24-hour energy expenditure and the menstrual cycle[1-3]

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ABSTRACT To determine whether 24-h energy expenditure changes during the menstrual cycle, 10 normally menstruating women in their 20s and 40s were measured repeatedly for periods of 36 and 46 h by simultaneous direct and indirect calorimetry. A standardized sedentary daily schedule included three meals to provide food intake equal to expenditure. Eight of the 10 women showed increases of 8–16% during the 14-day luteal phase following ovulation, a significant increase ($p < 0.00002$ by direct calorimetry, $p < 0.001$ by indirect calorimetry). One subject, whose increase was 14% following ovulation, showed no significant change during a month when she took an oral contraceptive. Progesterone from the corpus luteum is the likely cause of a 9% increase in 24-h energy expenditure in normally menstruating women. *Am J Clin Nutr* 1986;44:614–9.

KEY WORDS Calorimetry, luteal phase, metabolism, ovulation, pregnandiol, progesterone

Introduction

In a number of laboratories daily energy expenditure is measured by continuous 24-h direct and indirect calorimetry. Since subjects include men and women, it is natural to ask if women have a constant daily energy expenditure across the menstrual cycle. Three preliminary reports with 24-h data have indicated that expenditure increases during the postovulatory half (luteal phase) of the cycle. Aschoff and Pohl (1) published oxygen uptake for one woman, showing higher levels before menstruation than after it. Bisdee and James (2) found that nine women had a 6% increase in sleep metabolism in their postovulatory phases, and Webb (3) reported that four young women showed increases ranging from 7 to 15% in 24-h expenditure following ovulation.

Less conclusive were early studies of basal metabolism that showed either an increase (4–9) or no change (10–14) in the BMR during the luteal phase of the menstrual cycle. A recent study (15, 16), which employed the comfortable ventilated hood technique, found BMR elevated by 5%. Measurements of oxygen uptake and carbon dioxide output under standardized resting conditions have shown either an increase (17) or no increase (18–20) in resting metabolism during the luteal phase.

Reported here are the results of repeated 24-h calorimetric measurements in women in their 20s and 40s. Eight of ten showed definite increases in daily expenditure in the postovulatory phases of their menstrual cycles.

Methods

Eleven women volunteered as subjects for studies of various levels of food intake, results of which have been reported elsewhere (21–23). Four women were in their 20s, six were in their 40s, and all had normal menstrual histories. The eleventh woman, who served as a control, was 55 and postmenopausal for 7 yr. One subject (C) regularly took an oral contraceptive, but in one series of experiments she omitted it to see if this affected expenditure level. All eleven were healthy and free of disease, based on medical histories, physical examinations, and standard blood chemistries.

Physical characteristics of the subjects are given in **Table 1**. Body fat was calculated from density, determined from underwater weighing and residual lung volume.

The women were paid for their participation. After procedures had been explained and demonstrated, they

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TABLE 1
Physical descriptions of subjects

	Age	Height	Weight	Body fat
	yr	*cm*	*kg*	*%*
A	24	158	40	12
B	23	170	61	21
C*	23	169	72	41
D	23	170	88	43
E	43	171	95	46
F	43	161	49	27
G	48	154	72	40
H	45	167	69	36
I	46	158	62	31
J	45	167	74	39
Controls				
K	55	166	62	25
C*	22	169	72	41

* Subject C served both as a control and as an active subject, depending on whether or not she was taking birth control medication.

signed consent forms. The experiments were approved by the laboratory's Institutional Review Board.

Phases of the menstrual cycle were determined retrospectively by taking the onset of menstrual flow as the signal that ovulation had occurred 14 days earlier. Confirming data were obtained from pregnandiol in 24-h urines, determined by a gas chromatographic method (24).

