

Impact of Estrogen in Menstrual Cycle on Food Intake, Appetite, Energy Expenditure

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Abstract. Women have more difficulty with weight management compared to men, primarily because of sex variations in appetite and energy expenditure (EE) control caused by estrogen. In women, estrogen changes with the menstrual cycle and affects food intake (FI), appetite and EE. Research shows that in the luteal phase (LP), women's FI and appetite are significantly higher, while in the follicular phase (FP), FI and appetite are lower, and FI is the lowest in the FP. EE also increases significantly during the LP. In addition, polycystic ovary syndrome (PCOS) patients have higher FI and appetite due to higher androgens, making them more likely to be overweight and obese. The current study suggests that controlling estrogen levels through birth control pills does not have a significant impact on weight control. However, a diet plan based on appetite fluctuations during the menstrual cycle can be used to achieve better weight loss. This research can tailor more effective weight loss programs and targeted health recommendations for women by understanding a deep knowledge of the impacts of estrogen in women on the food consumption and appetite. Future research could continue to explore estrogen changes in the menstrual cycle, in combination with other human hormones, provide valuable insights into weight intervention measures and drug development to tailor more effective weight management strategies for women.

Keywords: Menstrual cycle, estrogen, appetite, food intake.

1. Introduction

For women who have experienced menarche (the first menstrual period), estrogen causes a woman's body to change differently each cycle because of the menstrual cycle. Estrogen is a type of sex hormone that functions in reproductive systems of both the male and female. For women, the development of their sexual characteristics is influenced by estrogen, which is a steroid hormone related to the female reproductive organs. [1]. Estrone, estradiol, and estriol are common references for estrogen [1]. For healthy premenopausal women, estradiol is the main estrogen [2]. The average duration of menstrual cycle is 28 days, and is divided into FP, ovulatory and LP [3]. The FP is the initial phase in the menstrual cycle, lasting approximately 14 days and ending with the beginning of ovulation [4]. The next 14 days are the LP [4]. Menstruation, during which changes occur in the lining of the uterus, is typically considered to take place on days 0-5 of a menstrual cycle [4].

Studies have shown that women's energy intake level (eating and energy expenditure), are affected by estrogen, and estrogen has a dominant impact on both cause and effect of obesity in women [5]. Due to the different estrogen levels in each menstrual cycle are different, women's dietary and EE will also change accordingly [6]. Moreover, FI and food preferences are also related to changes in estrogen ratios that take place within the menstrual cycle [6]. In the available research, the lack of estrogen promotes metabolic dysfunction, which can result in conditions such as obesity, metabolic syndrome, and type II diabetes [2]. Therefore, the effectiveness of preventing and treating obesity by interfering with estrogen levels varies significantly during each menstrual cycle.

In addition, PCOS, which the most common endocrine and metabolic disease in premenopausal women, with 18% of women suffering from this disease [7]. The characteristic of PCOS is hyperandrogenism, which affects the appetite of this patient group, causing 60% of polycystic ovary syndrome sufferers to experience binge eating behavior thus leading to weight gain [7]. Furthermore, compared to women without the disease, those with polycystic ovary syndrome have greater insulin resistance, which lead to a greater risk of developing type II diabetes, as well as experiencing overweight and obesity [7].

In this paper, a review of existing literature was undertaken to investigate the variations in estrogen levels observed in the average woman during the follicular and luteal phases of the menstrual cycle. The impact of estrogen fluctuations on appetite, FI, and energy metabolism was analyzed. Furthermore, the distinct alterations in appetite, FI, and energy metabolism observed in individuals with PCOS also be presented in this research. In the context of this study, the investigation focuses on assessing the potential influence of hormonal modulators, such as contraceptives, on weight management through drug administration in both FP and LP. Additionally, the exploration develops an effective weight loss strategy by considering appetite variations across each cycle.

2. The Effects of Estrogen on Women

2.1. Effect on FI

As shown in figure 1, the FP is categorized into the early FP and late FP. During the early FP, estrogen levels start off relatively low, but they increase significantly in the late FP, particularly estradiol, experiencing an exponential increase. This surge in estrogen marks the onset of ovulation, where an ovum is released. Subsequently, estrogen levels peak, coinciding with the initiation of an increase in progesterone levels [3]. The LP is the next phase of the menstrual cycle, it is characterized by the dominance of progesterone [3]. During most of the LP, elevated levels of circulating estradiol, progesterone, and inhibin lead to a decrease in luteinizing hormone (LH) levels [3]. In the absence of pregnancy, estradiol and progesterone levels decline in the later phase, and the corpus luteum degenerates, forming the corpus albicans [1].

