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## **The Impact of Intensive Physical Training on the Functioning of the Hypothalamic–Pituitary–Ovarian Axis in Female Athletes**

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## **Abstract**

### **Background**

Intensive physical training plays a crucial role in improving physical fitness and athletic performance; however, in female athletes it may also disrupt hormonal balance, particularly within the hypothalamic–pituitary–ovarian (HPO) axis. These disturbances are often associated with low energy availability and may lead to significant reproductive and systemic health consequences.

### **Aim**

The aim of this review was to analyze current scientific evidence regarding the impact of intensive physical training on the functioning of the HPO axis in female athletes, with particular emphasis on underlying physiological mechanisms, health outcomes, and prevention strategies.

### **Material and methods**

A narrative literature review was conducted based on publications from 2014 to 2026. Scientific databases including PubMed, Google Scholar, Scopus, and Web of Science were searched using relevant keywords related to HPO axis function, menstrual disorders, Female Athlete Triad, and Relative Energy Deficiency in Sport (RED-S). Only peer-reviewed review articles, clinical studies, and observational studies were included.

### **Results**

Intensive physical training, particularly when combined with low energy availability, disrupts the pulsatile secretion of gonadotropin-releasing hormone (GnRH), leading to decreased secretion of luteinizing hormone (LH) and follicle-stimulating hormone (FSH), and impaired ovarian function. The most common clinical manifestation is functional hypothalamic amenorrhea (FHA), along with a spectrum of menstrual disturbances. Key risk factors include high training load, inadequate energy intake, and psychological stress. The Female Athlete Triad and RED-S highlight the multisystem consequences of chronic energy deficiency, including reduced bone mineral density, metabolic dysfunction, impaired immunity, and decreased athletic performance.

## **Conclusions**

Intensive physical training may significantly impair HPO axis function in female athletes, especially in the presence of energy deficiency. Early identification of risk factors and a multidisciplinary approach focused on adequate energy availability, appropriate training management, and hormonal monitoring are essential to prevent long-term health consequences and optimize both health and performance.

**Key words:** hypothalamic–pituitary–ovarian axis, female athletes, intensive physical training, low energy availability, functional hypothalamic amenorrhea, menstrual disorders, Female Athlete Triad, Relative Energy Deficiency in Sport, hormonal regulation, reproductive health

## **INTRODUCTION**

Physical fitness is one of the fundamental determinants of human health and quality of life, as well as a key component of athletic performance. It is defined as the ability of the body to perform physical activity of a given intensity and duration without excessive fatigue, while maintaining the capacity for rapid recovery. This concept is multidimensional and encompasses both health-related and performance-related components. According to data from the World Health Organization (WHO), regular physical activity significantly reduces the risk of chronic diseases and improves overall physical fitness (Guthold et al., 2020; Strain et al., 2024).

The main components of physical fitness include cardiorespiratory endurance, muscular strength and endurance, flexibility, and body composition. Aerobic capacity, commonly assessed by maximal oxygen uptake ( $VO_{2max}$ ), plays a crucial role in the ability to sustain prolonged exercise and is an important indicator of cardiovascular health (Ras et al., 2023).

Muscular strength enables the body to overcome external resistance, whereas muscular endurance determines the ability to perform repeated movements over an extended period. Flexibility influences the range of motion in joints and may reduce the risk of injury, although its role in injury prevention remains a subject of ongoing

research. Body composition, particularly the ratio of lean mass to fat mass, is important not only for physical performance but also for metabolic health. A systematic review has demonstrated that higher levels of physical fitness are strongly associated with a reduced risk of cardiovascular disease (Gielen et al., 2015).

In the context of elite sport, physical fitness becomes particularly important as it directly determines athletic performance. In female athletes, fitness levels are influenced not only by training-related factors but also by genetic predisposition, nutritional status, and hormonal balance. Properly designed training leads to numerous physiological adaptations, including increased cardiac output, improved oxidative capacity of skeletal muscles, and enhanced muscular strength. However, excessive training intensity, especially when combined with low energy availability, may result in adverse health consequences. The International Olympic Committee consensus statement on Relative Energy Deficiency in Sport (RED-S) highlights that energy imbalance affects not only physical performance but also endocrine function (Mountjoy et al., 2018).

