **3**, A350, 1989, and **5**, A1648, 1991. (abstr).

variation in energy expenditure is the menstrual cycle. Food intake has also been reported to vary with the menstrual cycle. Dalvit[2] reported an increased dietary intake of about 500 kcal/day during the postovulatory phase of the menstrual cycle, while Lissner et al.[3] reported increases in self-selected intakes during the mid-follicular and mid-luteal phases of the menstrual cycle. Increased intake could be in response to increased energy expenditure or could stimulate an increase in energy expenditure. Basal body temperature is also known to rise during the periovulatory phase of the menstrual cycle. The increased body temperature is in direct response to the rise in progesterone,[4,5] which has been shown to have a direct effect on the thermoregulatory center in the hypothalamus.[6] Therefore, changes in energy expenditure might be observed at the stage of the menstrual cycle when progesterone is elevated.

This study was designed to determine variations in energy expenditure as related to the menstrual cycle. Both resting energy expenditure and 24-hour energy expenditure were measured in this study. Measurements of resting energy expenditure are quicker and loss costly than 24-hour measurements because they require less sophisticated equipment. However, measurements of shorter duration have been reported to be more variable[7] and consequently less precise. Therefore small changes in energy expenditure might only be detected during longer (i.e., 24-hour) measurements. Energy expenditure was also examined in relation to the actual levels of estradiol and progesterone to evaluate the impact of these hormones on energy expenditure.

Materials and methods

The study was conducted in two parts. Changes in resting energy expenditure (experiment 1) and 24-hour energy expenditure (experiment 2) were determined three times during one menstrual cycle. Subjects were healthy, premenopausal women. Study protocols were approved by the Human Study Committees of the U.S. Department of Agriculture and Georgetown University. Subjects were informed of the purpose of the study and of all procedures to be used in the study. Informed written consent was obtained. None of the subjects were taking contraceptive pills.

Subjects notified the investigator of the start of menses; this was considered day 1 of the menstrual cycle. At that time, subjects were scheduled for three measurements of energy expenditure (EE) to coincide with the following anticipated status of estradiol and progesterone: (1) both estradiol and progesterone levels are low–menstrual phase (measurement 1); (2) estradiol levels are high and progesterone levels are low–follicular phase (measurement 2); (3) progesterone levels are high–luteal phase (measurement 3). Scheduling of measurements to coincide with specific phases of the menstrual cycle can be difficult. Assumption of a 28-day cycle for prospective scheduling can misestimate the occurrence of the estradiol and progesterone peaks for individuals with shorter or longer cycles. In the current study, measurements of energy expenditure were scheduled on a timetable similar to that developed by Dr. P. P. Nair.† *Table 1* shows the timetable used in the scheduling of measurements based on the normal length of each subject's menstrual cycle. In experiment 1, subjects were asked to determine their basal body temperature each morning prior to arising using a Terumo Ovulation Monitor (Terumo Medical Corp.; Elkton, MD USA). The occurrence of increased basal body temperature, an indicator of ovulation, could be used to adjust the scheduling of the third measurement, if necessary. In only two cases, however, were minor (1 day) adjustments made to the schedule based on observed temperature changes. Consequently, this procedure was not used in experiment 2.

Table 1 Schedule of resting energy expenditure measurements based on normal length of menstrual cycle

	Measurement		
Length of cycle (days)	1 Menstrual	2 Follicular (days)	3 Luteal
24/25	3–6	8–12	18–22
26/27	3–6	9–13	19–23
28/29	3–6	10–12	20–24
30/31	3–6	11–15	21–25
32/33	3–6	12–16	22–26
34/35	3–6	13–17	23–27

In experiment 1, measurement 1 for subject 13 occurred on day 7 (normal cycle length was 27/28 days); measurement 2 for subject 2 occurred on day 10 (normal cycle length was 30/31 days).

Table 2 Physical characteristics of subjects-experiment 1

Subject no.	Age (yrs)	Height (cm)	Weight (kg)	BMI (kg/m^2)
1	40	160	52	20.5
2	30	161	51	19.7
3	35	162	49	18.6
4	24	168	60	21.4
5	32	168	74	26.1
6	22	156	57	23.5
7	36	163	124	46.6
8	20	167	47	17.0
9	37	167	73	26.3
10	36	172	63	21.2
11	30	166	65	23.9
12	33	174	106	34.9
13	24	173	76	25.4
14	39	161	58	22.4
Mean	31	166	68	24.8
± S.E.M.	± 1.7	± 1.4	± 6.0	± 1.1

BMI, body mass index (weight/$height^2$).