Energy expenditure was measured by continuous direct and indirect calorimetry carried out simultaneously over periods of 36 and 46 h. Direct calorimetry was done with a suit calorimeter, first described in 1972 (25); its present form was fully described recently (26). The suit contained a water-cooled undergarment and several layers of insulated overgarments for thermal isolation from the environment. Water circulating through the suit was adjusted for thermal comfort, and its mass flow times its change in temperature gave a continuous record of heat loss. Also measured were evaporative heat loss from the skin and from respiration, convective heat loss from the face, determined from temperature change and mass flow of air passing through the face mask measuring respiratory gas exchange, and losses and gains of heat from cold and hot foods. Continuous records of skin and rectal temperatures showed that there was virtually no heat storage or loss at the end of the 24 h day. Respiratory gas exchange (indirect calorimetry) was measured with a full face mask ventilated with room air at a fixed flow of 4 to 5 times the respiratory minute volume; samples of diluted exhaled room air were led to differential gas analyzers, resulting in a continuous record of oxygen uptake and carbon dioxide output (27).

A standardized schedule of sedentary activities was followed while subjects were in the calorimeter; the measurements took place in a small laboratory apartment. During waking hours subjects spent most of their time seated, during which they read, watched television, talked with the ever-present observer, or visited with friends. At night subjects slept in bed in a small bedroom in the apartment. Subjects stood and moved about as they wished, but they did no real exercise.

Three meals were served at regular hours. A mixed diet was comprised of ordinary foods that had been analyzed for energy content by bomb calorimetry. The daily energy intake was made to match each subject's daily expenditure.

Three subjects (A, B, and C) had energy expenditure measured for 2 days (46 h) each week across a full menstrual cycle and on several other occasions. The remaining subjects were measured for 36 h at 9- to 14-day intervals over periods of 6 or 9 wk, following experimental protocols not related to the present report. In these protocols the occurrence of pre- and postovulatory phases had no influence on the schedule of measurements, except to avoid measurements during menstrual flow. On two occasions there was menstrual flow during occupation of the calorimeter, not by design, but because subjects sometimes changed places on the original schedule and then experienced an early onset of menses. With these two exceptions measurements in the preovulatory phase occurred between day 7 (day 1 being the first day of menstrual flow) and 2 days before ovulation, while measurements in the postovulatory phase occurred between 12 days and 3 days before menstrual flow began.

Results

To illustrate the nature of the data, **Figure 1** shows a record of body temperature, metabolic rate, and rate of heat loss (energy expenditure by direct calorimetry) over four 46-h periods for subject B. The values graphed are hourly averages of the continuous data. Despite the marked variations in metabolic level from day to night, the subject was in energy balance at the end of each day, that is, total heat loss equalled total metabolism, and body temperature had returned to its level of the previous day. Two 46-h measurements made before ovulation are averaged together to contrast with two 46-h measurements taken following ovulation. To verify the difference apparent on the figure, the means of all the hourly preovulatory values were compared with the means of all the hourly postovulatory values. The differences between the means compared to the standard error of the differences were found to be highly significant ($p < 0.001$). Similar differences were verified for subject A when the hourly means over five 46-h periods were compared. For subject C, who was taking an oral contraceptive, there were no significant differences for the 4 wk between menses (*see* **Table 2** under *Controls*).

Daily energy expenditures as measured by direct calorimetry for all 11 women are shown in Table 2. The 24-h values are taken from the longer periods of measurement (36 and 46