In recent years, increasing attention has been paid to the relationship between physical fitness and hormonal health in women. Maintaining an optimal level of physical activity supports proper endocrine function, whereas both insufficient physical activity and excessive training loads may lead to hormonal disturbances. This relationship is particularly important in physically active women, in whom the balance between training, recovery, and energy intake is a critical factor in maintaining normal physiological function (Kochański et al., 2015).

The aim of this review is to analyze current scientific evidence regarding the impact of intensive physical training on the functioning of the hypothalamic–pituitary–ovarian (HPO) axis in female athletes. Particular attention is given to the physiological mechanisms leading to hormonal disturbances, their health consequences, and potential strategies for prevention and treatment. To ensure the relevance and high quality of the analyzed data, the literature review was limited to publications from 2014 to 2026. The analysis was conducted using reputable scientific databases, including PubMed, Google Scholar, Scopus, and Web of Science. The search process employed a set of keywords in both Polish and English, directly related to the topic of the study, such as: “hypothalamic–pituitary–ovarian axis (HPO axis)”, “amenorrhea in

athletes”, “female athlete triad”, “relative energy deficiency in sport (RED-S)”, “intensive physical training”, “hormonal regulation”, “gonadotropin-releasing hormone (GnRH)”, “luteinizing hormone (LH)”, “follicle-stimulating hormone (FSH)”, and “reproductive dysfunction in athletes”. Additionally, Boolean operators (AND, OR) were used to refine the search results, and filtering was applied based on publication type (review articles, clinical studies, and observational studies). Only peer-reviewed publications were included, ensuring the reliability and scientific rigor of the analyzed data. This approach allowed for a comprehensive evaluation of the current state of knowledge regarding the effects of intensive physical training on the HPO axis in physically active women.

## **FUNDAMENTALS OF THE PHYSIOLOGY OF THE HYPOTHALAMIC–PITUITARY–OVARIAN AXIS**

The hypothalamic–pituitary–ovarian (HPO) axis is one of the most important neuroendocrine systems responsible for the regulation of female reproductive function. Its proper functioning determines not only the course of the menstrual cycle but also the ability to ovulate, achieve fertilization, and maintain early pregnancy. This system operates through precisely controlled hormonal communication between the hypothalamus, the pituitary gland, and the ovaries, as well as through mechanisms of positive and negative feedback (Mikhael et al., 2019).

The hypothalamus, serving as the primary regulatory center, initiates the activity of the axis by secreting gonadotropin-releasing hormone (GnRH). A key feature of GnRH secretion is its pulsatile pattern, which is essential for the proper functioning of the HPO axis. The frequency and amplitude of GnRH pulses determine the secretion of gonadotropins by the anterior pituitary gland – luteinizing hormone (LH) and follicle-stimulating hormone (FSH). Disruptions in GnRH pulsatility directly lead to dysregulation of LH and FSH secretion, resulting in impaired ovarian function (Stafford, 2005; Saadedine et al., 2023).

The pituitary gland, specifically its anterior lobe, is responsible for the secretion of LH and FSH in response to GnRH stimulation. These hormones perform distinct but complementary functions. FSH stimulates the growth and maturation of

ovarian follicles, whereas LH is responsible for triggering ovulation and inducing luteinization of the follicle, leading to the formation of the corpus luteum. The coordinated action of LH and FSH enables the proper progression of the ovarian cycle and maintains the endocrine function of the ovaries (Reed & Carr, 2018).

The ovaries represent the final component of the HPO axis and perform both gametogenic and endocrine functions. In response to gonadotropin stimulation, ovarian follicles mature and produce sex hormones, primarily estrogens and progesterone. Estrogens, mainly synthesized by granulosa cells of developing follicles, play a crucial role in endometrial proliferation and in preparing the body for ovulation. Progesterone, secreted by the corpus luteum after ovulation, is responsible for the secretory transformation of the endometrium and its preparation for embryo implantation (Holesh et al., 2023).