Experiment 1

Subjects were free-living and no restrictions were imposed on dietary intake or activity. *Table 2* presents the age, height, weight, and body mass index of the 14 subjects in experiment 1. Subjects in this study were between 20 and 40 years of age and weighed between 49 and 124 kg. The average height was

†Personal communication with Dr. Padmanabhan P. Nair, Ph.D., Lipid Nutrition Laboratory, Beltsville Human Nutrition Research Center, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, MD USA.

166 cm (range, 156–174 cm). Body mass index (kg/m^2) ranged from 17.0–46.6.

Resting energy expenditure was determined by indirect calorimetry. The system utilized a clear plastic canopy (Beckman Instruments, Inc.; Anaheim, CA USA) developed by Kinney et al.;[9] the outlet port was connected to an air pump and the inlet side was connected to an outside air source. Air was pulled through the canopy at a constant rate and pushed through the analytical system, which was fashioned in our laboratory. Flow rate was determined utilizing a mass flow meter (Model 5812B, Brooks Instrument Division; Hatfield, PA USA). The mass of air flow was corrected for moisture content as measured by a relative humidity sensor (Model 850, General Eastern; Watertown, MA USA). Outlet gas was dried by passage through drierite (W.A. Hammond Drierite Co.; Xenia, OH USA). The concentration of oxygen (Zirconium cell: Model S-3A with M-22 sensor, Ametek; Pittsburgh, PA USA) and of carbon dioxide (infrared: CD-3A with P61B sensor, Ametek) in outlet gas was determined continuously. Analog outputs from all instruments were collected continuously (100 Hz) through a 16-bit analog to digital converter (Lab Master, Scientific Solutions; Solan, OH USA) and processed by a microcomputer. A 9-second average was used for all subsequent calculations. Oxygen consumption and carbon dioxide production were calculated as described by McLean and Tobin.[10] Energy expenditure was calculated by the Weir equation[11] not adjusted for protein oxidation: Energy expenditure (J/sec) = 275 (J/sec) × oxygen consumption (L/sec) + 77.2 (J/sec) × carbon dioxide produced (L/sec).

Standardized conditions for the measurements of resting energy expenditure in experiment 1 were as follows. Subjects reported to the Human Studies Facility at 0830 hours following a 12-hour fast. Subjects were asked to lie completely still during the measurements. Collection of data was begun following a 10-min acclimation period and continued for 1 hour. All subjects underwent a practice session in the canopy prior to the start of the study. Blood was drawn following measurements of resting energy expenditure. Fasted, stripped weights were determined with a Type E 1200 Balance (August Sauter, Ebingen, Germany); heights were also determined for each subject at this time using a stadiometer (Perspective Enterprises, Inc.; Kalamazoo, MI USA).

Experiment 2

The physical characteristics of the 12 subjects participating in experiment 2 are shown in *Table 3*. Subjects ranged from 21–45 years of age. The average weight was 64 kg, with an average lean body mass of 44.3 kg. The subjects ranged from 19–39% body fat. Lean body mass was determined by bioelectric impedance analysis (Model BIA-101, RJL Systems Inc., Detroit, MI USA) using the equation for females derived by Segal et al.[12]

Unlike experiment 1, dietary intake was controlled on the day prior to and during measurements of 24-hour energy expenditure (24EE). Dietary intake was set to maintain body weight and provided 14% protein, 52% carbohydrate, and 34% fat. One measurement of 24EE was made prior to the start of the study to familiarize subjects to the procedures. Scheduled measurements were as described above.

