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Changes in macronutrient, micronutrient, and food group intakes throughout the menstrual cycle in healthy, premenopausal women

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Abstract

Purpose—It is thought that total energy intake in women is increased during the luteal versus follicular phase of the menstrual cycle; however, less is understood regarding changes in diet composition (i.e., macro- and micronutrient intakes) across the cycle. The aim of this study was to investigate changes in macronutrient, micronutrient, and food group intakes across phases of the menstrual cycle among healthy women, and to assess whether these patterns differ by ovulatory status.

Methods—The BioCycle study (2005–2007) was a prospective cohort study of 259 healthy regularly menstruating women age 18–44 who were followed for up to two menstrual cycles. Dietary intake was measured using 24-h dietary recalls, and food cravings were assessed via questionnaire, up to four times per cycle, corresponding to menses, mid-follicular, expected ovulation, and luteal phases. Linear mixed models adjusting for total energy intake were used to evaluate changes across the cycle.

Results—Total protein ($P = 0.03$), animal protein ($P = 0.05$), and percent of caloric intake from protein ($P = 0.02$) were highest during the mid-luteal phase compared to the peri-ovulatory phase. There were also significant increases in appetite, craving for chocolate, craving for sweets in general, craving for salty flavor, and total craving score during the late luteal phase compared to the menstrual, follicular, and ovulatory phases ($P < 0.001$).

Conclusions—Our findings suggest an increased intake of protein, and specifically animal protein, as well as an increase in reported food cravings, during the luteal phase of the menstrual

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cycle independent of ovulatory status. These results highlight a plausible link between macronutrient intake and menstrual cycle phase.

Keywords

Menstrual cycle; Macronutrients; Micronutrients; Anovulatory

Introduction

There is suggestive evidence of increased caloric intake in women during the luteal phase compared to the follicular phase of the menstrual cycle [1–6]. These fluctuations are hypothesized to reflect the appetite suppressing and stimulatory effects of estrogen and progesterone, respectively [7]. To truly capture these variations, it is imperative that short-term dietary intake can be evaluated using 24-h recall or diet record and not long-term intake using food frequency questionnaires. Indeed, identifying whether these fluctuations are an important source of biological variability in dietary intake may be essential to consider when assessing associations between modifiable dietary factors and female reproductive outcomes and long-term health effects.

Findings between dietary intake and fertility are often conflicting, which could be due not only to the well-known limitations in measurement of dietary intake using available dietary assessment tools, but also due to potential biological effects on appetite throughout the menstrual cycle in reproductive age women [2–4]. Previous work has mainly been limited by small sample sizes [8], single dietary assessments in each cycle phase [5, 9–12], and lack of data on cravings and diet composition (i.e., macro- and micronutrient intakes).

Therefore, the objective of this study was to investigate changes in dietary patterns, including macronutrient, micronutrient, and food group intakes, as well as food cravings across multiple well-timed phases of at least one and up to two menstrual cycles in healthy premenopausal women, and to assess whether these patterns differed by ovulatory status.

Methods

The BioCycle study was designed to investigate oxidative stress levels across the menstrual cycle in healthy women age 18–44 [13] who were followed for one ($n = 9$) or two menstrual cycles ($n = 250$). The study design, procedures, and participants have been described in detail elsewhere [14]. The Health Sciences Institutional Review Board at the University at Buffalo approved the study and served as the Institutional Review Board designated by the National Institutes of Health under a reliance agreement. All study participants provided written, informed consent prior to any study procedures. The participants were regularly menstruating premenopausal women recruited from western New York. Other inclusion criteria included a self-reported body mass index (BMI) at screening between 18 and 35 kg/m^2, not planning to consume a restricted diet for intended weight loss or medical reasons and willingness to discontinue any supplement, vitamin, or antioxidant use during the study period [14]. Study visits were scheduled to occur up to eight times per cycle during the key phases of the menstrual cycle with visits timed using fertility monitors [15] to correspond to menstruation, the middle of the follicular phase, time of estrogen peak, time of the luteinizing hormone and follicle-stimulating hormone surge, the day of expected ovulation, time of progesterone elevation and peak, and prior to menstruation. The home fertility monitors measured urinary estrone-3-glucuronide and luteinizing hormone (LH). When the monitor indicated an LH surge, the participants were instructed to return to the clinical site for a blood draw. Participants were highly compliant with the study protocol, and 94 % of women completed seven or eight visits per cycle, which included blood sampling and questionnaires.