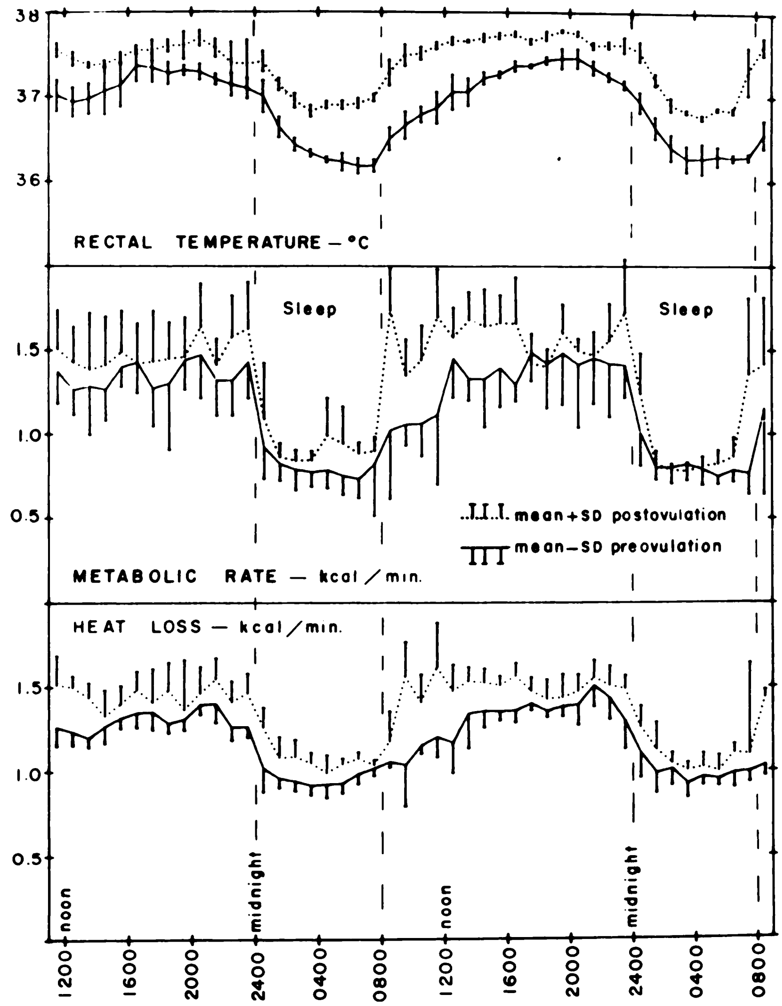

FIG 1. Hourly averages of rectal temperature, metabolic rate, and rate of heat loss for subject B for 46-h periods during 2 wk before ovulation (solid line) and 2 wk after ovulation (dotted line). Each hourly mean with its standard deviation is based on 12 10-min values.

h); the values are totals from awakening one morning to awakening the following morning. Subject C is shown as both a control subject and an active one, because while she was taking the oral contraceptive, she was very regular in her menses, ovulation was presumably suppressed, and there was no major change in expenditure across the month of observation. When she omitted the medication, her menses started early, and her expenditure increased following the presumed ovulation as shown in the upper part of Table 2.

For eight women the increase in daily energy expenditure following ovulation ranged from 8 to 16% (Table 2), with a mean of 11.5% (SD ± 2.6%). Two other women showed a small decrease of 2%. Taking the data for all ten women together (neglecting the controls), the mean increase in expenditure was 8.8% (SD ± 5.5%). The inherent variability of the measurement is shown by the data from the two controls, who showed standard deviations about their mean values of ±4% and ±3%. Using "Student's" t test for paired data, statistical treatment of the 19 pairs of data in Table 2 from ten women, excluding controls, showed a mean difference between pre- and postovulatory 24-h expenditure of 142 kcal/day, SEM ± 26 kcal/day. The difference was significant at $p < 0.00002$.

TABLE 2
24-h energy expenditures from direct calorimetry before and after ovulation

	Preovulation	Postovulation	Difference
	kcal/day	*kcal/day*	*%*
A	1245	1335	
	1215	1336	
	1226	1381	
	1235		
	$\bar{x}$ = 1230	1351	10
B	1692	1909	
	1583	1888	
	1620		
	$\bar{x}$ = 1632	1899	16
C	2001	2314	
	2022	2268	
	$\bar{x}$ = 2012	2291	14
D	2139	2278	
	1943	2160	
	$\bar{x}$ = 2041	2219	9
E	1771	1843	
	1801	2006	
	$\bar{x}$ = 1786	1925	8
F	1626	1608	
	1681	1635	
	$\bar{x}$ = 1654	1622	−2
G	1779	1791	
	1800	1728	
	$\bar{x}$ = 1790	1760	−2
H	1683*	1882	12
I	1522*	1686	
	1509	1710	
	$\bar{x}$ = 1516	1698	12
J	1497	1678	
		1570	
		1722	
	$\bar{x}$ =	1657	11
Controls			
K	1791		
	1657		
	1634		
	1741		
	1710		
	1753		
	1620		
	1636		
	$\bar{x}$ = 1693 ± 65 (SD)		
C	1994		
	2060		
	1964		
	1937		
	$\bar{x}$ = 1989 ± 53		

* Menstrual flow began during the measurement.