Twenty-four hour EE was determined by indirect calorimetry using the Beltsville room calorimeter. A complete description of the Beltsville calorimeter has been previously reported.[13] Energy expenditure was calculated by the Weir equation;[11] nitrogen losses were not determined. Subjects entered the calorimeter at 0800 and remained for 23.5 hr. While in the calorimeter, subjects followed the activity protocol reported by Rumpler et al.[14] Scheduled activities included desk work (4 hr), meal consumption (1.5 hr), exercise (two 30 min periods on a bicycle ergometer), and sleep (7.5 hr). The remaining time was spent at the subject's discretion watching TV, listening to the radio, reading, or desk work. Subjects were fasted during the last 12 hr in the calorimeter. Upon exiting from the calorimeter, blood samples were drawn. Calculations of total energy expenditure (24EE) were extrapolated and expressed on a 24-hr basis. Sleep EE was measured during the hours of 1230–0530. The rate of EE during sleep (sleep EE) is an index of basal metabolic rate and was therefore also extrapolated to 24 hr. EE during exercise (exc. EE) represents the sum of each 30-min exercise period. Activity, the amount of time spent in detectable movement (Microwave Intruder Sensor, Racal Security, Scotland, UK), was expressed as percent of total time.

Blood samples were centrifuged at 1000*g* for 20 min at 0–4°. Serum was then aliquoted for each of the analyses to be performed and stored at −20°. Progesterone and estradiol-17B

Table 3 Physical characteristics of subjects-experiment 2

Subject no.	Age (yrs)	Height (cm)	Weight (kg)	BMI (kg/m^2)	LBM (kg)	Fat (%)
1	30	173	67	22.5	45.5	30
2	41	168	61	21.5	45.7	25
3	23	166	74	26.6	48.3	34
4	37	172	68	23.0	47.6	30
5	21	161	47	18.0	38.0	19
6	28	168	53	18.8	41.7	22
7	40	160	58	22.6	40.8	30
8	34	167	77	27.5	47.2	39
9	33	166	68	24.9	46.5	32
10	35	162	64	24.4	45.5	29
11	23	166	64	23.2	44.9	30
12	45	154	63	26.6	39.7	37
Mean	32	165	64	23.3	44.3	30
± S.E.M.	± 1.2	± 0.8	± 1.3	± 0.5	± 0.6	± 0.9

BMI, body mass index (weight/height^2). LBM, lean body mass determined from measurements of bioelectric impedance analysis using the equation developed by Segal et al.[12]

levels were analyzed by radioimmunoassay (ICN Biomedicals, Inc.; Carson, CA USA). For each experiment, hormone samples were assayed at one time using kits from the same lot.

All data were statistically evaluated by analysis of variance using the General Linear Models Procedure of SAS (SAS Institute, Cary, NC USA).[15] All data were adjusted for between-subject variation. Log transformation of hormone data was performed when required to meet the criteria of homogeneity of variance. Differences among measurements were determined by Least Significant Differences (LSD). Analysis of covariance[15] was used to test the within-subject relationship between energy expenditure and the hormones associated with the menstrual cycle. The critical level for significance was $P < 0.05$.

Results

Experiment 1

For the three measurements taken *(Table 4)*, there were no significant differences among resting energy expenditures during one menstrual cycle ($P = 0.79$). Nor were any detectable differences in resting energy expenditure obtained when energy expenditure values were adjusted for body weight ($P = 0.81$) or body mass index ($P = 0.78$). The coefficient of variation (CV) for the model was 5.4%. Serum levels of progesterone and estradiol for the three measurements during the menstrual cycle are also reported in *Table 4*. Serum estradiol levels during the menstrual phase were significantly lower than during the follicular and luteal phases ($P < 0.0001$). Estradiol levels during the follicular and luteal phases did not differ significantly. Progesterone levels were significantly elevated during the luteal phase when compared with the menstrual and follicular phases ($P < 0.0001$). The levels of estradiol and progesterone verify that resting energy expenditure was measured during the planned phases of the menstrual cycle. There was no significant linear relationship between resting energy expenditure and either estradiol or progesterone analysis of covariance (ANCOV); the statistical significance was $P = 0.99$ and $P = 0.31$, respectively.

Experiment 2

As in experiment 1, estradiol ($P < 0.01$) and progesterone ($P < 0.0001$) levels varied significantly during the menstrual cycle *(Table 5)*. Estradiol levels were higher during the follicular and luteal phases when compared with the menstrual phase. Progesterone levels increased during the three phases, values being the greatest during the luteal phase. Results of hormone analyses in both experiments 1 and 2 indicate that the timetable used in this study was quite reliable for predicting periods of elevated estradiol and progesterone.

