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REVIEWS

Reproductive function and a menstrual cycle linked diet in sportswomen

Funcţia reproductivă şi diete adaptate fluctuaţilor hormonale lunare la atlete

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Abstract
Acquiring performance in sports requires many sacrifices: physical training, most often exhausting, a healthy lifestyle and a proper diet. Diet can often be helpful in achieving athlete performance, the recommended type of diet being different according to the type of effort, aerobic or anaerobic. This principle is valid only in the case of men; the diet regarding a sportswoman needs to take into account menstrual cycle phases. An intensive sport produces hormonal imbalances leading to anovulatory cycles, amenorrhea and infertility in women.
Key words: infertility, sportswomen, diet, menstrual dysfunction.

Rezumat
Performanţa sportivă necesită multe sacrificii: efort fizic intens, chiar epuizant de cele mai multe ori, un stil de viaţă sănătos şi o dietă adecvată. Dieta poate contribui de cele mai multe ori la atingerea performanţelor sportive urmărite, regimul alimentar fiind diferit în funcţie de tipul de efort, aerob sau anaerob. Această regulă generală se respectă doar în cazul sportivilor, sportivele având nevoie de adaptarea dietei în funcţie de fazele ciclului menstrual. Sportul de performanţă, pe de altă parte, produce dezechilibre hormonale care contribuie la apariţia ciclurilor anovulatorii, a amenoreei şi a infertilităţii.
Cuvinte cheie: infertilitate, sportive de performanţă, dietă, tulburări de ciclu menstrual.

Introduction

Normal reproductive function in females is reflected by regular menstruation. Ovarian function depends on normal cyclic pituitary gonadotropin stimulation as a response to pulsatile gonadotropin-releasing hormone (GnRH) release from the hypothalamus. The absence of menses is known as amenorrhea and is characterized by absent or infrequent luteinizing hormone (LH) pulses causing suppressed follicular development, ovulation and luteal activity. Low LH leads to low levels of hormones (estrogens and progesterone) and influences endometrial proliferation.

Monthly hormonal fluctuations can influence performance in sport, especially in endurance sports, this performance being correlated with plasma estrogen levels - increased in the follicular phase (maximum plasma concentration being reached at the end of this phase) and lowered in the luteal phase.

On the other hand, there is evidence suggesting that high-intensity activity is associated with menstrual dysfunction (Warren & Perlroth, 2001). Exercise can induce hypothalamic dysfunction suppressing GnRH and consecutively the secretion of luteinizing hormone (LH) and follicle-stimulating hormone (FSH), which will lead to delayed menarche or disrupt menstrual cycle patterns (Loucks & Thuma, 2003).

Every physical activity needs energy sources for muscle and exercise metabolism such as macronutrients (carbohydrate, fat and protein) and micronutrients (vitamins and minerals). The major energy source for muscular exercise is muscle glycogen, but there are alternative energy sources (blood glucose, intracellular lipids, free fatty acids and amino acids) allowing muscle glycogen to be spared and increasing the potential for prolonged high

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metabolic rates.

Carbohydrates as an energy source

Blood glucose, derived from liver glycogenolysis and gluconeogenesis, is the main energy alternative to muscle glycogen.

The use of carbohydrates as an energy source is directly proportional to plasma insulin levels. Hypoestrogenism stimulates pancreatic secretion of insulin, causing intracellular penetration of glucose and therefore its use as an energy source. On the other hand, insulin favors the entry of amino acids into muscle and stimulates protein synthesis. Progesterone, compared with estrogen, has opposite effects on insulin secretion (Oosthuyse & Bosch, 2010).

Since throughout the 28 days of the menstrual cycle there are fluctuations in both estrogen and progesterone plasma levels, Oosthuyse & Bosch (2010) recommend the use of the estrogen/progesterone (E/P) ratio to assess hormonal influence on glucose, protein and lipid metabolism.

In the early follicular phase (after the period), there are basic levels of estrogen and progesterone in the plasma, the E/P ratio increases as the woman approaches ovulation (starting with the mid-follicular phase, estrogen levels being the highest before ovulation), then estrogen levels drop. Following ovulation, the E/P ratio changes as plasma progesterone levels become significantly higher than estrogen levels.

Lipids as an energy source

Plasma free fatty acids derived from adipose tissue provide another energy alternative to muscle glycogen.

Studies in animals have revealed that 17β-estradiol (E2) favors lipid oxidation, increases resistance to endurance effort and "saves" muscle glycogen. Progesterone reverses estrogen effects regarding the use of lipids as an energy source. Because in the luteal phase progesterone levels are 12-20 times higher than in the follicular phase and estrogens are only 3 times higher, muscle metabolism may be affected during a menstrual cycle. Free fatty acids and glycerol levels are higher in the follicular phase than in the luteal phase, which proves that lipolysis is more pronounced in this phase, and it has been shown that carbohydrate ingestion during exercise lowers free fatty acid levels in both menstrual phases. Although insulin levels are not significantly different before and after physical effort, an increase in the basal insulin level in the luteal phase could be observed. Carbohydrate ingestion increases insulin levels in both phases (Campbell et al., 2001).

