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The Influence of Vegetarian Diets on Iron Metabolism and Supplementation in Female Athletes

Short Review

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Abstract

Vegetarian diets are becoming more popular for their potential health and weight benefits along with religious, social, and environmental concerns. Many athletes have adopted vegetarian diets because they typically consist of higher intakes of fruit, vegetables, fiber, antioxidants, phytochemicals, and folic acid than traditional omnivore diets. The perception still exists though that vegetarian diets are deficient in several key nutrients, including iron. As a result, athletes consuming vegetarian diets are considered high risk for developing iron deficiency despite limited data. Research on vegetarian diets is limited and hard to synthesize and compare because of the many variations of the diet. Much of the research on iron deficiency in athletes and the general population combines all types of vegetarians into one classification and does not differentiate between the different diets. This makes it difficult to apply results and prevalence rates in a meaningful way. Regardless of diet type, total iron intake in vegetarians has been demonstrated to be similar or greater than that of non-vegetarians. Most females, including athletes, already do not reach the current RDA for iron regardless of vegetarian or omnivore diet, so nearly doubling that value could prove difficult for most female athletes to reach. The purpose of this review was to examine the potential effects a vegetarian diet can have on iron intake and metabolism to determine if vegetarian diets do impose an increased risk of iron deficiency. The focus will remain on female athletes due to the higher prevalence of iron deficiency in this population.

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Introduction

Since 1932, when strong proof was presented that inorganic iron was needed for hemoglobin synthesis,[1] iron metabolism and its importance has been well researched. Much of this early research focused on iron's role in hemoglobin formation and oxygen transport.[2] Despite its importance, iron deficiency is still one of the most prominent and frequent metabolic dysfunctions in the world.[3] With this widespread prevalence, recent research has started to focus on the effects of iron deficiency in athletic populations.[4-7] Three factors are commonly labeled as high risk leading to iron deficiency in athletes: gender (female), activity (endurance), and diet (vegetarian).[4,8,9] The first two, female athletes[5,10-12] and endurance athletes,[6,13-16] have been well- covered in the literature. However, less data is available on whether a vegetarian diet leads to an increased likelihood of iron deficiency.

Vegetarian diets are becoming more popular for their potential health and weight benefits along with religious, social, and environmental concerns.[17-19] Many athletes have adopted vegetarian diets because they typically consist of higher intakes of fruit, vegetables, fiber, antioxidants, phytochemicals, and folic acid than traditional omnivore diets.[20] The Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine have position statements stating that vegetarian diets are nutritionally adequate for all stages of life and for athletes.[21-22] The perception still exists though that vegetarian diets are deficient in several key nutrients, including iron.[23,24] As a result, athletes consuming vegetarian diets are considered high risk for developing iron deficiency despite limited data.[4,22]

This review will examine the potential effects a vegetarian diet can have on iron intake and metabolism to determine if vegetarian diets do impose an increased risk of iron deficiency. The focus will remain on females and female athletes due to the higher prevalence of iron deficiency in this population.[5,6,10-12] Limited available data comparing these rates in female vegetarian athletes and their omnivore counterparts will also be reviewed along with effects of supplementation to combat iron deficiency in athletes.

Vegetarian Diets and Iron Absorption

Research on vegetarian diets is limited and hard to synthesize and compare because of the many variations of the diet. Table 1 provides an overview of the major dietary patterns that are considered vegetarian. This excludes other known, but not as common, vegetarian diets such as macrobiotic, fruitarian, sproutarian, vitarian, and liquidarian.[25-27] A lacto-ovo-vegetarian diet is the most commonly followed.[26] Much of the research on iron deficiency in athletes and the general population combines all types of vegetarians into one classification and does not differentiate between the different diets.[28] This makes it difficult to apply results and prevalence rates in a meaningful way. The term "vegetarian" will be inclusive of lacto-ovo-vegetarians, lacto-vegetarians, and ovo-vegetarians throughout this review. Data including semi-vegetarians or vegans will be specified.

Table 1. Definition of various types of vegetarian diets.

