The Impact of Menstrual Cycle Phases on Cardiac Autonomic Nervous System Activity: An Observational Study Considering Lifestyle (Diet, Physical Activity, and Sleep) among Female College Students

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Summary

Studies examining the impact of menstrual cycle phases on the cardiac autonomic nervous system have produced inconsistent results. This study aimed to investigate this relationship, controlling for the confounding effects of diet, physical activity, and sleep, which can be affected by the menstrual cycle. Fifteen female college students with regular menses were enrolled. Data regarding 24-h heart rate variability (HRV), dietary intake, eating behavior, menstrual distress, and sleep and activity parameters were obtained during the follicular and luteal phases. Power spectral analysis of HRV was used to calculate low-frequency (0.04–0.15 Hz, LF), high-frequency (0.15 Hz, HF), and total spectral power (TP). Cardiac sympathetic and parasympathetic nervous system activity indicators were evaluated as LF/HF and HF/TP, respectively. Intake of protein and fat, as well as total sleep time and number of awakenings, were higher in the luteal phase than in the follicular phase (p<0.05). Tendencies for increased mean activity counts, emotional eating scores, and behavioral change scores in the Menstrual Distress Questionnaire were observed in the luteal phase (p<0.10). Although LF/HF was higher in the luteal phase (p=0.036), the relationship was weakened after controlling for diet, physical activity, and sleep (p=0.113). Our findings suggest that altering sympathetic nervous system activity during the menstrual cycle was not independent from major lifestyle factors (diet, physical activity, and sleep). Menstrual cycle phase and changes of these parameters should be considered when assessing the cardiac autonomic function among menstruating women.

Key Words autonomic nervous system activity, menstrual cycle, dietary intake, women

Autonomic imbalance, characterized by a hyperactive sympathetic nervous system and a hypoactive parasympathetic nervous system, is a risk factor for cardiovascular disease (1). Women with severe Premenstrual Syndrome (PMS) have been shown to have reduced parasympathetic nervous system activity in both the follicular and late-luteal phases of the menstrual cycle, as compared to controls (2). PMS is defined as a collection of emotional symptoms, with or without physical symptoms, related to a woman’s menstruation cycle. These symptoms can occur during the luteal phase, but disappear with menstrual flow (3). A recent meta-analysis reported the pooled global prevalence of PMS to be 47.8% (95% CI: 32.6–62.9) (4).

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Spectral analysis of heart rate variability (HRV) has allowed for comprehensive quantitative and qualitative assessments of sympathetic and parasympathetic components of the autonomic nervous system (5). Recent studies suggest that estrogen affects several vital organ systems, including the cardiovascular system and autonomic nervous system, and contributes to the maintenance of an adequate sympathovagal balance (6). Because estrogen levels vary throughout the menstrual cycle, cardiac autonomic nervous system activity might also vary within the menstrual cycle. Nonetheless, studies examining the impact of menstrual cycle phases on cardiac autonomic regulation have produced inconsistent results. For instance, several studies have reported increases in sympathetic activity (7, 8), increases in parasympathetic activity (9), or no changes in HRV.
measurements (10) during the luteal phase, as compared to the follicular phase of the menstrual cycle. Conflicting results observed in studies that investigated HRV at different phases may be due to different methodologies, small sample sizes, or differences in sampling times during the menstrual cycle. Such differences in results could also potentially be explained by other factors affected by the menstrual cycle that have the potential to impact the cardiac autonomic nervous system.

With respect to dietary intake, a recent review indicated that energy intake decreases during the late follicular phase of the menstrual cycle, while it tends to increase during the luteal phase (11). Reed et al. showed that, especially among women with premenstrual dysphoric disorder (but not in control women), the desire for high-fat food increased during the luteal phase (11). Reed et al. showed that energy intake decreases during the late follicular phase of the menstrual cycle, while it tends to increase during the luteal phase (11). Conversely, Bryant et al. showed that the consumption of energy and macronutrient intake were similar between phases with or without PMS (13). Studies of dietary intake changes during the menstrual cycle have been somewhat inconclusive.

Previous studies have shown that dietary intake affects the cardiac autonomic nervous system (14). Therefore, dietary intake changes during the menstrual cycle may be associated with the factors that have led to inconclusive results regarding changes in autonomic nervous system function during the menstrual cycle. Few studies have simultaneously examined the cardiac autonomic nervous system and dietary intake during the menstrual cycle. Physical activity (15) and sleep (16), which can affect the cardiac autonomic nervous system, are rarely included as variables in studies on the impact of menstrual cycle phases on the cardiac autonomic nervous system.