Proteins as an energy source

Amino acids can provide approximately 10% of total energy (depending on exercise duration and intensity, glycogen stores and energy intake), being the most important carbon source for maintaining normal blood glucose levels. During recovery, amino acids play crucial roles in glycogen restitution. Post-endurance exercise, protein ingestion is important for skeletal muscle protein synthesis, muscle repair and growth (Aguirre et al., 2013). In women, protein intake during exercise is more important when progesterone concentration is elevated because it promotes protein catabolism (Oosthuyse & Bosch, 2010).

It is difficult to recommend a diet based on plasma hormone levels for sportswomen who perform sustained physical effort because they experience menstrual cycle disorders explained by hypoestrogenism due to secondary ovarian insufficiency (Welt et al., 2004). Estrogen deficiency induces insulin resistance that decreases insulin secretion from pancreatic beta-cells, decreases glucose uptake in skeletal muscles, increases gluconeogenesis and lipogenesis in the liver and increases lipolysis in adipocytes. Hypoestrogenism also affects bone mineralization and increases the risk of bone fractures and endothelial dysfunction (Saengsirisuwan et al., 2009).

The main causes of menstrual disorders in high performance athletes are body weight (diet), stress (physical and psychological), followed by the sport type and the maturity of gonads. In female athletes who begin training before puberty, primary amenorrhea (delayed menarche) is observed, while secondary amenorrhea occurs in postmenarcheal athletes (Márquez & Molinero, 2013).

Minerals and sports performance

Many metabolic and physiological processes, such as muscle contraction, bone integrity, cardiac activity, oxygen transport, enzyme activation, need minerals, especially iron, calcium, magnesium and zinc.

Iron (a component of hemoglobin and myoglobin) is the most important mineral for sports performance, being necessary for effective erythropoiesis and transport of oxygen, which are extremely important in aerobic exercise. On the other hand, iron is also found in mitochondrial cytochromes (which regulate oxidative phosphorylation activity) and very important enzymes involved in muscle metabolism (Buratti et al., 2015). Restrictive diet and intense physical activity could lead to iron deficiency through inadequate intake and post-workout hematuria, respectively, resulting in an impairment of muscular performance (Shephard, 2016; Laza, 2007).

Calcium is one of the most important minerals in the body, being especially involved in muscle contraction and bone integrity. Athletes who need to pay attention to their body weight usually have an inadequate dietary calcium intake, and renal calcium excretion seems to be increased after high intensity training. Moreover, when hypoestrogenism is involved, this mineral is not properly stored in bones.

Phosphates have ergogenic potential because they are incorporated into ATP, an energy substrate.

Although studies have revealed no beneficial effect of magnesium and zinc supplementation in increasing exercise performance, hundreds of enzymes that regulate muscle contraction, protein synthesis or oxygen delivery in the body contain these two minerals (Williams, 2005).

Vitamins

A study from 1992 revealed that vitamin supplementation does not enhance physical performance (Singh et al., 1992), but vitamins B are involved in carbohydrate, fat and protein metabolism, and their deficiency may affect both aerobic and anaerobic performance (Williams, 2004).

Skin exposure to ultraviolet B irradiation is mandatory for vitamin D_3 production, which is why vitamin D deficiency is frequently found in elite indoor athletes, who must be supplemented from diet. This vitamin is important for musculoskeletal system integrity and if deficiency occurs, it induces muscle fiber atrophy, with fatty infiltration, fibrosis and prolonged muscle relaxation time (Shuler et al., 2012). Vitamin D it is also important for the absorption of calcium from gut and for calcium storage in bones.

Vitamins with antioxidant properties such as vitamins E and C prevent oxidation of membrane lipids by scavenging free radicals, as well as muscle injury after intense workout (Kyparos et al., 2012).

The intensity of physical exercise and sex hormone variations

In the case of a short-term or low-intensity exercise, hormonal changes do not considerably affect performance (Campbell et al., 2001). Sustained physical effort, on the other hand, induces hypoestrogenism due to secondary ovarian insufficiency related to weight loss, stress and excessive exercise, and could affect performance (Męczekalski et al., 2014).

Body weight and sex hormone variations

In the case of female athletes who need to take care of their body weight to get the sports results pursued (ballerinas, dancers), restrictive eating behaviors are responsible for the onset of hormonal disorders that can lead to these menstrual cycle disorders (Doyle-Lucas et al., 2010; Rich-Edwards et al., 2002). In sports medicine, the term *anorexia athletica* is used to characterize an eating disorder in a female athlete who has an intense fear of gaining weight even though she is underweight. When energy intake does not compensate energy expenditure during exercise (especially in endurance sports), low energy availability may result (Márquez & Molinero, 2013).

