Possible factors for altered energy balance across the menstrual cycle: a closer look at the severity of PMS, reward driven behaviors and leptin variations

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Abstract:

This paper reviews the literature on the variations in energy intake (EI), energy expenditure (EE) and the factors which may affect the fluctuations in EI across the menstrual cycle. While no significant changes in body weight and body fat percentage have been noted across the cycle, increases in EI and EE have been well documented during the luteal phase in lean women. The occurrence and severity of the premenstrual syndrome (PMS) and food reinforcement are suggested to affect EI. It is not known, however, whether food reinforcement may affect EI across the menstrual cycle. These factors may also affect overweight/obese women differently than normal-weight women at times during which women may be more prone to episodes of overeating during the menstrual cycle. Certain studies have also noted fluctuations in leptin levels across the menstrual cycle, while others have not. It has also been suggested that variations in leptin levels may affect the rewarding value of food in order to maintain proper body weight and adiposity level. We emphasize that future studies should evaluate the variations in energy balance across the cycle in overweight/obese women, as well as the strength of the relationships between food reinforcement and the severity of PMS with energy and macronutrient intakes.

Article:

1. Introduction

Variations in energy balance are explained by changes in energy intake (EI) and energy expenditure (EE), which can possibly lead to changes in energy stores and body weight over time [1]. More closely related to the objective of this review, the presence of a cyclic hormonal variation pattern in women is not only be responsible for the regulation and occurrence of ovulation and menstrual bleeding, but may also influence eating behavior and EE [2]. Additionally, certain factors related to the menstrual cycle may also in part explain the possible

variations in EI and EE which may occur across the cycle. Among those are the occurrence and severity of the premenstrual syndrome (PMS) and possible changes in food reinforcement which may in part explain the possible variations in total EI and snack intake across the cycle.

Most of the studies evaluating energy balance variations during the menstrual cycle have focused on women with a body mass index (BMI) within the normal, recommended range (18.5–24.9 kg/m^2). To our knowledge, no study has evaluated the variations in EI, macronutrient intakes and EE across the menstrual cycle in overweight and obese women. And so, the possible variations in energy balance, the occurrence and severity of PMS and food reinforcement across the cycle may differ between overweight/obese and lean women.

This paper reviews the literature on the variations in EI, macronutrient intake and EE across the menstrual cycle. In addition, the severity of PMS, as well as possible variations in reward driven behaviors and leptin across the cycle will be addressed, particularly as it relates to differences in body adiposity.

2. Variations in energy and macronutrient intake across the menstrual cycle

Certain studies have demonstrated that estradiol seems to have a direct impact on food intake in animals and humans, by inhibiting it. More specifically, Asarian and Geary [3] demonstrated that the ovariectomy of adult rats lead to a significant increase in food intake, meal size and body weight over time, while treating ovariectomized rats with estradiol injections reversed these effects and led to decreases in food intake and body weight. Additionally, estrogen replacement therapy has been shown to diminish the increases in body weight and adiposity gains seen in women during the menopausal transition [4].

In regard to menstrual cycle phases in women, it has been previously observed that energy intake (EI) decreases during the late follicular and ovulation phases of the menstrual cycle, which are characterized by higher levels of estradiol, while EI tends to increase during the luteal phase, at which time plasma levels of both estradiol and progesterone are elevated [5], [6], [7], [8], [9], [10], [11], [12], [13], [14]. A fairly large variation can be observed when comparing the caloric intake values reported by the different studies (Table 1) which evaluated the variations in EI across the menstrual cycle; with increases in total EI ranging from ≈87 to 500 kcal during the luteal phase in comparison to the follicular phase. Even though variations in EI have been previously observed in lean women by many studies (Table 1), however, no significant changes in body weight or body fat percentage across the cycle has been noted in this specific population [5], [6], [15].

Certain studies have also noted changes in macronutrient intake across the cycle. These variations are shown in Table 2. Most of these studies noted similar results; increases in relative carbohydrate and fat intakes prior to menses, while relative protein intake decreases during this time. It is thus not surprising that these alterations in macronutrient intake are most likely directly related to changes in total EI, given the high energy density of fat and simple sugars.

Table 1. Variations in energy intake across the menstrual cycle in lean women.