As shown in *Table 5*, 24EE was similar during the menstrual and luteal phases, but was significantly lower during the follicular phase ($P = 0.013$). This variation in 24EE measurements was also observed when values were expressed per kg body weight ($P = 0.012$) or per kg lean body mass ($P = 0.032$). Twenty-four hour EE values (mean ± S.E.M.) were 141 ± 6, 135 ± 6, and 139 ± 5 kJ/kg body weight/d for the menstrual, follicular, and luteal phases, respectively; 24EE expressed per kg lean body mass was 201 ± 7 kJ/d (menstrual phase), 193 ± 6 kJ/d (follicular phase), and 202 ± 5 kJ/d (luteal phase). Breakdown of 24EE values to reflect the contribution of EE during sleep (an indicator of basal metabolic rate) and exercise are also shown in *Table 5*. Sleep EE was significantly elevated during the luteal phase ($P < 0.0001$), but was similar during the menstrual and follicular phases. There was no statistically significant difference in total energy expended for exercise during the menstrual cycle. However, if the individual exercise periods are examined, subjects appeared to expend less energy for the morning exercise period during the follicular phase ($P = 0.056$). EE during afternoon exercise period was similar in all three phases. The balance of EE following adjustment of 24EE for both sleep EE and exercise EE further reduced the differences between phases ($P = 0.067$). The percentage of time spent in movement (spontaneous activity and exercise) was significantly lower during the follicular phase when compared with the menstrual and luteal phases ($P < 0.05$). This inactivity would also contribute to the reduced

Table 4 Resting energy expenditure and hormone levels of subjects at three stages of the menstrual cycle-experiment 1

Variable	Measurement 1 Menstrual	2 Follicular	3 Luteal	ANOVA P =
Resting energy expenditure				
(MJ/d)	6.45 ± 0.30	6.53 ± 0.34	6.52 ± 0.32	0.79
(kJ/kg body weight/d)	98 ± 4	99 ± 4	99 ± 5	0.81
(kJ/BMI/d)*	267 ± 9	271 ± 11	274 ± 10	0.78
Estradiol†				
(pmol/L)	121[a] ± 25	562[b] ± 122	382[b] ± 35	0.0015
Progesterone†				
(nmol/L)	0.54[a] ± 0.13	1.08[a] ± 0.45	31.99[b] ± 4.55	0.0001

Values represent the mean ± S.E.M. for 14 subjects.
*Resting energy values adjusted for body mass index (wt/ht²).
†Values with similar superscripts within a row are not significantly different as tested by least significant differences.

Table 5 Components of 24 energy expenditure (24EE) at three stages of the menstrual cycle

Variable	Measurement 1 Menstrual	2 Follicular	3 Luteal	ANOVA P =
Estradiol (pmol/L)	316[a] ± 47	743[b] ± 106	585[b] ± 82	0.0009
Progesterone (nmol/L)	0.34[a] ± 0.08	4.05[b] ± 2.03	27.98[c] ± 6.71	0.0001
Energy expenditure (MJ/d)	8.86[b] ± 0.26	8.52[a] ± 0.22	8.96[b] ± 0.21	0.013
Sleep EE (MJ/d)	5.49[a] ± 0.09	5.56[a] ± 0.10	5.86[b] ± 0.11	0.0001
Exc. EE—Total (kJ)*	1144 ± 178	957 ± 168	1058 ± 165	0.145
Period 1 (kJ)	614[b] ± 91	501[a] ± 87	539[b] ± 89	0.056
Period 2 (kJ)	531 ± 88	456 ± 83	519 ± 82	0.31
Balance (MJ/d)†	2.23[b] ± 0.08	2.01[a] ± 0.08	2.04[ab] ± 0.08	0.067
Activity (%)‡	19.7[b] ± 0.4	18.1[a] ± 0.5	18.7[b] ± 0.5	0.049
RQ	0.868 ± 0.009	0.861 ± 0.007	0.867 ± 0.007	0.60

Values represent the mean ± S.E.M. for 12 subjects; values with similar superscripts within a row are not significantly different as analyzed by Least Significant Difference.
Abbreviations: Sleep EE, the rate of energy expenditure during sleep (12:30 a.m. to 5:30 a.m.) extrapolated to 24 hours as an index of metabolic energy expenditure; Exc. EE, energy expenditure during exercise; RQ, respiratory quotient, CO_2/O_2.
*Subjects exercised for 30 min periods twice a day (Period 1 = 10:30–11:00 a.m.; Period 2 = 3:00–3:30 p.m.) on a bicycle ergometer.
†Balance = 24 EE − Sleep EE − Total Exc. EE.
‡Activity refers to the amount of time subjects were moving around as a percent of total time spent in the chamber and includes time spent in exercise.