This study investigated the impact of menstrual cycle phases on diet, physical activity, sleep, and cardiac autonomic nervous system function, while controlling for the confounding effects of diet, physical activity, and sleep, which can be affected by the menstrual cycle and potentially impact cardiac autonomic regulation.

MATERIALS AND METHODS

Participants. Twenty-one female college students at the Tokyo University of Agriculture (Tokyo, Japan), whose menstrual cycles had been regular for the past 6 mo, were recruited via a notice posted on bulletin boards. Inclusion criteria were as follows: having regular menstrual cycles (25 to 38 d, with no more than 6 d of variance) (17), not engaging in habitual vigorous physical activity (greater than 6.0 METs), not being pregnant or lactating, not taking any medications (including oral contraceptives), and not using alcohol habitually (drinking more than 180 mL of Japanese sake (almost equal in alcohol to a glass of wine) more than 3 times per week) and not using cigarettes. Each participant gave her written informed consent after receiving explanations of the study protocol and potential effects of the study on health. All study procedures were reviewed and approved by the Ethics Committee at the Tokyo University of Agriculture (Authorization Number 1121).

Study design. In this cross-sectional study, recordings for 24-h ambulatory heart rate variability (HRV) were obtained during the follicular and luteal phases of the menstrual cycle, based on basal body temperature. At the same time, dietary intake, eating behavior, menstrual distress, activity, and sleep parameters were assessed. Participants were asked to undergo a 24-h electrocardiograph (ECG) recording and other measurements, starting before breakfast, and going about usual daily activities while abstaining from excessive physical activity or any alcohol use. A questionnaire regarding eating behavior and menstrual distress was completed before going to bed.

Measurements.

Basal body temperature: Prior to obtaining data, menstrual cycle phase was determined by measuring basal body temperature for at least 2 mo. Basal body temperature was measured orally using a digital basal thermometer (W520, Terumo Corporation, Tokyo, Japan) for 5 min immediately after awakening and before any physical activity. Data were transferred from digital basal thermometers to personal computers, and were recorded graphically to confirm the regularity of the menstrual cycle with a biphasic pattern of basal body temperature. Experimental days were determined based on each participant’s schedule, including one standard day in both the follicular phase (from the end of menstruation to ovulation) and luteal phase (from ovulation to the beginning of menstruation). Participants were asked to measure basal body temperature every day throughout the experiment.

Anthropometric measurements: Anthropometric measurements were assessed for the follicular and luteal phases during laboratory visits on days that differed from experimental days. Body weight and body fat ratio were estimated in the overnight fasting state using an electronic impedance device (InBody 430, Biospace Japan Inc., Tokyo, Japan). For the evaluation of height, a metallic stadiometer with 0.1 cm precision was used (YS101-S, AS ONE Corporation, Osaka, Japan). Body mass index (BMI) was calculated by dividing body weight (in kilograms) by height (in meters) squared.

24-Hour electrocardiograph recording: Cardiac autonomic nervous system activity was assessed noninvasively by measuring HRV under free living conditions (5). Bipolar 5-lead ECG readings were recorded using a digital ambulatory ECG recorder (RAC3103, Nihon Kohden Corp., Tokyo, Japan). Electrocardiograph signals were then amplified and digitized at a sampling frequency of 250 Hz. R-R intervals (RRIs) were calculated based on a pulse during the rising phase of each spike in the QRS complex, which was detected with a customized computer program (QP-432D, Nihon Kohden Corp.). Spectral analysis was used for segments of approximately 10 min of HRV (600 data points) every 5 min. HRV data from each segment were then aligned sequentially, using the mean RRI to obtain equally spaced sam-
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Table 1. Dietary intake in follicular and luteal phases.

|                | Follicular phase | Luteal phase | p \(^1\) |
|----------------|-----------------|--------------|---------|
| Total energy intake (kcal) | 1,578±484 | 1,840±537 | 0.108 |
| Protein (g) | 56.2±6.7 | 68.2±10.5 | 0.002 |
| Fat (g) | 47.5±10.8 | 64.3±13.8 | 0.003 |
| Carbohydrate (g) | 221±23 | 239±28 | 0.097 |
| Potassium (mg) | 1,922±352 | 2,490±1,137 | 0.047 |
| Calcium (mg) | 415±166 | 565±271 | 0.017 |
| Iron (mg) | 5.3±1.7 | 7.4±3.8 | 0.072 |
| Retinol (µg) | 424±304 | 428±200 | 0.966 |
| Vitamin B₁ (mg) | 0.8±0.2 | 0.9±0.3 | 0.097 |
| Vitamin B₂ (mg) | 1.0±0.2 | 1.2±0.3 | 0.024 |
| Vitamin C (mg) | 75.5±47.3 | 92±72 | 0.245 |
| Saturated fat (g) | 15.7±4.7 | 23.2±7.1 | 0.001 |
| Dietary fiber (g) | 9.5±2.0 | 13.9±9.3 | 0.118 |
| Salt equivalent (g) | 6.4±1.9 | 8.3±3.2 | 0.122 |

Values are expressed as mean±SD.

