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Review

Female athletes: A population at risk of vitamin and mineral deficiencies affecting health and performance

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ABSTRACT

Adequate vitamin and mineral status is essential for optimal human health and performance. Female athletes could be at risk for vitamin and mineral insufficiency due to inadequate dietary intake, menstruation, and inflammatory responses to heavy physical activity. Recent studies have documented poor iron status and associated declines in both cognitive and physical performance in female athletes. Similarly, insufficient vitamin D and calcium status have been observed in female athletes, and may be associated with injuries, such as stress fracture, which may limit a female athlete's ability to participate in regular physical activity. This review will focus on recent studies detailing the prevalence of poor vitamin and mineral status in female athletes, using iron, vitamin D, and calcium as examples. Factors affecting the dietary requirement for these vitamins and minerals during physical training will be reviewed. Lastly, countermeasures for the prevention of inadequate vitamin and mineral status will be described.

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Introduction

Micronutrient deficiencies remain a global health concern. For example, the estimated global prevalence of anemia is approximately 25%, affecting over 1.5 billion people [1]. Women may be affected by micronutrient deficiencies to a greater degree than men, as anemia affects over 40% of pregnant women and 30% of non-pregnant women, respectively [1]. Although poor nutritional status is most common in the developing world, women in developed nations also experience suboptimal micronutrient status. For example, over 15% of premenopausal women in the United States (US) may be affected by poor iron status [2].

Female athletes depend upon a healthy and complete diet to provide the nutrients required to maintain and promote physical performance and protect against injury. However, female athletes may experience difficulties in maintaining adequate micronutrient status due to the consumption of energy or nutrient inadequate diets or declines in nutritional status due to heavy physical activity [3,4]. This review will focus on select micronutrients such as iron, vitamin D, and calcium, for which female athletes may be at particular risk of inadequacy. Topics will include dietary sources, effects of poor nutritional status, and recommendations for maintaining the

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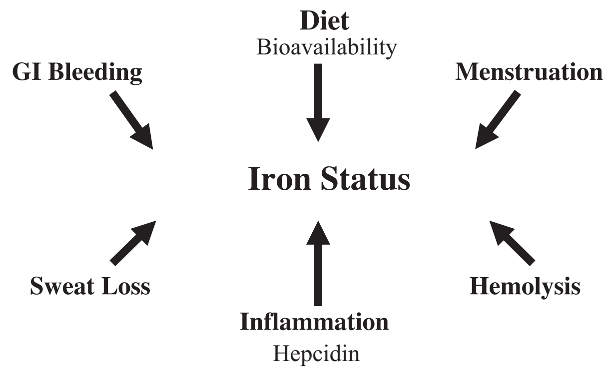

Fig. 1. Factors affecting iron status in female athletes. Adapted from [8].

biochemical levels of these nutrients required for optimal health and performance.

Iron

The critical importance of iron nutrition for female athletes is established through its biological role in supporting the function of proteins and enzymes essential for maintaining physical and cognitive performance. The best characterized biological role for iron occurs through its incorporation into hemoglobin and myoglobin, proteins responsible for the transport and storage of oxygen. In fact, approximately 65% of body iron is incorporated into hemoglobin, and classical human studies have demonstrated that diminished maximal oxygen consumption (VO_{2max}) occurs as hemoglobin levels decline, affecting exercise performance [5,6]. Other proteins and enzymes that incorporate iron function in energy metabolism and include dehydrogenases, which participate in the oxidation of substrates in the mitochondria, and cytochromes, which function in electron transport. In the brain, iron is a cofactor for enzymes required for neurotransmitter synthesis, such as tryptophan and tyrosine hydroxylase [7], and poor iron status has been linked to decrements in cognitive function, affect, and behavior [8].

Many factors, including diet, contribute to iron status. Two forms of iron are found in foods. Heme iron, found in meat products, is best absorbed. The absorption of nonheme iron, found in non-meat items such as vegetables and fortified cereals, may be affected by a number of other factors in the diet, such as phytate and phenolic compounds. These compounds may bind iron making it unavailable for cellular uptake through divalent metal transporter-1 (DMT-1), the protein responsible for iron uptake at the enterocyte. The recommended dietary allowance (RDA) for iron is significantly higher for premenopausal women (18 mg/day) than it is for men (8 mg/day), due to the regular losses of iron that occur through menstrual bleeding. Female athletes may experience difficulty in consuming 18 mg/iron per day for a number of reasons, to include energy restriction, the avoidance of foods (such as red meat) with highly bioavailable iron, and vegetarianism [3].