On four of the study visits, corresponding to menses, mid-follicular phase, expected ovulation, and mid-luteal phase, participants completed 24-h dietary recalls. 96 % of participants completed at least three 24-h dietary recalls in each of their two cycles, and 73 % completed all eight 24-h dietary recalls. Women with fewer than four recalls per menstrual cycle were not different by age, BMI, or other demographic characteristics. 32 % of the 24-h recalls were conducted on the weekends with the largest proportion of weekend visits occurring on the peri-ovulatory phase visits. The dietary intake data were collected and analyzed using the Nutrition Data System for Research by the Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN. On those same study visits, a questionnaire regarding 17 menstrual symptoms and the severity of those symptoms in the previous week was completed, which included the assessment of women's food cravings throughout the menstrual cycle (craving questionnaires were complete for 97 % of clinic visits). Symptom severity was ranked as none, mild, moderate, or severe. At the baseline visit, a trained research assistant measured height, weight, and waist circumference at the natural waist using standardized protocols. Information regarding age, BMI, race, education, cigarette smoking, and habitual physical activity was also collected at baseline. Physical activity was measured using the International Physical Activity Questionnaire [16]. Anovulatory cycles were defined as cycles where the peak progesterone concentration across the cycle was ≤5 ng/mL, and there was no serum LH peak on the later cycle visits ($n = 42$ cycles) [17, 18].

Statistical analysis

Statistical analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, NC, USA). Descriptive characteristics of the study population were calculated. Linear mixed models were used to determine the association between menstrual cycle phase and macronutrient, micronutrient, and food group intakes adjusting for total energy intake. Normality was assessed using a histogram and log-transformation of variable with no differences noted. The differences in nutrient intake across menstrual cycle phases were assessed in Table 2. Nutrient intake across phases of the menstrual cycle was also assessed by anovulatory cycles adjusting for total energy intake in Table 3. The phases noted in the anovulatory cycles are meant to imply expected time frames mirroring those in ovulatory cycles. Pairwise comparisons between cycle phases were evaluated with P values corrected using the Holm–Bonferroni method to account for multiple comparisons. Differences in reported cravings across menstrual cycle phase were also determined using generalized linear mixed models (Table 4). All statistical analyses accounted for repeated measures across the cycle and multiple cycles per woman.

Results

Table 1 presents demographic information on our study population. Of the 259 women who participated, the average age of the participant was 27.3 (SD 8.2) years with an average BMI of 24.1 (3.9) kg/m^2. 59.5 % of the population was non-Hispanic white, 55 % reported participating in high levels of physical activity, 13.5 % had at least one anovulatory cycle (*n* = 42 total anovulatory cycles; 28 women with one anovulatory cycle, seven women with two anovulatory cycles).

Table 2 presents the mean macronutrient, micronutrient, and food group intakes across the menstrual cycle phases adjusted for energy intake for all cycles. The following number of dietary recalls was available at each visit: menses (*n* = 499), follicular (*n* = 499), peri-ovulation (*n* = 495), and mid-luteal (*n* = 473). The mean (SD) total energy intake was higher during the mid-luteal phase as compared to the follicular phase, though the difference was not statistically significant (1662 [28] vs. 1591 [27] kcals, respectively, (*P* = 0.20). There were also no significant differences in fat and carbohydrate intakes across phases of the cycle. There was a significant increase in energy-adjusted protein intake (*P* = 0.03), animal protein intake (*P* = 0.05), and percent energy intake from protein (*P* = 0.02), however, during the mid-luteal phase compared to the other cycle phases. After Bonferroni correction, energy-adjusted protein intake and percent energy intake from protein were significantly greater in the midluteal phase compared to the peri-ovulatory phase. There were no other significant differences among macronutrients across menstrual cycle phases. The majority of micronutrients examined did not significantly differ between phases of the menstrual cycle. However, there was significantly lower zinc intake (8.0 [0.2] mg) during the ovulatory phase compared to the follicular (8.7 [0.2] mg) and mid-luteal (8.8 [0.2] mg) phases, (*P* = 0.01). Moreover, there were no significant differences in food group intake by phase only that animal/nut fat was marginally higher (*P* = 0.07) during the follicular phase (78 [2.3] kcals) compared to the ovulatory phase (70 [2.3] kcals).