Values are adjusted for total energy intake using the residual method, except for total energy intake.

\(^1\) Paired t-test.

After eliminating any linear trends by linear regression, coarse-graining spectral analysis was performed for 10 time-shifted subsets of 512 data points to break down total power into regular periodic and fractal components (19, 20). Total power (TP) and integrated spectral power of periodic components in the low-frequency (LF, 0.04–0.15 Hz) and high-frequency (HF, > 0.15 Hz) power ranges, the ratio of LF to HF (LF/HF) power, and the ratio of HF power to TP (HF/TP) were calculated for a 24-h average. The HF/TP ratio can be used to assess cardiac vagal tone, and LF/HF can be used to assess cardiac sympathovagal balance (19, 20).

Activity and sleep monitoring: While undergoing the 24-h ECG recording, participants wore an actigraphy [Motionlogger® Micro Watch, Ambulatory Monitoring, Inc. (AMI), Ardsley, NY] device on their non-dominant wrist. According to the American Academy of Sleep Medicine, actigraphy is a valid way to assist in determining sleep patterns in healthy adult populations (21). Activity data were collected in 1 min intervals and downloaded using AMI commercial software (Action W 2.4, AMI). The periods during which participants wore the actigraphy device were divided into the following intervals: waking period, defined as the period of time spent out of bed; and sleeping period, defined as the period of time spent in bed. Total sleep time (TST; time spent sleeping during the sleep interval), sleep efficiency (100×TST/total time in bed), sleep-onset latency (minutes taken to fall asleep after lights out), and number of awakenings (number of continuous blocks of one or more minute intervals from the end of sleep latency to lights on) were calculated from the sleeping period as nighttime sleep parameters. The mean activity counts during the waking period (counts/minute) was calculated as a physical activity parameter.

Dietary intake: Foods and beverages consumed on days of the experiment were reported through dietary records. Participants were asked to provide details of all food and beverages consumed (e.g., ingredients, quantities, cooking methods, and whether homemade or readymade), as well as any nutritional supplements. At the end of the 24-h ECG recording, trained dietitians reviewed the dietary records for completeness and accuracy. Total energy intake and nutritional intake during the recording were calculated using the Standard Food Composition Table published by the Science and Technology Agency of Japan (2005).

Eating behavior: Eating behavior was assessed using the Dutch Eating Behavior Questionnaire (DEBQ), which was developed by van Strien et al. (22) and consists of 33 items. These 33 items were classified according to three categories as emotional eating, external eating and restrained eating. Scores on each scale ranged from one (never) to five (often), with higher scores indicating that the behavior or attitude is more frequent. Scores can indicate greater restraint, sensitivity to changes in emotional conditions, and sensitivity to external cues. This scale, especially in regard to emotional eating, was used in a previous study of ovarian hormones and binge-eating, and was able to predict menstrual-cycle changes in binge-eating habits (23).

Menstrual distress questionnaire: Participants filled out the Menstrual Distress Questionnaire (MDQ), which evaluated physical, emotional, and behavioral symptoms within their menstrual cycles (24). The MDQ consists of 46 symptoms, which are divided into eight categories: pain, concentration, behavioral changes, autonomic reactions, water retention, negative affect, arousal, and control. Participants were asked to rate their experience of all 46 symptoms on the questionnaire using a six-point scale, which ranged from no experience of the symptom to symptoms so severe that they disrupted daily activities. Higher scores indicate a higher level of disturbance.
Of the 21 women enrolled, six were excluded from the analysis because their basal body temperature lacked a biphasic pattern ($n=2$), which raised the suspicion of an anovulatory menstrual cycle, irregular menstrual cycle ($n=2$), or missing data in the follicular or luteal phase ($n=2$). Consequently, a total of 15 participants were analyzed. To examine dietary composition, all nutrient intake were adjusted for total energy intake using the residual method. The paired $t$-test was used to compare dietary intake, physical activity, sleep parameters, eating behavior, and MDQ scores between the follicular and luteal phases. Mixed model analysis was used to control for diet (intake of fat and emotional eating score), physical activity (mean activity counts), and sleep parameters (total sleep time and number of awakenings) and to compare cardiac autonomic nervous system activity between the follicular and luteal phases. Although dietary intakes of protein and fat were both significantly higher in the luteal phase, as compared to the follicular phase, intake of protein and fat had a strong correlation. We chose the intake of fat as a dietary factor because most studies have noted increases in fat prior to menses (11). All analyses were performed using SPSS statistical software (IBM SPSS 20.0 for Windows, SPSS Japan, Tokyo, Japan). $p<0.05$ was considered statistically significant, based on two-tailed tests.