Vegetarian Diet Type	Definition
Semi-vegetarian	Avoids some, but not all animal-derived foods; limited amounts of meat consumed
Lacto-ovo-vegetarian	Excludes meat, poultry, fish, and other seafood, but includes milk, other dairy products, and eggs
Lacto-vegetarian	Includes milk and other dairy products and excludes all animal products and eggs
Ovo-vegetarian	Includes eggs and excludes all animal and dairy products
Vegan	Excludes all animal products including animal derived additives

Regardless of diet type, total iron intake in vegetarians has been demonstrated to be similar or greater than that of non-vegetarians.[21,24,27,29-34] Dietary intake does not appear to be the initial problem though. Multiple studies have shown similar iron intakes between vegetarians[35] or semi-vegetarians[36] to non-vegetarians to have lower bioavailability as measured by serum ferritin (sFer) concentration. This is because dietary iron is found in heme and non-heme forms and their absorption occurs under different mechanisms.[37] As such, iron absorption from intake can range from 5% to 35% depending on the iron type and other circumstances.[38] Heme iron comes from hemoglobin and myoglobin through consumption of meat, poultry, and fish. It is highly bioavailable at 15% to 30% and other dietary factors have little effect on its absorption.[34] Non-heme iron, though, is the most common form accounting for nearly 90% of dietary iron[38] and is obtained from non-meat items such as cereals, pulses, fruits, legumes, and vegetables.[2,10] Thus, vegetarian diets obtain almost all their dietary iron in the non-heme form. Non-heme iron has a much lower absorption rate, 2% to 20%, and is strongly influenced by other dietary components.[34] The Food and Nutrition Board and the Institute of Medicine suggest that the mean iron absorption of a vegetarian diet is only 10% compared to 18% in a diet containing meat.[34] This is a main reason why vegetarians are often classified as high risk for iron deficiency. Despite identical or increased iron intake, less overall iron is thought to made bioavailable. Due to the decreased bioavailability of non-heme iron in the vegetarian diet, it has been recommended that vegetarians consume 80% more than the RDA for iron.[7,10,27] The current RDA for iron in premenopausal women is 18 mg/day [10] meaning a female vegetarian should theoretically aim for 32.4 mg/day of iron intake.

Most females, including athletes, already do not reach the current RDA for iron regardless of vegetarian or omnivore diet,[11,12,39,40] so nearly doubling that value could prove difficult for most female athletes to reach. Vegetarian athletes should look to increase iron absorption and bioavailability through non-heme iron enhancers. Ascorbate and citrate increase iron uptake by helping solubilize the metal in the duodenum.[2] The duodenum and upper portions of the jejunum are where most dietary iron absorption occurs.[41] Ascorbic acid is the main absorption enhancer in vegetarian diets and thus meals should be planned to include fruit and vegetables containing ascorbic acid.[42] There are also several factors that inhibit iron uptake such as phytate, polyphenols, calcium, bran, hemicellulose, cellulose, and pectin.[2,9] In many fruits and vegetables, the enhancing effect of ascorbic acid on iron absorption is diminished by the inhibiting effects of polyphenols.[43] In vegetarian diets, phytate is the main inhibitor of iron absorption.[44] The effect of phytate is dose dependent and can be reduced in meals containing enhancers.[2] In cereals and legumes polyphenols add to the inhibitory effect of phytate.[44] Unlike other inhibitors, calcium negatively effects absorption of both heme and non-heme iron.[2] Calcium should therefore be limited or avoided during meals with high iron content. These inhibitors can cancel out the enhancing effects of ascorbic acid and citric acid and thus proper meal planning is vital for vegetarian diets.

In most vegetarian diets, it does not appear that increased enhancers are able to fully offset the lower bioavailability of non-heme iron.[27] A study looking at the effects of enhancers and inhibitors on iron absorption in young women found that a vegetarian diet containing 2.5 times more fiber, 3 times more phytic acid, and no heme iron compared to an otherwise equivalent non-vegetarian diet resulted in 70% less non-heme iron absorption and total iron absorption only one-sixth that of the omnivore diet.[45] This could be due other factors as well. Iron absorption is also dependent on body iron stores, hypoxia, and the rate of erythropoiesis.[46] Other micronutrients such as zinc and copper may also play a competing role with iron absorption.[2,47] Recent reviews have covered in detail the mechanisms behind iron absorption and metabolism.[2,46]