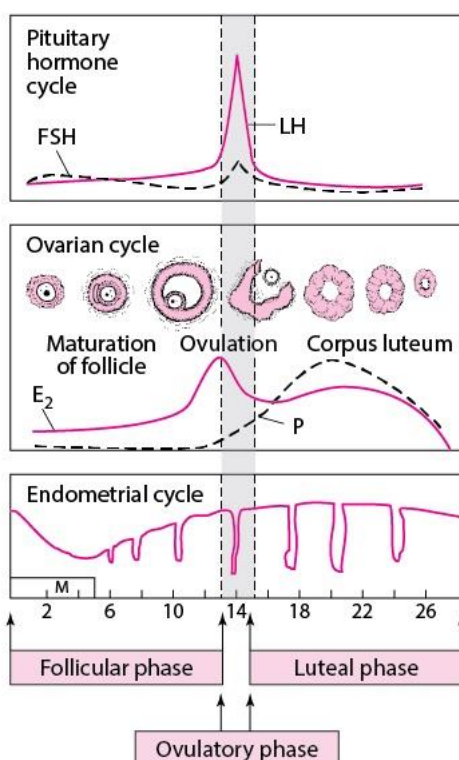


Fig. 1 Fluctuations in pituitary gonadotropin, estradiol (E2), progesterone (P), and endometrial changes follow an idealized pattern during the normal menstrual cycle [1].

In women with healthy body weight and regular menstruation, their daily FI has been observed to gradually decrease from the early follicular, mid-follicular and ovulatory phases, with the lowest FI during the ovulation phase throughout the menstrual cycle (Fig.2) [5]. During the LP, FI is highest throughout the menstrual cycle, and differs from the lowest value during ovulation by 200-300 kcal/day (Fig.2) [5].

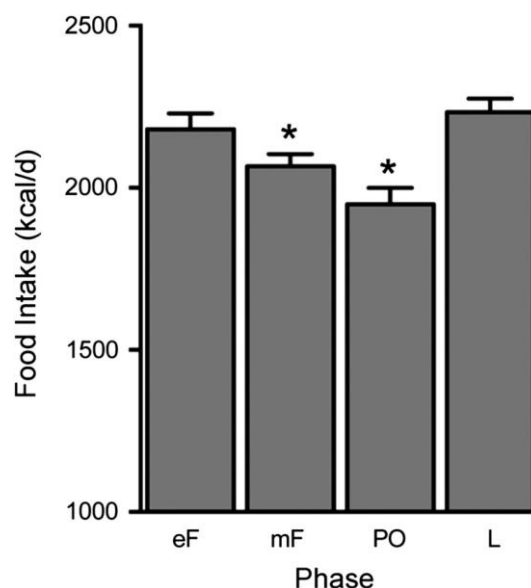


Fig. 2 Daily FI during menstrual cycle. Data in this investigation are divided into the early-follicular (eF), mid-follicular (mF), peri-ovulatory (PO) and luteal (L) phases [5].

From the three major macronutrients-carbohydrate, protein, and fat intake, during the premenstrual period, women's carbohydrate intake gradually increases and peaks around the second day of premenstrual period, then the intake values start to decline and are at lower levels in the postmenstrual period. In contrast, protein and fat intake values are at lower levels during the premenstrual period but began to rise during the mid-menstrual period. As well as observed in other study, there is no significant evidence to suggest consistent variations in fat or protein levels through different periods. [8]. It should be noted that the ten days before menstruation are after ovulation, which is the LP of the menstrual cycle, while the ten days after menstruation are before ovulation, which are the FP of the menstrual period. Judging from the results of carbohydrates, the changes in FI are basically consistent with the changes in FI in Figure 2: the FI is the highest in the LP, and the FI gradually decreases in the FP.

In animal studies, a decrease in energy intake (EI) is observed during ovulation, with the peak of plasma estrogen levels, and there is an increase in EI following the ovulation, paralleled by elevated plasma progesterone levels [9]. Data from an experiment on rats suggest that progesterone alone has no significant impact on energy intake (EI) but might increase EI when interacting with estrogen [9]. Similarly, findings from most human studies suggest that variations in EI are inverse and noncausal related to estrogen, rather than attributed to an appetite-stimulating effect of progesterone [9]. It is also consistent with the results of the variations in FI during the menstrual cycle investigated in this paper.