Study	Days measured	Food assessment method	N	Energy intake (kcal)				
				M	F	O	L	Δ between F and L
Li et al. [5]	Days 6–10 after onset of menses and days 6–10 after ovulation	Self-monitored food records	20	–	1456	–	1667	211
Johnson et al. [6]	One complete menstrual cycle	Self-monitored food records	26	1815	–	1709.52	1873	164
Dalvit [11]	Two complete menstrual cycles	Self-monitored food records	8	–	1440	–	1940	500
Lissner et al. [13]	Days 1–10 and 19–28	Ad libitum selection and weighed food	23	–	2248	–	2335	87
Lyons et al. [7]	35 days	Self-monitored food records	18	2155	2012	1874	2198	186
Dalvit-McPhillips [10]	10 days pre- and 10 days post-ovulation	Dietary recall	8	–	1247	–	1725	478
Gong et al. [12]	One complete menstrual cycle	Self-monitored food records	7	1885	1832	1765.07	2040	208
Manocha et al. [14]	10 days pre- and 10 days post-ovulation over 2 complete menstrual cycles	Self-monitored food records	11	–	1299	–	1610	311
Martini et al. [9]	3 days pre- and 3 days post-ovulation	Self-monitored food records	18	–	1748	–	1906	158
Tarasuk and Beaton [8]	10 days pre- and 10 days post-ovulation	Ad libitum selection and weighed food	14	–	1820	–	1911	91

Note: N, number of participants; M, menses; F, follicular phase; O, ovulation; L, luteal phase; Δ, difference; kcal, kilocalorie.

Table 2. Variations in macronutrient intake across the menstrual cycle in lean women.

Study	Macronutrient intake (% energy intake)											
	Carbohydrate				Fat				Protein			
	M	F	O	L	M	F	O	L	M	F	O	L
Li et al. [5]	–	51	–	52	–	29	–	31	–	19	–	18
Johnson et al. [6]	47.9	–	47.5	47.9	35.8	–	35.4	37.4	15.1	–	15.4	14.7
Lyons et al. [7]	47	48	48	47	36	35	36	36	13	14	14	14
Dalvit-McPhillips [10]	–	39.9	–	55.8	–	44.4	–	32.6	–	15.7	–	11.6
Martini et al. [9]	–	51.3	–	50.1	–	33.1	–	34.2	–	15.6	–	15.6
Tarasuk and Beaton [8]	–	43.8	–	43	–	36	–	37.6	–	14.6	–	14.1

Note: M, menses; F, follicular phase; O, ovulation; L, luteal phase.

3. Possible factors for altered energy intake across the menstrual cycle

3.1. The occurrence and severity of the premenstrual syndrome (PMS)

A number of women are affected by the occurrence and severity of PMS in the late luteal phase. Approximately 50% of women suffer from a minimal level of distress related to PMS, from which 30.6%, 13.6% and 8.1% of women reported low, moderate and severe levels of distress, respectively [16]. Some studies have noted that women who reported more severe PMS symptoms consumed on average more calories, and presented more frequent episodes of overeating and cravings for sweet-fatty foods during the late luteal phase [17], [18], [19]. More specifically, one study [20] observed that increased carbohydrate intake was related to negative mood and decreased physical activity during the late luteal phase in normal-weight women. Additionally, Wurtman et al. [21] noted that the consumption of a high-carbohydrate, low-

protein meal during the late luteal phase alleviated depression, anger, tension, confusion, sadness, fatigue, and improved alertness and calmness in women who reported suffering from PMS. The same symptoms were not changed after the consumption of this meal during the follicular phase, as well as in either phase in women who did not report suffering from PMS. More specifically, in a double-blind crossover study, Sayegh et al. [22] noted that the consumption of a beverage containing a mixture of simple and complex sugars decreased self-reported depression, anger, confusion, and appetite between 90 and 180 minutes following intake in women who reported suffering from PMS during the luteal phase. Moreover, the isocaloric placebo drinks consumed on separate occasions (one containing a mixture of protein and simple sugar and the other containing only simple sugar) had no significant effect on any of these variables in the same women. These results thus suggest that certain psychological and appetitive symptoms related to PMS may be alleviated following the consumption of a food/beverage item containing both complex and simple sugars, regardless of caloric content. Despite these results, Bryant et al. [23] found no significant differences in total EI between the follicular and luteal phases in women who reported suffering from PMS, when compared to women who reported not suffering from PMS. In addition, even though not significant, the women who reported suffering from PMS consumed more calories during the follicular phase, even though PMS symptoms were not necessarily reported being higher at this time. These results thus suggest that the occurrence and severity of PMS may not systematically lead to increased total EI.