The functioning of the HPO axis is based on feedback mechanisms that ensure stability and precise hormonal regulation. Negative feedback involves the inhibitory effects of estrogens and progesterone on the secretion of GnRH and gonadotropins, preventing excessive activation of the axis. In contrast, positive feedback occurs during the preovulatory phase of the cycle, when elevated estrogen levels trigger a rapid surge in LH (the “LH surge”), which initiates ovulation. This mechanism represents one of the best-known examples of positive feedback in human physiology. The menstrual cycle, which results from the activity of the HPO axis, can be divided into three main phases: the follicular phase, ovulation, and the luteal phase. The follicular phase begins on the first day of menstruation and is characterized by an increase in FSH levels, which stimulates follicular development. As follicles mature, estrogen levels rise, leading to proliferation of the endometrial lining. High estrogen levels at the end of this phase induce positive feedback, resulting in an LH surge and ovulation. The luteal phase begins after ovulation and is characterized by progesterone dominance, which prepares the endometrium for potential implantation. In the absence of fertilization, the corpus luteum regresses, hormone levels decline, and menstruation is initiated (Reed & Carr, 2018).

The role of the hypothalamic–pituitary–ovarian axis in regulating reproductive function is fundamental. It is responsible for the initiation and maintenance of the menstrual cycle, ovulation, preparation of the endometrium for implantation, and

maintenance of early pregnancy. Moreover, hormones produced within this axis influence multiple other systems, including the skeletal, cardiovascular, and nervous systems. Estrogens play a significant role in maintaining bone mineral density, regulating lipid metabolism, and supporting nervous system function, highlighting their importance beyond reproductive processes (Gordon et al., 2017).

Disruptions in the functioning of the HPO axis can lead to numerous clinical consequences. One of the most common manifestations is irregular menstrual cycles or their complete absence (amenorrhea). These disturbances may result from dysfunction at the level of the hypothalamus (e.g., suppression of GnRH secretion), the pituitary gland, or the ovaries. In physically active women, particular attention is given to functional hypothalamic amenorrhea (FHA), which represents an adaptive response of the body to stress, energy deficiency, and intensive physical exercise (Gordon et al., 2017).

In summary, the hypothalamic–pituitary–ovarian axis is a complex and precisely regulated hormonal system essential for female reproductive health. Its function is based on dynamic interactions between brain structures and the gonads, as well as on feedback mechanisms. Disruptions within this axis, regardless of their origin, may lead to significant health consequences, underscoring the importance of its proper regulation.

## **DISORDERS OF THE HYPOTHALAMIC–PITUITARY–OVARIAN AXIS IN FEMALE ATHLETES**

Disruptions in the functioning of the hypothalamic–pituitary–ovarian (HPO) axis represent one of the most common consequences of intensive physical training in women, particularly under conditions of chronic energy deficiency. The most characteristic clinical manifestation of these disturbances is functional hypothalamic hypogonadism, which leads to suppression of reproductive function. This condition is commonly referred to as functional hypothalamic amenorrhea (FHA) and results from an adaptive response of the organism to metabolic, physical, and psychological stress. Under conditions of limited energy availability, the body suppresses reproductive processes as non-essential for survival, leading to inhibition of the HPO axis (Gordon et al., 2017).

Menstrual cycle disturbances are the most frequently observed manifestation of HPO axis dysfunction in female athletes and may present in various forms depending on the severity of hormonal dysregulation. One such disturbance is anovulatory cycles, in which menstrual bleeding occurs without ovulation, significantly reducing reproductive potential (Czajkowska et al., 2019). Another disorder is luteal phase deficiency, characterized by an insufficient duration of the post-ovulatory phase, which impairs adequate endometrial preparation for embryo implantation. Some women may also develop oligomenorrhea, defined as infrequent menstruation with cycle lengths exceeding 35 days. The most severe form is amenorrhea, defined as the absence of menstruation for at least three consecutive months in secondary cases or the failure to initiate menstruation at the expected age in primary cases. All these disturbances represent significant clinical concerns, as they may lead to reduced fertility and reflect profound hormonal alterations in physically active women (De Souza et al., 2014).

It is important to emphasize that menstrual disturbances in female athletes often exist along a continuum – from subtle hormonal alterations, such as anovulatory cycles, to complete absence of menstruation. Notably, even in the presence of regular menstrual bleeding, significant ovulatory dysfunction may occur, making early diagnosis more challenging (De Souza et al., 2014).