Energy-adjusted macronutrient, micronutrient, and food group intakes by ovulation status across the four menstrual cycle phases are shown in Table 3. Macronutrient intake throughout ovulatory and anovulatory cycles showed similar patterns of higher protein intake (total protein intake, percent energy intake from protein, and animal protein) in the mid-luteal phase compared to the other phases; however, the associations were only observed to be significant during the ovulatory cycles. Zinc intake was observed to vary across ovulatory cycles, and a similar marginally significant trend was also observed among anovulatory cycles. After Bonferroni correction, energy-adjusted protein intake, percent energy intake from protein, and zinc intake were significantly higher in the mid-luteal phase compared to the peri-ovulatory phase for ovulatory cycles. For anovulatory cycles, egg intake was significantly higher in the peri-ovulatory compared to the follicular group after Bonferroni correction. No other significant differences in micronutrient intakes were observed, and no differences were observed by ovulatory status. Mean caloric intake of eggs was significantly different across menstrual phases for anovulatory cycles, with the lowest intakes observed during the follicular phase (*P* = 0.03).

Table 4 displays the mean craving scores across the menstrual cycle. There was a significantly higher score for overall appetite, craving for chocolate, craving for sweets, craving for salty flavor, other food cravings, and total craving score during the late luteal phase as compared to all of the other menstrual cycle phases ($P < 0.001$ for all).

Discussion

These data suggest an increased intake of protein, specifically animal protein, as well as an increase in reported food cravings, during the luteal phase of the menstrual cycle independent of ovulatory status. These data support the hypothesis that progesterone may stimulate, and estrogen may suppress appetite during the cycle. Taken together, these findings highlight the need to consider menstrual cycle phase when assessing relationships with protein intake, as well as cravings and appetite, among premenopausal women.

Though we observed no significant changes in total energy intake, fat, or carbohydrates, some other studies have observed fluctuations in certain macronutrients across the menstrual cycle [5, 6, 8, 10, 11]. Specifically, in contrast to our findings, carbohydrate consumption was observed to vary in one small ($n = 23$) study of young women (mean age 20 years), while noting no changes in protein or fat consumption [10]. Still, others report an increased intake in energy, protein, fat, and carbohydrates during the luteal phase but without changes in the proportions of caloric intake from each of these macronutrient groups over the two phases [5]. Though we did not observe similar changes in the macronutrients, our results are not inconsistent with an increase in total energy intake during the mid-luteal phase [2–4, 6, 9, 19], though this measure was not found to be significantly increased in our study. Differences in study design may account for some of these differences; in particular, many previous studies were small and only compared the follicular to mid- to late luteal phases.

We did however observe a significant increase in reported appetite, sweet cravings, chocolate cravings, salty cravings, and other food cravings during the late luteal phase, which is consistent with findings of increased cravings in several other studies [20–23]. However, our observations of increased cravings during the late luteal phase were not paralleled by significant increases in total energy intake. This apparent inconsistency may be due to the timing of the different types of assessments, specifically that food cravings were assessed during the late luteal phase, whereas the 24-h dietary recall for measuring actual intake was conducted during the mid-luteal phase. Thus, this approach perhaps did not capture the true relationship between cravings and total energy as well as specific nutrient and food group intakes. It may be that we would have observed significant increases in total energy intake had we assessed nutrient intake during the *late* luteal phase, which would more closely align with the timing of dietary assessment used in previous studies and with the cravings assessment.