**RESULTS**

Mean participant age was $21.9\pm0.3$ y and mean BMI was $20.3\pm1.6$ kg/m$^2$. Mean menstrual cycle length was $29.9\pm3.7$ d. Measurements were taken on day $9.7\pm2.1$ in the follicular phase and day $23.2\pm4.4$ in the luteal phase, measured from the first day of men-
struation. Basal body temperature was observed to increase in the luteal phase, as compared to the follicular phase (36.23 ± 0.23°C, increasing to 36.48 ± 0.3°C), \( p < 0.001 \).

Dietary intake of protein, fat, saturated fat, potassium, calcium, and vitamin B2 were significantly higher in the luteal phase, as compared to the follicular phase (Table 1). Total sleep time and number of awakenings were significantly higher in the luteal phase, as compared to the follicular phase (Table 2). Mean activity counts, emotional eating scores in the DEBQ, and behavioral change scores in the MDQ tended to increase in the luteal phase (Tables 2 and 3). Although LF/HF was significantly higher in the luteal phase, as compared to follicular phase, the relationship was weakened after controlling for diet, physical activity, and sleep parameters (Table 4).

**DISCUSSION**

To our knowledge, this study is the first to investigate the impact of menstrual cycle phases on cardiac autonomic regulation using 24-h HRV, while controlling for the confounding effects of diet, physical activity, and sleep, which could be affected by the menstrual cycle and potentially impact cardiac autonomic regulation. We found that diet, physical activity, and sleep were altered during the menstrual cycle. Although LF/HF was significantly higher in the luteal phase, as compared to the follicular phase, the relationship was not independent from diet, physical activity, and sleep, which were altered during the menstrual cycle phase.

Dietary intake of protein, fat, saturated fat, potassium, calcium, and vitamin B2 was significantly higher in the luteal phase, as compared to the follicular phase. A recent review suggested that energy intake tended to decrease during the follicular phase, and to increase during the luteal phase, although large variations were observed when comparing energy intake values reported by different studies, with mean increases in total energy intake ranging from 87 to 500 kcal (11). In the present study, even though the mean increase in total energy intake was 262 kcal, the difference between phases was not significant. In regard to changes in macronutrient intake throughout the menstrual cycle, most studies have noted increases in fat and carbohydrate intake prior to menses (11). Consistent with our present results, one study conducted in an Asian country reported increases in protein intake during the luteal phase, as compared to the follicular phase (25). Cultural or regional differences may moderate changes in food intake throughout the menstrual cycle.

The appetite-related neuropeptide, leptin, is secreted by adipocytes and induces satiety (26). Leptin concentrations increase during the menstrual cycle from menses to the late luteal phase, with a mid-cycle peak at the time of the luteinizing hormone surge (27). The changes in energy intake observed in the present study, however, do not correlate with cyclical changes in leptin levels. Similarly, estrogen levels are linked with appetite. Animal studies have found that estrogen treatment leads to significantly higher serum leptin levels and lower food intake (28). Klump et al. showed that increases in DEBQ Emotional Eating Scale scores were associated with decreases in estradiol and increases in progesterone across the menstrual cycle among women in community samples (23). Although we did not assess ovarian hormone levels, DEBQ Emotional Eating Scale scores tended to increase in the luteal phase more than in the follicular phase. These results suggest that the observed changes in dietary intake may be due to changes in ovarian hormone levels throughout the menstrual cycle.