There are a number of factors other than diet that may affect iron status in female athletes (Fig. 1.). First, blood losses from menstruation represent the major route of iron excretion in most premenopausal women, and female athletes that experience heavy menstrual volume may be at greater risk for poor iron status [9]. Other factors that may affect iron status in athletes include losses due to hemolysis or through gastrointestinal bleeding, which may occur following activities such as distance running. Another recently identified mechanism by which female athletes may experience decrements in iron status occurs in response to inflammation. Acute inflammation may arise following physical activity, and results in increased circulating levels of interleukin-6 (IL-6), a proinflammatory cytokine. IL-6 stimulates the expression of hepcidin, a hormone regulator of iron homeostasis [10], which affects both iron absorption at the brush border as well as basolateral iron export from both the enterocyte and the macrophage. Effects on iron absorption and the sequestering of iron at the cellular level result in functional deficits in iron status, as iron is not available for incorporation into the proteins and enzymes necessary to support physical function.

Acute elevations in hepcidin have been demonstrated in a number of studies with athletes and other populations participating in heavy physical activity. In the initial study describing the hepcidin response to exercise, Roecker et al. [11] observed increased IL-6 and urinary hepcidin levels in women following a marathon. More recently, elevated hepcidin has been observed in blood from athletes following a variety of forms of exercise [12,13], and declines in iron status have been observed in women following prolonged periods of physical training, to include military training [14].

Poor iron status may be characterized as iron deficiency (ID, reduced iron stores), and iron deficiency anemia (IDA), which occurs when iron stores are depleted to the point at which hemoglobin is reduced. When screening female athletes for ID and IDA, multivariable models including several different biochemical indicators of iron status should be utilized to overcome errors or confounding that may occur through the reliance on a single biomarker. For example, assessment of iron status in large population studies such as the National Health and Nutrition Examination Surveys (NHANES) employs cut-off values for erythrocyte protoporphyrin, serum ferritin, and transferrin saturation for the diagnosis of ID, with an additional cut-off value for hemoglobin for the diagnosis of IDA [2]. Both ID and IDA result in decrements in physical and cognitive function which may affect athletic performance [8]. As indicated previously, the effects of IDA on physical performance have been well described in humans and result from reduced oxygen-carrying capacity [6]. The physiologic effects of ID are not as well described, but include effects on tissue oxidative capacity, which have been linked to decrements in endurance, aerobic adaptation and metabolic responses, and muscle fatigue [8]. For example, in a randomized, placebo-controlled trial, women with ID that were provided with supplemental iron (45 mg elemental iron/day) exhibited lower energy expenditure and a reduced fractional utilization of peak oxygen consumption during a 15-km simulated time trial on a cycle ergometer as compared to placebo-treated controls [15]. In a similar study, daily iron supplementation (approximately 15 mg elemental iron/day) during an aerobic training program improved time to complete an exercise performance trial, work rate, and aerobic adaptations in a group of women with ID as compared to placebo-treated controls [16,17].

Countermeasures for preventing and treating ID and IDA have been studied extensively. For female athletes not experiencing ID or IDA, a conventional diet that includes highly bioavailable sources of iron, such as meat, seafood, or legumes, coupled with foods rich in enhancers of iron absorption, such as ascorbic acid, may be sufficient for maintaining iron status. For individuals that have been diagnosed with ID or IDA, the use of iron fortified foods or iron supplements may be considered. Recent reviews have highlighted the potential benefits (and limitations) of both iron supplementation and iron fortification [18,19]. In a systematic review of 60 randomized controlled trials assessing the efficacy of iron fortified foods (to include biofortified crops), Gera et al. [18] found fortification to be an effective method for improving serum ferritin and hemoglobin levels and for reducing the risk of poor iron status. Similarly, a second systematic review assessed the effects of iron intake, to include both the consumption of iron fortified foods and iron supplements on indicators of iron status [19]. This study also demonstrated benefits of iron supplementation and fortification for maintaining iron status. Most recently, scientists have explored novel (experimental) methods of inhibiting hepcidin as a