An association between body mass index - BMI (calculated as fat percentage) and the occurrence of oligomenorrhea or amenorrhea was observed. These sportswomen are usually considered underweight because of their low BMI (usually under 20) (Stokić et al., 2005); therefore, they are more prone to menstrual disorders due to sustained physical effort and low BMI (Castelo-Branco et al., 2006).

Some researchers have proposed a theory that a "critical threshold" of body fat (17% of body weight) is required for the onset of menarche and that menstruation is disturbed when body fat falls below the "critical threshold" of 22% of body weight (Frisch & McArthur, 1974).

In the absence of fat stores, the metabolic rate decreases and the sensitivity of the hypothalamus to gonadal steroids is altered. Studies have shown that adipose tissue has an endocrine function via adipokines (the first adipokine discovered being leptin), which are involved in the control of energy balance, plasma insulin level and normal reproductive function. The two most abundant stores are visceral and subcutaneous adipose tissues, which produce unique profiles of adipokines, stores that are absent in low weight sportswomen.

Leptin regulates feeding behavior, food intake and energy expenditure in an endocrine manner through the central nervous system (Ouchi et al., 2011). The level of plasma leptin reflects food uptake and caloric dietary balance because blood leptin levels are positively correlated with adipose mass; in case of restrictive diets, plasma leptin levels suddenly decrease (Roupas & Georgopoulos, 2011). A correlation between leptin levels and progesterone levels throughout the menstrual cycle has been identified (Michalakis et al., 2010). If leptin levels drop under a critical level, the GnRH pulse is affected as a consequence of low energy availability and menstrual dysfunction results (Márquez & Molinero, 2013).

Adiponectin is another cytokine produced by adipose tissue. Adiponectin levels in the plasma and adipose tissue are increased in lean individuals and decreased in obese individuals (Ryo et al., 2004). Adiponectin has beneficial effects on insulin sensitivity, increases fatty acid oxidation in muscle tissue and reduces plasma glucose levels, free fatty acids and triglycerides, by activating AMP-activated protein kinase (AMPK) in skeletal muscle and liver (Winder & Hardie, 1999). Adiponectin has a negative influence on GnRH secretion from the hypothalamus, LH and FSH secretion from the pituitary, and contributes to chronic anovulation (Márquez et al., 2013).

Proper diet linked to the menstrual cycle

Dietary intake should therefore be different throughout the menstrual cycle; during the pre-menstrual phase, appetite is increased and thus, the consumption of carbohydrates, proteins and lipids increases, a general preference for carbohydrates being observed (Cheikh Ismail et al., 2009). When the E/P ratio is increased, endurance sport is favored because estrogen stimulates the 5'-AMP-activated protein kinase (AMPK) (Oosthuyse & Bosch, 2010). This enzyme stimulates fatty acid oxidation in the liver and muscles, activates the synthesis of ketone bodies (ketogenesis) and inhibits the synthesis of cholesterol and *triglycerides* (Winder & Hardie, 1999).

In menstrual cycle periods during which the E/P ratio is low, it is recommended to follow a protein diet because progesterone promotes protein catabolism (Oosthuyse & Bosch, 2010).

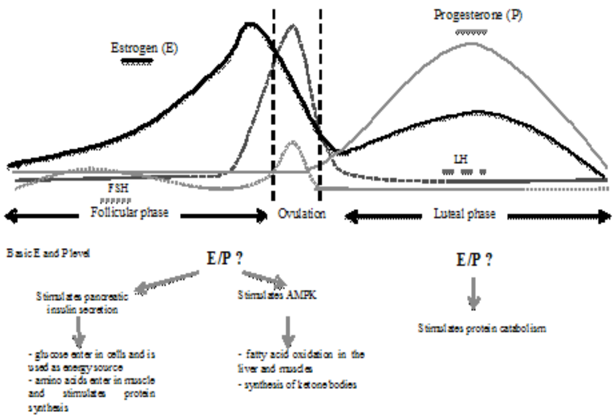

Fig. 1 – Optimal energy sources linked to menstrual cycle phases.

Conclusions

1. Females who perform short-term or low-intensity exercise do not need to adjust their diet according to hormonal changes that occur during a menstrual cycle to maximize performance.

2. In endurance sports, however, performance is favored when the E/P ratio is increased, and carbohydrate

ingestion is recommended in this phase because glucose is the main energy source.

3. When the E/P ratio is low, a protein-based diet is the best option because protein catabolism is stimulated.

4. In sportswomen who are underweight and in those who exercise intensely, menstrual dysfunctions occur and it is very difficult to recommend a menstrual cycle-based diet.

Conflict of interests

There were no conflicts of interests.

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