Our findings of increased protein intake during the mid-luteal phase are consistent with previous work [24] among a smaller population ($n = 23$) of young women (20.0 ± 1.9 years) and with previous findings [11] of significantly increased protein intake during the pre-versus postmenstrual phase. However, others [10] did not observe differences in protein intake across the cycle, but this latter study was limited by few women ($n = 8$) of a relatively small age range (ages 18–22). We observed women consuming on average 65 g/day of total protein during the mid-luteal phase compared to 61–62 g/day during the other phases of the cycle. Though the magnitude of this difference is small, if we had been able to assess intake during the late luteal phase it is likely the difference observed would have been larger. Clinical implications of this difference are likely limited; however, it may be important for research in this area as not taking into account menstrual fluctuations may increase variability and reduce power to detect associations between protein intake and health outcomes. Furthermore, in addition to including multiple assessments in 259 women, here we assessed differences in specific protein intake (i.e., animal vs. vegetable), which has not been previously evaluated [11, 24]. Interestingly, the only micronutrient we observed to differ across menstrual cycle phase was zinc being lowest during the periovulatory phase compared to the mid-luteal phase, a finding which agrees with our observed higher animal protein intake in the mid-luteal, as high zinc-containing foods are typically animal sources, such as seafood, beef, and lamb. Although insignificant, we found that iron intake followed a similar pattern as zinc potentially due to the similarity of prominent sources. The lack of significant variation in protein and zinc intake observed across anovulatory cycles may have been due to limited power in the anovulatory group as there were a small number ($n = 42$) of anovulatory cycles. 42 out of 509 cycles were classified as anovulatory (8.3 %).

This study is the largest, to our knowledge, to assess differences in macronutrient, micronutrient, and food group intake in a cohort of reproductive aged women, and to assess differences in ovulatory status. This study expands on previous work by including up to four 24-h recalls per menstrual cycle and repeated across up to two cycles (and all women contributed at least two recalls per cycle). The use of multiple validated 24-h recalls is a significant improvement over previous studies [25–27]. Although we assessed intake across four phases of the cycle, we were limited to a single 24-h recall during each phase for two cycles, and our assessment during the luteal phase was closer to the middle rather than the end of the luteal phase, thus limiting our ability to align these data with our food craving assessments and compare to previous work assessing diet in the latter part of the luteal phase. However, our assessment of food cravings at four time points per cycle, and particularly during the late luteal phase, was novel and provides interesting information regarding appetite during the late luteal phase. We were also limited in that there were a small number of anovulatory cycles under study. As such, we had limited power to detect differences in nutrient intake across phases of the cycle during anovulatory cycles. Due to high day-to-day variability of micronutrients, two 24-h recalls may not be sufficient to truly capture intake and potential differences across cycle phases.

In conclusion, total energy, fat, and carbohydrate intakes did not fluctuate across the menstrual cycle but protein intake, specifically animal protein, was significantly higher during the mid-luteal phase of the menstrual cycle. We also observed significant increases in appetite and food cravings during the late luteal phase. Overall, our findings support the need to account for menstrual cycle phase for longitudinal research regarding protein intake and appetite in premenopausal women in regard to women's reproductive health and fertility.

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Abbreviations

BMI	Body mass index
IPAQ	International Physical Activity Questionnaire
SE	Standard error

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Table 1

Baseline characteristics of BioCycle study participants

Baseline characteristics **Sociodemographics**	***N*=259**
Age, years	27.3 (8.2)
Age, years (*n*, %)	
18–24	133 (52.4)
25–29	42 (16.2)
30–34	19 (7.3)
35–39	32 (12.4)
40–4	33 (12.7)
Race (*n*, %)	
Non-Hispanic white	154 (59.5)
Non-Hispanic black	51 (19.7)
Other	54 (20.9)
Highest level of education (*n*, %)	
High school or less	33 (12.7)
Some college	121 (46.7)
Bachelor's degree or higher	105 (40.5)
Lifestyle	
Cigarette smoking (*n*, %)	
Non-smoker	249 (96)
Current smoker	10(4)
Physical activity	
IPAQ category (*n*, %)	
Low	25 (9.6)
Moderate	92 (35.5)
High	142 (54.8)
Health	
Body mass index (kg/m^2)	24.1 (3.9)
Age at first menstrual period, years	12.5 (1.2)