## **RISK FACTORS FOR HYPOTHALAMIC–PITUITARY–OVARIAN AXIS DISORDERS IN FEMALE ATHLETES**

Disorders of the HPO axis in physically active women are multifactorial and result from the interaction between training load, energy availability, and psychosocial factors. Contemporary research indicates that three primary categories of risk factors play a crucial role: training intensity and volume, energy deficiency, and psychological stress. These factors act synergistically, leading to neuroendocrine disturbances that suppress HPO axis function.

One of the key risk factors is the intensity and volume of physical training. In elite sports, particularly in endurance disciplines such as long-distance running, triathlon, and gymnastics, athletes are exposed to prolonged and high training loads. High training volume increases total energy expenditure and induces chronic

physiological stress. Under conditions of adequate energy intake, the body adapts through beneficial changes in the cardiovascular and muscular systems. However, when there is an imbalance between training load and recovery, physiological overload occurs, leading to hormonal disturbances.

Studies have shown that intensive physical activity can alter the pulsatile secretion of gonadotropin-releasing hormone (GnRH), resulting in a secondary reduction in luteinizing hormone (LH) and follicle-stimulating hormone (FSH) secretion (Stafford, 2005). A decrease in LH pulse frequency has been particularly observed in endurance-trained women and is considered an early marker of HPO axis dysfunction. Importantly, even moderate increases in training volume, if not adequately supported by sufficient energy intake, may lead to menstrual disturbances (Raj et al., 2023).

The type of training is also relevant. High-intensity exercise leads to increased activation of the hypothalamic–pituitary–adrenal (HPA) axis, resulting in elevated cortisol levels. Cortisol exerts an inhibitory effect on the HPO axis both directly, by influencing GnRH neurons, and indirectly, through modulation of other hormonal pathways. Chronically elevated cortisol levels reduce pituitary sensitivity to GnRH and disrupt gonadotropin secretion (Maya & Misra, 2022).

Another critical risk factor is low energy availability (LEA), defined as a state in which dietary energy intake is insufficient to cover both exercise-related energy expenditure and basic physiological needs. LEA may result from unintentional underestimation of caloric requirements or from intentional dietary restriction, often observed in sports emphasizing low body weight or specific body composition (Raj et al., 2023).

Energy deficiency is widely recognized as the primary mechanism underlying HPO axis disruption. In response to insufficient energy availability, the body initiates adaptive mechanisms aimed at conserving energy. One such mechanism is the suppression of reproductive function, as it is energetically costly and not essential for immediate survival. Consequently, GnRH secretion is inhibited, leading to reduced LH and FSH levels and impaired ovarian function.

Energy deficiency is also associated with significant alterations in metabolic hormones. Reduced leptin levels, reflecting decreased energy availability, inhibit

GnRH neuronal activity. Simultaneously, decreased insulin and insulin-like growth factor 1 (IGF-1) levels further impair ovarian function. Increased levels of ghrelin and cortisol reinforce the inhibitory effect on the HPO axis.

An important aspect of energy deficiency is the presence of eating disorders, which constitute a significant issue among female athletes. Conditions such as anorexia nervosa, bulimia nervosa, and orthorexia may lead to severe energy deficits and profound hormonal disturbances. Even subclinical disordered eating behaviors, not meeting full diagnostic criteria, may significantly affect HPO axis function. The literature indicates that energy availability below approximately 30 kcal per kilogram of fat-free mass per day represents a critical threshold below which hormonal disturbances are likely to occur (Mountjoy et al., 2018).

The third major risk factor is psychological stress, which often coexists with intensive training and performance pressure. Stress may arise from competitive demands, expectations from coaches, societal pressures, or the pursuit of a specific body image. Chronic psychological stress activates the HPA axis and increases cortisol secretion, which, similarly to physical stress, exerts an inhibitory effect on the HPO axis. Research suggests that psychological stress alone may lead to menstrual disturbances, even in the presence of adequate energy availability. The underlying mechanisms involve both direct effects of cortisol on the hypothalamus and alterations in neurotransmitters regulating GnRH secretion (Gordon et al., 2017).

Moreover, psychological stress frequently co-occurs with disordered eating, amplifying its negative impact on the HPO axis. In clinical practice, it is often observed that the combination of stress, intensive training, and energy deficiency significantly increases the risk of developing functional hypothalamic amenorrhea.