2.2. Effect on Appetite

Some studies believe that the relationship between estradiol and leptin is a determining factor in whether women crave sweet and high-carbohydrate foods [10]. Leptin, an appetite-suppressing hormone, is negatively correlated to food cravings [10]. Premenopausal women experience different cravings according to changes in leptin concentration caused by circulating ovarian hormones [10].

One mechanism for the reduction in diet before ovulation, during the FP, is the central role of estrogen in increasing the satiety potency of the gastrointestinal hormone cholecystokinin [5]. An additional mechanism involves a decreased inclination for sweet foods during the FP [5].

While during the LP, which is before menstruation, a higher craving for high-sugar (carbohydrates) and fat foods (such as snacks and desserts), has been observed [9]. This is one reason why women in the LP eat more than those in the FP, with subsequent effects on body weight. However, the use of combined sugar and fat foods (e.g., donuts) to test women's cravings for such foods in some studies has led to these experiments not being able to determine whether women are eating cravings for

carbohydrates or fats alone, or a combination of the two [9]. Interestingly, surveys show that chocolate is the most frequently crave among women and the craving for chocolate is not affected by its pharmacological characteristics (for example, smokers' perception from the pharmacological effects of nicotine and are satisfied), but more by the perception of the aroma, sweetness and texture of chocolate [9]. This craving for sweetness and aroma also increases during the LP, which explains the higher food cravings during this phase [9].

Premenstrual syndrome (PMS) also affects women's food cravings, especially sweets [11]. PMS consists of clinically significant physical and psychological manifestations of the LP in the menstrual cycle, with a global co-prevalence of 47.8% of premenopausal women affected by premenstrual syndrome, and changes in appetite are one of the symptoms of PMS, although these symptoms disappear within a few days after the start of menstruation [11]. Some researchers have also suggested that women with PMS show more desire to eat than women without PMS [9].

In essence, when estradiol and elevated progesterone levels go down during the LP, there is a heightened appetite, with a pronounced desire for carbohydrates and fats. Thus, modulating estradiol and progesterone levels may serve as a pivotal endocrine strategy in the regulation of body weight.

2.3. Effect on Energy Expenditure (EE)

Several research have demonstrated that daily EE varies with the phases of the menstrual cycle. In addition, sleep metabolic rate and basal metabolic rate have also been observed to increase during the premenstrual period, which is LP [9]. Metabolic rate during sleep shows cyclic variation, with the lowest in the late FP and the highest in the late LP [9]. It has been reported that the average difference in sleep metabolic rate between the FP and LP is 6.1-7.7%, while the average 24-h EE Increase 2.5-11.5% [9]. The rise in 24-hour EE during the LP is equivalent to an increase of 89-279 kcal [9].

3. Comparison between PCOS and Healthy Women

PCOS is marked by long and irregular menstrual cycles, which are linked to elevated androgen and reduced sex hormone binding globulin levels [8]. Compared with healthy controls, higher levels of insulin resistance, an increased risk of developing type II diabetes, and a heightened risk of being overweight or obese are observed in women with PCOS. [8].

The results of many investigations have indicated that women with PCOS exhibit significantly higher total energy and nutrient intake, with a higher percentage of energy coming from fat and a slightly but not strongly lower rates of energy from carbohydrates compared with National Diet and Nutrition Survey [12]. In this study, 68% of women with PCOS had a total fat intake of more than 35% of total energy and a saturated fatty acid intake of 12% of total energy, significantly surpassing the recommend nutritional intake [12]. The total sugar intake constituted 19% of the overall energy intake (comprising 44% of total carbohydrate consumption) [12]. Non-dairy exogenous sugar intake represented 10.5% of the total EI, surpassing the recommended maximum intake. In contrast, non-starch polysaccharides fell below the reference nutrient intake of 18 grams per day [12].

In terms of appetite, compared with healthy controls, females with PCOS are hard to achieve a sense of fullness after eating the same food but reported increased hunger, which may be attributed to an imbalance in ghrelin, the hormone responsible for regulating appetite [13]. PCOS patients exhibit heightened ghrelin levels associated with increased elevated androgens, contributed to obesity and overweight [13].