Urinary excretion of pregnandiol increased by an average of 2.75 times following ovulation in the ten ovulating subjects, the mean having been 0.78 mg/24 h before ovulation and 2.15 mg/24 h after ovulation. For the two controls, pregnandiol stayed low (mean 0.63 mg/24 h) and varied by < 15%.

The values given in Table 2 are the 24-h expenditures measured in the direct calorimeter. Daily expenditure from respiratory gas exchange matched the calorimetric data within ±3%, which agrees with previous reports from this laboratory (21, 23, 28). The difference between pre- and postovulatory energy expenditure based on metabolic rate was significant at $p < 0.001$. Data from direct calorimetry tend to be less variable than those from respiratory gas exchange, which is the likely explanation of the difference in the p values for the two types of measurement.

Discussion

The direct measurement of 24-h expenditure under standardized conditions clearly shows that energy expenditure increases in the 2 wk following ovulation, in contrast to the inconclusive results of previous studies that were based on shorter periods of measurement, for example, as in the measurement of BMR. This probably reflects the influence of the large changes seen in the day-night variation in expenditure (Fig 1) and the difficulty of standardizing the state of rest. BMR values typically vary by ±15%, which is larger than the 9% difference between pre- and postovulatory energy expenditure reported here. The 24-h measurement without the effect of the menstrual cycle had a variability of about ±4%, as seen in the control data (Table 2) and as observed in men under similar sedentary conditions (21–23).

Why two subjects (F and G) failed to show the increase in expenditure is not clear. Their 24-h urinary excretions of pregnandiol were increased as much as those of the other women; their menses were not irregular during the weeks of measurement. However, progesterone levels change quickly downward as menses approach, which is reflected more slowly in 24-h urinary pregnandiol, so that it is possible that circulating progesterone was actually low during some of their postovulatory measurements.

Subject C provided interesting confirmation of the effects of ovulation. The oral contraceptive which she took (Ortho Novum (R)) contains norethindrone, a progestational compound that suppresses ovulation. The sequence of doses over 28 days permits the uterine changes which result in menstrual flow. While C was on the medication, she showed a preovulatory level of energy expenditure for all 4 wk of her cycle, but when the pills were omitted, she showed a 14% increase in expenditure during the 2 wk following ovulation.

Admittedly, the occurrence of ovulation was not conclusively identified by the methods used, but more detailed hormonal studies were beyond the resources available. However, Bisdee and James (2) followed salivary and urinary hormones daily to establish the preovulatory LH surge and to follow the changes in the ratio of estrone-3-gluconuride to pregnandiol-3a-gluconuride. Their results, while not identical to ours (see below), are similar enough to be considered supportive. In the present study we made the conventional assumption that ovulation occurred 14 days before menstrual flow and found confirming data in the 24-h secretion of pregnandiol in urine.

Natural progesterone is said to act as a general metabolic stimulant (29), especially the elevated levels found in pregnancy. The moderately increased level of progesterone secreted by the corpeus luteum in the postovulatory phase, confirmed by the higher levels of its metabolic product, urinary pregnandiol, is the likely cause of the elevated 24-h expenditure reported here. There was no particular correlation between the amount of pregnandiol and the degree of elevation of expenditure, but the increases in both were small. We saw no age effect in either expenditure or pregnandiol; there was no correlation between percent body fat and expenditure or pregnandiol, although progesterone diffuses rapidly from the blood, especially into adipose tissue (30).

Energy expenditure during sleep was somewhat higher in the postovulatory days than in the preovulatory days (Fig 1), but the 24-h data were more clearly different. By contrast, Bisdee and James (2) employed a ventilated metabolic chamber to determine respiratory gas exchange and observed that sleep metabolic rate was significantly higher in the postovulatory phase but that 24-h data were more variable. It is possible that our sedentary routine in the apartment was reproducible enough to let the difference in 24-h data be apparent.

The higher expenditure following ovulation may be related to the observation of Dalvit (31) that women eat 500 kcal/day more in the days following ovulation than in the days before.

In conclusion, the measurements show that there is a 9% elevation in 24-h energy expenditure in the postovulatory (luteal) phase of the menstrual cycle presumably caused by the increased secretion of progesterone.

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