As for the occurrence and severity of PMS in overweight and obese women, certain studies [17], [24] have noted an increase in the prevalence of PMS in relation to increasing BMI, identifying overweight and obese women as being nearly 2–3 times more likely to suffer from PMS symptoms when compared to normal-weight women. More specifically, one study [25] observed that overweight women who suffered from PMS had significantly higher EI for each macronutrient during the luteal phase, compared to the follicular phase, while overweight women without PMS only showed significant differences in fat intake between the luteal and follicular phases. After adjusting for total EI, the women who suffered from PMS showed significant increases in fat, carbohydrate and simple sugar intake, while the women without PMS showed no significant differences in macronutrient intakes between the luteal and follicular phases.

In summary, the occurrence and severity of PMS may lead to an increased consumption of sweet-fatty foods in some lean and overweight women who reported suffering from PMS during the luteal phase of the menstrual cycle. Moreover, the consumption of high-carbohydrate meals has been shown to alleviate certain negative and emotional symptoms related to PMS, which may in part explain the increase in simple sugar intake in some PMS sufferers. However, the consumption of a beverage containing a mixture of complex and simple carbohydrates not only improved certain psychological PMS symptoms, but also decreased appetite for up to 3 h following ingestion. These results thus suggest that the occurrence and severity of PMS may in part explain the increases in total energy, simple sugar and fat intakes during the luteal phase in certain women. Furthermore, the consumption of a food or beverage item containing a mixture of complex and simple carbohydrates during the luteal phase in PMS sufferers is recommended to alleviate psychological PMS symptoms and induce an adequate level of satiety following the ingestion of this item. This may help in reducing total EI in women who may be more prone to increasing their consumption of sweet-fatty foods during the luteal phase.

3.2. Reward driven behaviors and the relative-reinforcing value of food

Generally speaking, reward driven behaviors are goal oriented choices made by the higher cortical association areas of the brain, and are based on our past experiences and positive associations that we make with, for instance, specific types of foods [26], [27]. And so, if eating a specific type of food provides a good, pleasurable experience, then the behavior related to consuming this food will be reinforced and later repeated [27]. These chosen eating behaviors are often influenced by different cognitive, hedonic and environmental factors, which may greatly influence our choices in food consumption [27].

Through the use of functional MRI scans, certain studies have investigated the activation of the corticolimbic structures, or reward centers of the brain, to visual cues of different rewards, such as food [28], [29] and money [30] across the different phases of the menstrual cycle. More specifically, Dreher et al. [30] noted an augmented reactivity of the reward centers of the brain during the mid-follicular phase, in comparison to the mid-luteal phase, when the participants anticipated and received a monetary reward. As for food cues, a more elicit response to both high and low calorie visual food cues in most of the reward centers of the brain during the late follicular and ovulation phases, in comparison to the luteal phase, was observed [28], [29]. Additionally, Frank et al. [29] noted that participants rated high fat foods as being more appealing during menses and the luteal phase (weeks 1, 3 and 4), in comparison to the late follicular phase (week 2), even though no significant difference in total EI was seen between the follicular and luteal phases with food journals. Along those lines, Tucci et al. [31] observed an increase in sweet food intake during the luteal phase, in comparison to the follicular phase. However, they did not observe a relationship between the hedonic ratings (liking) of these sweet foods and actual EI in both phases. And so, based on these results, it would seem that preference and hedonic ratings for food may not necessarily coincide with actual food intake when assessed across the menstrual cycle, or vice versa. As for food reinforcement, this specific aspect of appetitive motivation can be generally portrayed as the amount of work and effort one individual is willing to do in order to obtain a certain type of food [32]. To our knowledge, no study to date has evaluated the changes in the reinforcing value of food in lean and overweight/obese women during the different phases of the menstrual cycle. Future studies would also be needed to relate the variations in reward center activation in the brain across the cycle to actual food intake.