When examining resting metabolic rate (RMR), no discernible difference was observed between women with PCOS and their healthy counterparts [14]. Nevertheless, the respiratory exchange ratio (RER) was remarkably higher in women with PCOS compared to controls, a distinction that retained significant even after accounting for age and BMI [14]. Additionally, both RMR and RER were higher in overweight/obese women in comparison to those with a normal weight. Specifically, within the overweight/obese subgroup, individuals with PCOS exhibited a higher RER when compared to their non-PCOS counterparts [14].

Overall, PCOS patients are more likely to be overweight and obese because of their high-fat diet and low-to-moderate carbohydrate intake with higher appetite compared to healthy women, but there was no significant difference in RMR.

4. Implications for Weight Control

4.1. Hormonal Regulation

In the US, oral contraceptives typically consist of a combination of synthetic estrogen and progesterone, or progestin alone [9]. These medications disrupt the natural hormonal fluctuations during the menstrual cycle, suggesting a potential impact on energy balance. Modulating the variations in female sex hormones through this intervention may positively influence weight loss [9]

Nevertheless, the market offers various types of contraceptives, including combined contraceptives, progestin-only contraceptives, and triphasic contraceptives [9]. Different contraceptive formulations may exert varying impacts on FI and EE, with some even causing notable increases in fat storage and food consumption among users [9].

From the provided data, it appears that the use of oral contraceptives does not significantly affect body weight and might even contribute to weight gain, particularly when utilizing contraceptives formulated with specific progestins [9]. Overall, the comprehension of the effects of hormonal contraceptives on energy balance remains restricted [9]. Consequently, based on the available research, it is not possible to confirm whether estrogen regulating contraceptives can have an effective effect on weight loss.

4.2. Food Intake (FI) Management

A weight loss plan can be crafted based on appetite fluctuations throughout the menstrual cycle. Women experience a rising in appetite and EI during the LP, preceding menstruation. However, as the FP begins with the onset of menstruation, appetite gradually diminishes. A viable weight loss strategy involves reducing dietary intake after the commencement of menstruation when food cravings are less pronounced. During the LP, a moderate increase in FI can address the body's heightened energy requirements [9].

To address the elevated craving for carbohydrates during the LP, incorporating fruits into the diet is recommended [9]. Furthermore, for those with the highest chocolate cravings, opting for dark chocolate with high cocoa content is advisable due to its richness in healthier monounsaturated oleic acid [9, 15]. Notably, moderate consumption of cocoa may be associated with lower risk of vascular disease, given its potent antioxidant effects demonstrated both in vitro and in vivo [15].

It's important to note that in the days leading up to menstruation and the initial menstrual days, an increase in weight is observed due to the body's water retention [9]. This temporary fluctuation doesn't signify actual weight gain, merely a transient change that typically restores the previous weight after menstruation concludes.

5. Conclusion

Estrogens, especially estradiol and progesterone, have a crucial effect on a woman's FI, appetite and EE. This study highlights how estrogen fluctuates at various stages of the menstrual cycle. During the LP, which is characterized by decreased estradiol and elevated progesterone, women's FI and appetite increase significantly, especially carbohydrates and fats. PMS further exacerbates a woman's craving for sweets during this stage. In contrast, during the FP, as estradiol rises and peaks around ovulation, women's FI and appetite gradually decline, reaching their lowest point late in the FP. At the same time, during the LP, EE increases significantly, providing a physiological basis for the increased metabolic activity in the female body. In addition, PCOS patients characterized by elevated androgen levels show increased FI and appetite, making them more likely to be overweight and obese.

Current studies have not conclusively verified the efficacy of using birth control pills to regulate estrogen levels for weight loss. While this study suggests effective dietary plans for weight management through estrogen's effect on changes in appetite.

The study lacked research on other hormone-controlling drugs for weight loss and ignored the effects of androgens on women's FI, appetite and EE. Other hormones that may also affect body weight, such as thyroid hormone and insulin, could be further studied in the future. In addition, individual differences in addressing dietary habits and physical differences in diet management remain unexplored. Future research efforts could lead to more effective menstrual cycle eating plans tailored to individual differences and specific needs. Furthermore, for PCOS patients, more explorations of their physiological mechanisms under estrogen fluctuations is expected to develop personalized treatment plans.

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