Table 2

Mean macronutrient, micronutrient, and food group intakes across the menstrual cycle phases (adjusted for total energy intake)

	Menstrual phase *n* = 499 Mean (SE)	Follicular phase *n* = 499 Mean (SE)	Peri-ovulatory phase *n* = 498 Mean (SE)	Mid-luteal phase *n* = 473 Mean (SE)	*P* value
Macronutrient					
Energy (kcal)	1600 (27)	1591 (27)	1591 (27)	1662 (28)	0.20
Fat (g)	63 (0.8)	62 (0.8)	61 (0.8)	62 (0.8)	0.17
Carbohydrates (g)	200 (2.2)	202 (2.2)	205 (2.2)	198 (2.2)	0.26
Protein (g)	62 (0.9)	62 (0.9)	61 (0.9)[a]	65 (0.9)[a]	0.03*
Animal protein (g)	40 (1.0)	40 (1.0)	39 (1.0)	43 (1.0)	0.05*
Vegetable protein (g)	21 (0.4)	22 (0.4)	21 (0.4)	21 (0.4)	0.97
Alcohol (g)	2.3 (0.4)	2.6 (0.4)	3.3 (0.4)	2.6 (0.5)	0.45
Total sugars (g)	85 (1.8)	84 (1.8)	87 (1.8)	83 (1.8)	0.08
Total dietary fiber (g)	13.4 (0.3)	13.7 (0.3)	13.5 (0.3)	13.9 (0.3)	0.69
Soluble DF (g)	3.7 (0.1)	3.7 (0.1)	3.8 (0.1)	3.8 (0.1)	0.73
Insoluble DF (g)	9.5 (0.3)	9.7 (0.3)	9.5 (0.3)	9.9 (0.3)	0.73
%Fat	34.4 (0.4)	33.8 (0.4)	33.4 (0.4)	33.9 (0.4)	0.41
% Carbohydrates	51 (0.5)	51 (0.5)	51 (0.53)	50 (0.5)	0.37
% Protein	15.6 (0.2)	15.6 (0.2)	15.4 (0.2)[a]	16.4 (0.2)[a]	0.02*
Micronutrient					
Vitamin A (RE)	781 (40)	808 (40)	861 (40)	798 (41)	0.54
Vitamin D (μg)	2.96 (0.16)	3.20 (0.16)	2.88 (0.16)	3.34 (0.16)	0.14
Vitamin E (mg)	6.4 (0.2)	6.1 (0.2)	6.0 (0.2)	6.3 (0.2)	0.54
Vitamin C (mg)	70 (2.9)	67 (2.9)	73 (3.0)	70 (3.0)	0.61
Thiamin (mg)	1.37 (0.02)	1.40 (0.02)	1.36 (0.02)	1.38 (0.02)	0.49
Riboflavin (mg)	1.66 (0.03)	1.69 (0.03)	1.69 (0.03)	1.66 (0.03)	0.85
Niacin (mg)	19.2 (0.4)	19.2 (0.4)	19.8 (0.4)	20.1 (0.4)	0.30
Total folate (μg)	362 (9)	376 (9)	372 (9)	370 (9)	0.71
Vitamin B-6 (mg)	1.45 (0.03)	1.46 (0.03)	1.49 (0.03)	1.49 (0.03)	0.78
Vitamin B-12(μg)	4.56 (0.48)	3.99 (0.47)	4.24 (0.48)	3.86 (0.49)	0.75