Lastly, there seems to be a relationship between the occurrence of PMS and reward driven behaviors. Freeman et al. [33] used the Tridimensional Personality Questionnaire (TPQ), which measures harm avoidance, novelty seeking and reward dependence, in women who suffer from moderate to severe levels of PMS. They observed a slight, but not significant, increase in reward dependence scores in these women. They also noted a significant increase in harm avoidance and novelty seeking scores in women with PMS, with high novelty seeking personality traits correlating with premenstrual food cravings, headaches, mood swings and anxiety [33]. These results thus suggest that PMS sufferers with high novelty seeking personality traits may be more prone to food cravings and, possibly, increased simple sugar and fat intakes.

3.3. Variations in leptin levels

Leptin, a hormone which is secreted by adipocytes and circulates in the plasma at concentrations relative to fat mass [34], may indeed act as a mediator between the levels of adiposity and the onset of a new menstrual cycle every month [35]. Higher levels of leptin have been observed in women of reproductive age, in comparison to men and postmenopausal women after adjusting for body fat content [36]. Moreover, a sufficient amount of fasting leptin concentration, which is based on energy availability, is required for the onset of puberty and the maintenance of proper reproductive functions in women [35]. More specifically, one study [37] indicated that a critical serum leptin level of 1.2 ng/ml and 1.85 ng/ml is required to initiate the release of FSH and LH, respectively. This suggests that serum leptin levels lower than these may lead to the occurrence of primary or secondary amenorrhea. Certain studies have also noted increases in leptin values of ≈35–60% during the early to mid-luteal phase in comparison to the early follicular phase (Table 3). Other studies [38], [39], [40], however, noted no significant variations in leptin levels across the cycle. The discrepancy between these studies may be in part related to the frequency at which measurements of leptin were taken. The studies which measured leptin levels on four or more occasions across the menstrual cycle reported significant variations of this hormone [15], [41], [42], [43]. Some of these studies [15], [41], [43] even measured leptin from blood samples taken every 2–3 days for one entire menstrual cycle. On the other hand, other studies [30], [31], [32], [33], [34], [35], [36], [37], [38], [39], [40] which noted no significant variation in leptin only assayed blood samples for leptin on three occasions across the cycle, suggesting that frequent (i.e., four or more) measurements of leptin at times when leptin levels have been suggested to change [15], [41], [42], [43] may be needed to observe significant variations in this hormone across the menstrual cycle.

A relationship between reward driven behavior and leptin has also been observed; leptin has been coined as a long-term feeding signal related to adiposity level and, consequently, regulates EI through its interactions with certain neurons of the central nervous system [27], [44]. It is also predicted that under-nutrition and over-nutrition would respectively increase and decrease the rewarding value of food, in order to maintain proper body weight and adiposity level [45]. However, even though relative increases in leptin have an anorexigenic effect on EI, leptin signaling is not able to prevent overconsumption of food short-term because the difference in EI from one meal to the next is usually very small when taking whole body energy reserves into consideration [46].

In summary, the rewarding aspects of foods do take on a great importance in the regulation of EI. Future studies are needed to evaluate the existence of a possible relationship between leptin and food reward and/or food reinforcement, and its possible effects on energy and macronutrient intakes when assessed across the menstrual cycle. Mechanistic studies would also be needed to determine the exact underlying reasons behind the variations in leptin levels during the menstrual cycle.

Table 3. Variations in leptin levels across the menstrual cycle.

Study	Days measured	Assessment of leptin levels	N	Leptin levels (ng/ml)			
				M levels or day 3	F levels; % variation compared to M	Post-O levels; % variation compared to M	Mid-L levels; % variation compared to M or F
Mannucci and Ognibene [43]	Days 3, 10, 17 and 24	Fasting blood sample	18	11.2	13.8; ↑ 23%	14.67; ↑31%	15.12; ↑35% (M)
Riad-Gabriel et al. [15]	Every other day from days 1–9 and days 17–28; Every day from days 10–16.	Fasting blood sample	9	14.9	–	–	20.4; ↑51%
Hardie et al. [41]	Day 2, and every 3rd day afterwards; Every day from days 11–17.	Blood sample	6	22.9	27.5; ↑20%	–	36.7; ↑ 60% (M)
Al-Harithy et al. (2006) [53]	Days 3, 10, 17 and 24	Fasting blood sample	33 Obese:	10.6	7.7; ↓38.3	9.60; ↓25.5	12.67; ↑19.75 (M)
			32 Lean:	6.70	8.0; ↑20.5	7.77; ↑15.97	10.01; ↑49.40 (M)
Thong et al. [42]	One pre- and one post-ovulation	Fasting blood sample	8 Elite athlete:	–	3.0	–	4.38; ↑46% (F)
			13 Recreationally active:	–	6.0	–	8.4; ↑40% (F)
Mills et al. [38]	One pre- and one post-ovulation	Blood sample	30	–	15.4	–	17.1; ↑10% (F)
Capobianco et al. [39]	One menses, one pre-ovulatory and one luteal	Blood sample	18	10	13; ↑23% (M)	–	11; ↑9% (M)
Teirmaa et al. [40]	One menses, one ovulatory and one luteal	Fasting blood sample	8	10.2	10.7; ↑5% (M)	–	11.8; ↑14% (M)