24EE observed during the follicular phase. The respiratory quotient (RQ) did not vary during the menstrual cycle.

The independent association of estradiol and progesterone on 24EE, sleep EE, and EE adjusted for exercise and/or sleep EE were determined. There was no significant association between EE and estradiol. Progesterone had the greatest impact on sleep EE ($P < 0.0001$) after removal of subject variation. Differences among measurements were still highly significant ($P < 0.0036$) after adjustment for the effect of progesterone; the effect of progesterone on sleep EE was 1.5 times more important than that of all other contributing factors. Progesterone also contributed significantly to differences in 24EE ($P < 0.05$) during the menstrual cycle, but its effect was not as great as its impact on sleep EE; the relative importance of progesterone to 24EE was 0.64 as compared with 1.5 for all other factors. No significant effect of progesterone was detected when 24EE was adjusted for sleep EE and exercise. The remaining differences in adjusted EE during the menstrual cycle were apparently due to other factors.

Discussion

Studies by Blunt and Dye[16] and by Wiltshire[17] reported no significant changes in basal metabolic rate (BMR)[16] or oxygen consumption[17] in relation to the menstrual cycle. Our data on resting energy expenditure (experiment 1) support these findings. On the other hand, both Wakeham[18] and Solomon et al.[19] reported a premenstrual rise in BMR. In fact, Solomon et al.[19] observed a cyclical change in BMR with the menstrual cycle: BMR was lowest 1 week before ovulation and rose before the next menstrual cycle. In the latter study,[19] energy intake and physical activity were constant during three test periods lasting 22, 28, and 35 days. The subjects in the current study were free-living subjects with no restrictions on intake or activity. It is possible that variations in either or both of these factors may have obscured changes in REE. Under the conditions of our study (CV = 5.4%), there was a 99% probability of detecting a difference in resting energy expenditure of 9.21% between time periods. In the study reported by Solomon et al.,[19] the factor considered most likely to effect the observed increase in BMR was the presumed rise in serum progesterone, which occurs at this same time in the menstrual cycle. However, phases of the menstrual cycle were determined retrospectively following the onset of menses[19] and serum progesterone was not actually measured. In the current study, serum estradiol and progesterone levels were determined on the same day as resting energy expenditure. Because resting energy expenditure did not vary during the menstrual cycle and was not significantly influenced by either estradiol or progesterone, we conclude that under the conditions of this study, the menstrual cycle had little impact on resting energy expenditure.

Webb[20] also reported changes in energy expenditure with the menstrual cycle. A 9% increase in 24-hour energy expenditure during the luteal phase of the menstrual cycle was observed in normally menstruating women. The subjects in Webb's study[20] were measured by both direct and indirect calorimetry for continuous periods of 36–46 hours. As in Solomon's study,[19] these subjects were on controlled food intake and activity. In our study (experiment 2), 24-hour energy expenditure did not increase during the luteal phase of the menstrual cycle. In fact, a decrease in 24-hour energy expenditure was observed just prior to ovulation. Dietary intake for the subjects in experiment 2 was controlled on the day of and prior to the measurements of 24-hour energy expenditure and all subjects followed a similar activity

protocol while in the calorimeter. Based on the coefficient of variation in our measurements of 24-hour energy expenditure, there was a 99% probability of detecting measurement differences of 7.4%.