	Menstrual phase	Follicular phase	Peri-ovulatory phase	Mid-luteal phase	*P* value
	n **= 499**	***n*** **= 499**	***n*** **= 498**	***n*** **= 473**	
	Mean (SE)	**Mean (SE)**	**Mean (SE)**	**Mean (SE)**	
Potassium (mg)	1897 (30)	1931(30)	1901 (30)	1968 (31)	0.33
Iron (mg)	12.3 (0.3)	12.5 (0.3)	12.0 (0.3)	12.6 (0.3)	0.37
Phosphorus (mg)	952 (13)	970 (13)	939 (13)	977 (13)	0.13
Calcium (mg)	704 (17)	697 (17)	716(17)	686 (17)	0.65
Magnesium (mg)	223 (3.7)	225 (3.7)	218 (3.7)	226 (3.8)	0.45
Zinc (mg)	8.2 (0.2)	8.7 (0.2)	8.0 (0.2)	8.8 (0.2)	0.01*
Food group (kcal/serving/day)					
Meat	158 (8)	157 (4.8)	151 (5.0)	151 (6)	0.76
Dairy	82 (3.0)	87 (3.0)	81 (3.1)	83 (3.1)	0.54
Vegetable fat	53 (3.6)	54 (3.6)	51 (3.6)	53 (3.7)	0.96
Eggs	48 (2.5)	44 (2.5)	47 (2.5)	43 (2.5)	0.31
Animal/nut fat	74 (2.3)	78 (2.3)	70 (2.3)	71 (2.3)	0.07
Fruits	30 (2.5)	30 (2.5)	33 (2.5)	30 (2.5)	0.70
Vegetables	138 (3.6)	145 (3.6)	140 (3.6)	137 (3.7)	0.38
Sweet/cake/pie	166 (8)	165 (8)	168 (8)	167(8)	0.99
Candy/syrup/sugar	56 (3.6)	67 (3.6)	59 (3.6)	59 (3.7)	0.16

P represents the overall effect of phase on nutrient intake

[a] Significant pairwise comparisons ($P < 0.05$) are indicated by similar superscripts, with Holm–Bonferroni correction for multiple comparisons

Table 3

Mean macronutrient, micronutrient, and food group intake by ovulatory status throughout the four menstrual cycle phases (adjusted for total energy intake)