Total sleep time and number of awakenings were significantly higher in the luteal phase than in the follicular phase, suggesting a decrease in sleep quality. In a previous study, actigraphy-defined sleep efficiency declined gradually across the menstrual cycle, but the decline became pronounced in the premenstrual period (29). It remains unclear whether sleep structure or melatonin (a pineal hormone with high nocturnal secretion) is affected by menstrual phase. Shechter et al. showed increases in polysomnography-defined sleep onset latency, and decreases in rapid eye movement (REM) sleep in the mid-luteal phase, as compared to the midfollicular phase, although salivary melatonin profiles

### Table 4. Sympathetic and parasympathetic nervous system activity in follicular and luteal phases.

|                     | Follicular phase | Luteal phase | Base model (crude) | Model 1\(^1\) | Model 2\(^2\) | Model 3\(^3\) | Model 4\(^4\) |
|---------------------|-----------------|--------------|--------------------|---------------|---------------|---------------|---------------|
|                     |                 |              | \( \beta^1 \)  | \( p \)       | \( \beta^2 \)  | \( p \)       | \( \beta^3 \)  | \( p \)       |
| TP (ms\(^2\))       | 4.073 ± 2.351   | 3.081 ± 1.347| -9.91             | 0.109         | -7.69         | 0.280         | -7.72         | 0.240         | -1.213         | 1.838         | -0.856         | 0.304         |
| LH/HF               | 2.7 ± 1.7       | 3.7 ± 0.6    | 0.99              | 0.036         | 0.94          | 0.086         | 0.98          | 0.056         | 0.92           | 0.058         | 0.95           | 0.113         |
| HF/TP               | 20.5 ± 13.6     | 20.7 ± 2.5   | 0.23              | 0.953         | 2.05          | 0.619         | 2.12          | 0.771         | 2.85           | 0.541         | 0.10           | 0.985         |

Values are expressed as mean ± SD.

\(^1\) Adjusted for dietary factors (intake of fat and emotional eating score) with mixed model analysis.

\(^2\) Adjusted for activity counts with mixed model analysis.

\(^3\) Adjusted for sleep parameters (total sleep time and number of awakenings) with mixed model analysis.

\(^4\) Adjusted for all variables in model 1, 2 and 3 with mixed model analysis.

\(^5\) Parameter estimates indicate the differences in adjusted means between follicular and luteal phase.
did not change significantly (30). In another study, the same group showed a significant reduction in plasma melatonin levels during the luteal phase, as compared to the follicular phase, among women with premenstrual dysphoric disorder (31). Further studies will be needed to draw conclusions about changes in sleep parameters across the menstrual cycle, because participants in the present study showed fewer symptoms of premenstrual distress, and melatonin levels were not assessed.

LF/HF reflects sympathetic nervous activity, and was higher in the luteal phase, as compared to the follicular phase. Estrogen levels reportedly have effects on the cardiovascular system and the autonomic nervous system, increasing parasympathetic and decreasing sympathetic activity (6). In contrast, progesterone reportedly correlated with the LF/HF ratio in both non-REM sleep and REM sleep and negatively correlated with HF power in non-REM sleep among non-PMS women (32). Sympathetic hyperactivity is associated with anxiety and mood disturbance (33). It is possible that sympathetic activity and the tendency to increase emotional eating in the luteal phase were affected by changes in ovarian hormones during the menstrual phase. Moreover, after controlling for diet, physical activity, and sleep parameters, the relationship between changes in LF/HF and menstrual cycle phase was weakened. Intake of protein and fat was significantly higher, and intake of carbohydrates and mean activity counts tended to be higher, in the luteal phase than in the follicular phase. Some studies have reported that meal intake (34, 35) and physical activity (15) increase sympathetic nervous activity. Although we did not assess ovarian hormone levels, and our cross-sectional study could not establish cause-and-effect relationships, these results are consistent with a cause-and-effect sequence between changes in sympathetic nervous system activity, dietary intake, and physical activity across the menstrual cycle.

This study has some limitations worth noting. First, because menstrual phase was determined by basal body temperature rather than serum hormone levels, it is possible that the phase timings were inaccurate. Similarly, the findings of this study cannot be attributed to specific hormones or other mechanisms. Based on prior evidence, however, different hormonal levels during follicular and luteal phases likely contribute to the observed phase differences. Second, although we measured physiological factors and food intake, recordings were only performed during one day of each menstrual cycle. Thus, it is possible that experimental days did not reflect standard days of each menstrual period, and that the results should be interpreted with caution. Third, we didn’t consider the timing of meals, which could affect the 24-h period rhythm of cardiac autonomic nervous system (36, 37). Fourth, as our results were derived from a small sample of young women, this study should be interpreted as a pilot study. Further studies will be needed to repeat these measurements with inclusion of more experimental days and more than one menstrual cycle, as well as confirmation of serum hormone levels.

CONCLUSION

Although sympathetic nervous system activity was altered during the menstrual cycle phase, the relationship was not independent from diet, physical activity, and sleep, which were altered during the menstrual cycle phase. Our findings suggest that menstrual cycle phase and changes of these parameters should be considered when assessing the cardiac autonomic function among menstruating women.

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