A 5.4% increase in sleep energy expenditure was observed during the luteal phase of the menstrual cycle. Under the conditions of our study, a difference of 5.3% in sleep energy expenditure (CV = 2.76%) would have been detected (99% probability). Our data support the findings of Bisdee et al.,[7] who reported a 6.1% increase in sleep metabolic rate during this phase of the menstrual cycle; they also reported that 24-hour energy expenditure did not vary significantly during the menstrual cycle. Energy expenditure was determined by indirect calorimetry; subject diet and activity were controlled.[7]

The results from this study indicate that the menstrual cycle is a significant contributor to variation in metabolic energy expenditure. When compared with menstrual and follicular phases, sleep EE during the luteal phase was increased 6.7% and 5.4%, respectively. Furthermore, the elevation in serum progesterone during the luteal phase of the menstrual cycle is associated with this increased metabolic energy expenditure. In this experiment, there also appeared to be a decrease in activity associated with the menstrual cycle, which contributed to a decrease in total 24-hour energy expenditure. Twenty-four hour EE during the follicular phase was decreased by 4.9% and 3.8% when compared with the luteal and menstrual phases, respectively. The factors moderating this event could not be detected under the present study conditions.

References

1 FAO/WHO/UNU Expert Consultation. (1985). Energy and Protein Requirement. Technical Report Series 724, WHO, Geneva, Switzerland

2 Dalvit, S. (1981). The effect of the menstrual cycle on patterns of food intake. *Am. J. Clin. Nutr.* **34,** 1811–1815

3 Lissner, L., Stevens, J., Levitsky, D.A., Rasmussen, K.M., and Strupp, B.J. (1988). Variation in energy intake during the menstrual cycle: implications for food-intake research. *Am. J. Clin. Nutr.* **48,** 956–962

4 Barton, M. and Weisner, B.P. (1945). Thermogenic effect of progesterone. *Lancet* **2,** 671–672

5 Kappas, A. and Palmer, R.H. (1965). Thermogenic properties of steroids. In *Methods in Hormone Research,* vol. 4, part B, (R.I. Dorfman, ed.), p. 1–19, Academic Press, New York, NY USA

6 Israel, S.L. and Schneller, O. (1950). Thermogenic property of progesterone. *Fertil Steril* **1,** 53–65

7 Bisdee, J.T., James, W.P.T., and Shaw, M.A. (1989). Changes in energy expenditure during the menstrual cycle. *Br. J. Nutr.* **61,** 187–199

8 Horvath, S.M. and Drinkwater, B.L. (1982). Thermoregulation and the menstrual cycle. *Aviat. Space Environ. Med.* **53,** 790–794

9 Kinney, J.M. (1980). The application of indirect calorimetry to clinical studies. In *Assessment of Energy Metabolism in Health and Disease,* Ross Laboratories, Columbus, OH USA

10 McLean, J.A. and Tobin, G. (1987). *Animal and Human Calorimetry,* p 100–112 University Press, Cambridge, MA USA

11 Weir, J.BdeV. (1949). New methods for calculating metabolic rate with special reference to protein metabolism. *J. Physiol.* **109,** 1–9

12 Segal, K.R., Van Loan, M., Fitzgerald, P.I., Hodgdon, J.A., and Van Italie, T.B. (1988). Lean body mass estimation by bioelectric impedance analysis: a four-site cross-validation study. *Am. J. Clin. Nutr.* **47,** 7–14

13 Seale, J.L., Rumpler, W.V., and Moe, P.W. (1991). Description of a direct-indirect room-sized calorimeter. *Am. J. Physiol.* **260,** E306–E320

14 Rumpler, W.V., Seale, J.L., Conway, J.M., and Moe, P.W. (1990). Repeatability of 24-h energy expenditure measurements in humans by indirect calorimetry. *Am. J. Clin. Nutr.* **51,** 147–152

15 SAS Institute Inc. (1985). *SAS User's Guide: Statistics.* SAS Institute Inc., Cary, NC USA

16 Blunt, K. and Dye, M. (1921). Basal metabolism of normal women. *J. Biol. Chem.* **47,** 69–87

17 Wiltshire, M. (1921). Some observations on basal metabolism in menstruation. *Lancet* **2,** 388–389

18 Wakeham, G. (1923). Basal metabolism and the menstrual cycle. *J. Biol. Chem.* **56,** 555–567

19 Solomon, S.J., Kurzer, M.S., and Calloway, D.H. (1982). Menstrual cycle and basal metabolic rate in women. *Am. J. Clin. Nutr.* **36,** 611–616

20 Webb, P. (1986). 24-hour energy expenditure and the menstrual cycle. *Am. J. Clin. Nutr.* **44,** 614–619