Note: N, number of participants; M, menses; F, follicular phase; Post-O, post-ovulation; Mid-L, mid-luteal phase; ng, nanogram; ml, milliliter.

4. Variations in energy expenditure across the menstrual cycle

The possible variations in basal metabolic rate (BMR), 24-h EE and physical activity energy expenditure (PAEE) across the menstrual cycle have been previously addressed. Mean increases in BMR [47] and 24-h EE [48] (15% and 11.5%, respectively) following ovulation have been previously noted. However, not all participants demonstrated an increase in BMR and 24-h EE following ovulation [47], [48]. Hence, factors which may or may not be related to the reproductive system may contribute to this between-subject variation observed in EE. As for PAEE, no variations in regard to this aspect of EE have been noted between the different phases of the menstrual cycle [6]. It should be noted, however, that PAEE was assessed with self-reported physical activity records in this study which underscore the need to obtain more objective measures of PAEE under free-living conditions across the cycle to confirm these results.

5. Energy balance in overweight and obese women and the menstrual cycle

Granted the documented variations in EI and EE across the menstrual cycle and the previously discussed secondary factors which may alter EI, it is important for the purpose of this review to consider these variations in relation to body adiposity. In previous studies, no significant changes in body weight or body fat percentage across the cycle have been noted in women with a BMI within the normal, recommended range [5], [6], [15]. Not much is known, however, regarding the effects of menstrual cycle phase on energy balance in overweight and obese women. Cross et al. [25] demonstrated that overweight women who reported suffering from PMS showed increases in fat, carbohydrate and simple sugar intakes during the luteal phase, in comparison to women without PMS. However, the degree to which the severity of PMS symptoms affect total energy and macronutrient intakes in overweight/obese women differs from that previously noted in normal-weight women is not known. As for food reinforcement, it has been previously observed that obese individuals were willing to work harder in order to obtain a snack food versus receiving a low-fat food [49] or engaging in a sedentary activity [50]. Obese women also consumed more calories when given the snack food than did the non-obese women [50]. It is not known, however, whether food reinforcement may vary in relation to menstrual cycle phase and if differences in food reinforcement may occur between lean and overweight/obese women at times during which women may be more prone to episodes of overeating during the cycle. If more severe PMS symptoms and greater food reinforcement occur during the luteal phase, it may be hypothesized that these factors may coincide with more frequent episodes of overeating and, ultimately, greater total EI during this phase of the menstrual cycle. The investigation of these underlying factors across the menstrual cycle may indeed provide a new insight into how these behavioral factors may affect different aspects of EI in women.

6. Conclusion

In many instances, EI and EE appear to be higher during the luteal phase in comparison to the follicular phase. Additionally, women who suffer from PMS may be more prone to food cravings, as well as increased sweet-fatty food and total energy intakes, which may ultimately lead to potential weight gain over time. Thus, nutritional treatments, such as the consumption of a complex and simple carbohydrate beverage or food item, which may alleviate PMS symptoms,

while maintaining an adequate level of satiety, are recommended. To our knowledge, no study to date has evaluated the variations in EI and EE across the cycle in overweight and obese women. It has been previously suggested, although only a mere hypothesis at this time, that women who are more prone to weight gain may be more vulnerable to frequent episodes of overeating during the luteal phase, which may possibly lead to a cyclic weight gain over time [51]. This emphasizes that it is important to take possible cyclic weight gain, whether through alterations in EI and/or EE, into consideration, especially since ovulatory dysfunctions and amenorrhea are more common in women who have rapidly increased body weight [52].

Conflict of interest

None disclosed.

Acknowledgement

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