Daily intake	Anovulatory (n = 42)					Ovulatory (n = 467)				
	Menstrual phase	Follicular phase	Peri-ovulatory phase	Mid-lute al phase	*P* value day	Menstrual phase	Follicular phase	Peri-ovulatory phase	Mid-luteal phase	*P* value day
	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)		Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)	
Macronutrients										
Energy (kcal)	1641 (100)	1500 (95)	1543 (100)	1749(117)	0.36	1596 (28)	1599 (28)	1594(28)	1656 (29)	0.35
Fat(g)	60 (5.1)	61 (2.6)	60 (2.7)	68 (3.2)	0.21	63 (1.6)	62 (1.6)	60 (1.6)	64 (1.6)	0.30
Carbohydrates (g)	216 (8.1)	205 (7.7)	209 (8.1)	189 (9.5)	0.19	199 (2.2)	202 (2.2)	204 (2.2)	199 (2.3)	0.30
Protein (g)	56 (3.1)	62 (2.9)	60 (3.1)	63 (3.6)	0.51	62 (0.9)	62 (0.9)	61 (0.9)[a]	65 (1.0)[a]	0.04
Animal protein (g)	31 (3.9)	37 (3.7)	36 (3.9)	39 (4.5)	0.49	41 (1.0)	40 (1.0)	40 (1.0)	43 (1.0)	0.08
Vegetable protein (g)	26 (2.0)	25 (1.9)	24 (2.0)	23 (2.3)	0.88	21 (0.4)	21 (0.4)	21 (0.4)	21 (0.4)	0.94
Alcohol (g)	0.1 (0.7)	1.6 (0.6)	1.3 (0.7)	0.4 (0.8)	0.36	2.5 (0.5)	2.7 (0.5)	3.4 (0.5)	2.8 (0.5)	0.52
Total sugars (g)	85 (5.6)	78 (5.3)	84 (5.6)	70 (6.5)	0.26	84 (1.9)	85 (1.9)	87 (1.9)	81 (1.9)	0.15
Total dietary fiber (g)	17.9 (1.7)	16.3 (1.6)	17.4 (1.7)	19.6 (2.0)	0.86	13.0 (0.3)	13.5 (0.3)	13.2 (0.3)	13.8 (0.4)	0.36
Soluble fiber (g)	4.7 (0.4)	4.1 (0.4)	4.6 (0.4)	4.7 (0.4)	0.56	3.6 (0.1)	3.7 (0.1)	3.7 (0.1)	3.8 (0.1)	0.62
Insoluble fiber (g)	13.0 (1.4)	12.0 (1.3)	12.6 (1.4)	11.2 (1.6)	0.82	9.2 (0.3)	9.5 (0.3)	9.3 (0.3)	9.8 (0.3)	0.18
% Fat	33.2 (1.5)	33.7 (1.4)	33.5 (1.5)	37.7 (1.7)	0.19	34.5 (0.4)	33.7 (0.4)	33.3 (0.4)	33.7 (0.5)	0.34
% Carbohydrates	54.7 (1.9)	51.9 (1.8)	52.2 (1.9)	48.4 (2.2)	0.20	50.4 (0.6)	51.1 (0.6)	51.4 (0.6)	50.3 (0.6)	0.42
% Protein	14.3 (0.8)	15.7 (0.8)	15.8 (0.8)	15.7 (1.0)	0.56	15.7 (0.2)	15.6 (0.2)	15.4 (0.2)[a]	16.4 (0.3)[a]	0.02
Micronutrients										
Vitamin A (mg)	818(162)	891 (155)	1125(162)	1098(190)	0.48	778 (42)	801 (42)	840 (42)	778 (42)	0.70
Vitamin D (μg)	2.33 (0.4)	2.59 (0.3)	2.68 (0.4)	2.77 (0.4)	0.85	3.06 (0.2)	3.19 (0.2)	2.91 (0.2)	3.43 (0.2)	0.16
Vitamin E (mg)	6.9 (0.7)	6.6 (0.7)	6.8 (0.7)	7.1 (0.8)	0.98	6.4 (0.2)	6.0 (0.2)	5.9 (0.2)	6.2 (0.2)	0.52
Vitamin C (mg)	61.9(11)	74.1(10)	72.8(11)	86(13)	0.56	70.7 (3.1)	66.8 (3.1)	73.0 (3.1)	69.4 (3.1)	0.54
Thiamin (mg)	1.46 (0.08)	1.34 (0.08)	1.27 (0.08)	1.42 (0.07)	0.38	1.37 (0.02)	1.41 (0.02)	1.37 (0.02)	1.37 (0.02)	0.45
Riboflavin (mg)	1.49 (0.09)	1.51 (0.09)	1.60 (0.09)	1.68 (0.10)	0.53	1.68 (0.03)	1.70 (0.03)	1.70 (0.03)	1.66 (0.03)	0.79
Niacin (mg)	18.0 (1.3)	18.6 (1.2)	18.8 (1.3)	18.7 (1.5)	0.97	19.3 (0.4)	19.3 (0.4)	19.8 (0.4)	20.2 (0.4)	0.32
Total folate (μg)	363 (33)	373(31)	373 (33)	393 (38)	0.95	362 (8.9)	376 (8.9)	372 (8.9)	369 (9.0)	0.72
Vitamin B-6 (mg)	1.40 (0.10)	1.48 (0.10)	1.39 (0.10)	1.57 (0.12)	0.67	1.46 (0.04)	1.46 (0.04)	1.50 (0.04)	1.49 (0.04)	0.80
Vitamin B-12(μg)	2.78 (0.6)	3.45 (0.6)	3.35 (0.6)	3.37 (0.7)	0.86	4.72 (0.5)	4.02 (0.5)	4.31 (0.5)	3.91 (0.5)	0.69