It is important to emphasize that these risk factors rarely occur in isolation. More commonly, they interact and form a complex network of interrelated mechanisms leading to neuroendocrine dysfunction. For example, intensive training increases energy demands, which, if not met, leads to low energy availability, while simultaneously increasing both physiological and psychological stress. This cumulative burden markedly elevates the risk of hormonal disturbances.

Understanding these mechanisms is essential for the prevention and management of HPO axis dysfunction in female athletes. Early identification of risk

factors, appropriate training planning, adequate energy intake, and psychological support are fundamental components of prevention strategies. All of the mechanisms described ultimately lead to suppression of the hypothalamic–pituitary–gonadal axis, which is interpreted as an adaptive response of the organism. Under conditions of limited energy availability, reproductive function is “downregulated” because it is energetically demanding and not essential for short-term survival (Łagowska et al., 2022).

From an evolutionary perspective, this mechanism is protective, preventing pregnancy under conditions unfavorable for its maintenance. However, in modern contexts – particularly among female athletes – it results in a range of adverse health outcomes, including hormonal disturbances, reduced bone mineral density, and impaired fertility (Gordon et al., 2017).

### **FEMALE ATHLETE TRIAD AND RED-S**

One of the best-described clinical syndromes associated with dysfunction of the hypothalamic–pituitary–ovarian (HPO) axis in physically active women is the so-called Female Athlete Triad. This concept was initially introduced in the 1990s and has since been significantly expanded as scientific understanding of the effects of energy deficiency on the body has evolved. The Female Athlete Triad consists of three interrelated components: low energy availability (with or without disordered eating), menstrual dysfunction, and decreased bone mineral density (Williams et al., 2019). These components do not necessarily occur simultaneously; rather, they represent a continuum of disorders with varying severity that may exacerbate one another (Coelho et al., 2021; Raj et al., 2023).

The central element of the triad is low energy availability (LEA), which serves as the primary trigger for hormonal disturbances. Under conditions of energy deficiency, the body suppresses non-essential physiological functions, including reproduction, leading to disruption of the HPO axis and the development of functional hypogonadism (Williams et al., 2017). Menstrual dysfunction, the second component of the triad, encompasses a spectrum ranging from irregular cycles to complete absence of menstruation (amenorrhea). Its direct cause is the suppression of GnRH secretion and, consequently, reduced secretion of luteinizing hormone (LH) and

follicle-stimulating hormone (FSH). The third component, decreased bone mineral density (BMD), results primarily from estrogen deficiency and associated metabolic disturbances. Estrogens play a fundamental role in inhibiting bone resorption; therefore, their deficiency leads to osteopenia and, eventually, osteoporosis (Raj et al., 2023). The Female Athlete Triad has significant clinical implications, as it may lead to an increased risk of stress fractures, impaired fertility, chronic skeletal alterations, and decreased physical performance. Studies indicate that this condition is particularly prevalent in endurance sports and disciplines emphasizing low body mass, such as gymnastics and long-distance running (Lodge et al., 2022).

With the advancement of scientific research, it became evident that the Female Athlete Triad does not fully capture the wide range of consequences associated with energy deficiency. In response, the International Olympic Committee (IOC) introduced the concept of Relative Energy Deficiency in Sport (RED-S) in 2014. RED-S expands upon the triad by addressing the broader impact of low energy availability on multiple physiological systems, not limited to reproductive and skeletal health (Mountjoy et al., 2018). It encompasses dysfunctions in the endocrine, metabolic, immune, cardiovascular, gastrointestinal, hematological, and developmental systems (Coelho et al., 2021). Importantly, RED-S applies to both women and men, representing a significant expansion beyond the original concept of the Female Athlete Triad.

From the perspective of HPO axis function, both the Female Athlete Triad and RED-S exert significant effects on the reproductive system. Low energy availability suppresses GnRH secretion, leading to decreased LH and FSH levels, inhibition of ovulation, and reduced estrogen production. These changes constitute the central mechanism underlying menstrual disturbances observed in female athletes and represent one of the earliest signs of developing RED-S (Witkoś & Hartman-Petrycka, 2022).

The consequences of the Female Athlete Triad and RED-S are multisystemic and may include both short-term and long-term health impairments. These include osteopenia, osteoporosis, and increased fracture risk within the skeletal system; ovulatory dysfunction and infertility within the reproductive system; metabolic slowing and disturbances in energy homeostasis; increased susceptibility to infections

due to immune dysfunction; and impaired recovery and reduced physical performance. Untreated RED-S may lead to irreversible health consequences, particularly in terms of bone mineral density, which is especially critical in young women who have not yet achieved peak bone mass (Cabre et al., 2022).

Both the Female Athlete Triad and RED-S present significant diagnostic and therapeutic challenges. A major issue is underdiagnosis, often due to the underestimation of symptoms such as amenorrhea or chronic fatigue. Early diagnosis is based on the assessment of energy availability, evaluation of menstrual function, hormonal testing, and measurement of bone mineral density. The cornerstone of both prevention and treatment is the restoration of adequate energy balance through appropriate nutritional strategies and modification of training loads (Thein-Nissenbaum & Hammer, 2017).

In summary, the Female Athlete Triad and RED-S are essential conceptual models describing the impact of energy deficiency on the health of physically active women. While the triad focuses on three key aspects – energy availability, menstrual function, and bone health – RED-S provides a more comprehensive framework encompassing the broader, multisystem effects of this condition. Both models emphasize the central role of the hypothalamic–pituitary–ovarian axis, whose dysfunction represents a key element in the pathophysiology of these syndromes. Understanding these mechanisms is crucial for the prevention, diagnosis, and management of hormonal disturbances in female athletes.

## **CONCLUSIONS**

Intensive physical training exerts a significant and multifaceted influence on the functioning of the HPO axis in female athletes. While appropriately structured physical activity supports overall health and physiological adaptation, excessive training loads – particularly when combined with insufficient energy intake – may lead to substantial neuroendocrine disturbances. These alterations primarily manifest through disruption of the pulsatile secretion of GnRH, resulting in downstream suppression of LH and FSH, and consequently impaired ovarian function.

One of the central mechanisms underlying HPO axis dysfunction in physically active women is low energy availability (LEA), which triggers adaptive responses

aimed at energy conservation. Suppression of reproductive function under these conditions reflects a physiological prioritization of survival over reproduction. This adaptive mechanism, although evolutionarily advantageous, may lead to clinically significant conditions such as FHA, menstrual irregularities, and reduced fertility.

The findings summarized in this review highlight that menstrual disturbances in female athletes exist along a continuum, ranging from subtle hormonal disruptions to complete amenorrhea. Importantly, normal menstrual bleeding does not necessarily indicate normal ovulatory function, which underscores the need for comprehensive clinical assessment in this population.

The Female Athlete Triad and the broader concept of RED-S provide essential frameworks for understanding the systemic consequences of chronic energy deficiency. These conditions extend beyond reproductive dysfunction and include adverse effects on bone health, metabolic regulation, immune function, and overall athletic performance. In particular, reduced bone mineral density represents a serious long-term consequence, especially in young athletes who have not yet достигли peak bone mass.

Risk factors for HPO axis dysfunction – namely high training intensity and volume, inadequate energy intake, and psychological stress – rarely occur in isolation. Instead, they interact synergistically, amplifying their negative impact on neuroendocrine regulation. This highlights the importance of a holistic approach to athlete health, integrating training management, nutritional support, and psychological care.

From a practical perspective, early identification of at-risk athletes is crucial. Preventive strategies should focus on maintaining adequate energy availability, optimizing training loads, and promoting awareness of menstrual health as an important indicator of physiological well-being. Interdisciplinary management involving physicians, dietitians, coaches, and psychologists is essential for both prevention and treatment.

In conclusion, maintaining the balance between training, recovery, and energy intake is fundamental for preserving normal HPO axis function and overall health in female athletes. Greater awareness, early diagnosis, and evidence-based interventions

are key to minimizing the risk of long-term health consequences associated with intensive physical training.

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**Conflicts of Interest**

The authors declare no conflict of interest.

**Supplementary Materials.**

No additional materials.

**Declaration of Generative AI and AI-Assisted Technologies**

During the preparation of this work, the authors used ChatGPT-5.2 to improve grammar and language clarity. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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