Daily intake	Anovulatory ($n = 42$)					Ovulatory ($n = 467$)				
	Menstrual phase	Follicular phase	Peri-ovulatory phase	Mid-lute al phase	*P* value day	Menstrual phase	Follicular phase	Peri-ovulatory phase	Mid-luteal phase	*P* value day
	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)		Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)	
Potassium (mg)	1892(107)	2058(102)	1997 (107)	2123 (126)	0.53	1896 (32)	1921 (32)	1894 (32)	1958 (32)	0.46
Iron (mg)	11.9 (0.9)	12.2 (0.8)	11.6 (0.9)	12.6 (1.0)	0.90	12.3 (0.3)	12.5 (0.3)	12.0 (0.3)	12.6 (0.3)	0.44
Phosphorus (mg)	967 (42)	975 (40)	974 (42)	1023 (49)	0.83	950(13)	970 (13)	935 (13)	973 (13)	0.15
Calcium (mg)	672 (50)	619 (48)	689 (50)	719 (59)	0.59	706(18)	704 (18)	719(18)	685 (18)	0.60
Magnesium (mg)	254(17)	246 (16)	250 (17)	258 (19)	0.97	220 (4)	224 (4)	216 (4)	224 (4)	0.38
Zinc (mg)	8.6 (0.6)	7.9 (0.6)	7.1 (0.6)	9.6 (0.7)	0.07	8.2 (0.2)	8.8 (0.2)	8.0 (0.2)[a]	8.7 (0.2)[a]	0.03
Food group intake										
Meat	208 (25)	142 (27)	173 (23)	181(29)	0.36	156 (6)	155 (6)	149 (5)	150 (6)	0.76
Dairy	79(13)	82(12)	101 (12)	120(15)	0.15	82(3)	89(3)	79(3)	80(3)	0.10
Vegetable fat	53 (10)	49(10)	51(10)	77(12)	0.27	54(4)	55(4)	50(4)	51(4)	0.83
Eggs	72(11)	32 (11)[a]	75(11)[a]	61 (13)	0.03	46(3)	45(3)	45(3)	42(3)	0.61
Animal/nut fat	74(9)	84(8)	70(9)	74 (10)	0.71	74(2)	77(2)	71(2)	71(2)	0.21
Fruits	31(7)	29(7)	38(7)	23’ (8)	0.61	29(3)	30(3)	33(3)	31(3)	0.61
Vegetables	167(17)	141 (17)	152(17)	153 (20)	0.76	137 (4)	145 (4)	137 (4)	137 (4)	0.25
Sweet/cake/pie	120(19)	142 (18)	120 (20)	120 (23)	0.80	170 (8)	166(8)	172 (8)	170(8)	0.96
Candy/syrup/sugar	42(9)	67(8)	48(9)	50(10)	0.20	60(4)	67(4)	60(4)	58(4)	0.40

Anovulatory cycles were defined as cycles where the peak progesterone concentration across the cycle was ≤5 ng/mL, and there was no serum LH peak on the later cycle visits

[a]Significant pairwise comparisons ($P < 0.05$) are indicated by similar superscripts, with Holm–Bonferroni correction for multiple comparisons

Table 4

Mean craving scores across the four phases of the menstrual cycle

	Menstrual phase	Follicular phase	Peri-ovulatory phase	Late luteal phase	*P* value
Change in appetite	1.48 (0.03)	1.30 (0.03)	1.43 (0.03)	1.76 (0.03)	<0.001*
Craving for chocolate	1.58 (0.03)	1.38 (0.03)	1.45 (0.03)	1.81 (0.03)	<0.001*
Craving for sweets in general	1.60 (0.03)	1.40 (0.03)	1.46 (0.03)	1.81 (0.03)	<0.001*
Craving for salty flavor	1.38 (0.03)	1.30 (0.03)	1.35 (0.03)	1.57 (0.03)	<0.001*
Other food cravings	1.26 (0.03)	1.21 (0.03)	1.25 (0.03)	1.39 (0.03)	<0.001*
Total symptom score	7.27 (0.12)	6.58 (0.12)	6.95 (0.12)	8.31 (0.12)	<0.001*