Vegetarian Diets and Iron Deficiency

Iron deficiency can be diagnosed into three levels of severity: iron depletion (IDNA), iron-deficient erythropoiesis, and iron-deficient anemia (IDA).[4] IDNA occurs when iron stores in the bone marrow, liver, and spleen are depleted. Iron-deficient erythropoiesis, also known as latent iron deficiency, is marked by impairment of the transport of the iron pool, so iron supply to cells is decreased. IDA occurs when hemoglobin (Hb) production falls due to insufficient iron supply.[4,48,49] Clinical diagnosis and prevalence of each category are difficult to compare across literature due to differences in cutoff ranges. There is no standard for the cutoff to detect iron depletion.[40] Various research has used sFer values ranging between <12 μg/L to <35 μg/L to classify participants as IDNA.[12,40,50] The World Health Organization defines IDA as Hb concentration <12g/dL and sFer levels <12μg/L.[12,50] It has recently been suggested that it is somewhat arbitrary to classify athletes as IDNA or IDA based on Hb and sFer concentrations.[51] To form a complete picture, this review will use any sFer values <35μg/L as a cutoff for IDNA to include the most possible literature and will classify IDA by the definition of WHO when possible.

sFer concentrations have long been used as the most common and convenient laboratory test to estimate iron stores. This is because under steady state conditions, sFer correlate strongly with total body iron stores.[2] However, athletes are not commonly in a steady state condition physiologically and inflammatory states can cause falsely elevated sFer readings.[4,7,52] Thus, using sFer concentrations to determine iron status of female athletes could prove to be an inaccurate measure and potentially mask depleted iron stores if taken after exercise. Recently, soluble transferrin receptor (sTfR) index has been suggested for use determining iron status in athletes as it is a more sensitive index of functional iron deficiency.[52,53] STfR reflects overall erythropoiesis and is not an acute phase protein and is less likely to be acutely affected by exercise[13] and thus day to day variations are less for sTfR (4-16%) compared to sFer (13-75%).[4] It has been shown to have less intrasubject variability in training athletes [54]. This could allow a more accurate reflection of iron status in athletes whom are rarely in steady state conditions. The ratio of sTfR/sFer has also been suggested as an important marker in athletes since it can help determine total body iron.[7,13,52] The sTfR/log[ferritin] index has a much higher diagnostic value than sFer alone in detecting iron-deficient erythropoiesis.[7,55] The sTfR/log[ferritin] index could help detect and determine more mild forms of IDNA athletes. This can lead to earlier intervention and treatment for individuals at risk of becoming IDA. However, high cost and lack of standardization of the sTfR assay has limited implementation of this method.[2]

For female athletes, early detection of IDNA is crucial because while the effects of mild iron deficiency on performance are still debated,[13,20,52,55,56] IDA has clear negative performance effects.[14,55,57] Oxygen transport can be affected by IDA resulting in reduced aerobic capacity and lethargy and long-term IDA can also affect cardiac function.[12,13,55,58] IDA can lead to cognitive and behavior dysfunctions as well as physical.[57] Sensitivity to IDA could be greater in athletes because exercise requires maximal oxygen delivery to the muscle and efficient oxygen utilization. Several factors have been suggested as potentially causing increased iron deficiency rates in female athletes such as hemolysis (foot strike and impact),[59] increased sweating,[60,61] increased inflammation and hepcidin,[56,62] hematuria,[63-64] gastrointestinal bleeding,[65,66] NSAID overuse,[15,67] and menstrual bleeding.[68] While sweating is proven to be a significant source of iron loss in athletes, the iron content in their sweat decreases with heat acclimation.[69] Hemolysis is when mechanical deformation causes the destruction of blood cells and is often attributed to the repetitive mechanical loading on the heel during foot strike causing an increase cell destruction. The half-life of iron is approximately 1,300 days in sedentary females, but has been estimated at only 1,000 days in runners.[70] In total, from combining all these causes, iron loses have been estimated to be between 30% and 70% greater in female athlete.[71] Because of these potential influences on iron loss, the most recent position statement by the Academy of Nutrition and Dietetics, Dietitians of Canada, and the ACSM suggest iron requirements for all female athletes may be increased by 70% of EAR (8.1 mg/d in healthy individuals).[22] Similar to the suggestion for vegetarian diets, this recommendation would put female athletes needing to consume 5.7 mg of iron more each day. That would leave female vegetarian athletes with a recommended dietary intake of 38 mg of iron a day. The feasibility of this and ways to reach that goal will be discussed in a later subsection.

Prevalence of IDNA and IDA in female athletes is well documented in literature. Early research thought this was a problem mostly concerning endurance athletes and focused largely on these athletes.[6,72-76] This is because it was presumed that endurance athletes would have greater rates of iron turnover due to more gastrointestinal bleeding, hemolysis, and sweating.[56] More recent data appears to support that iron deficiency affects female athletes across all types of sports. In a recent study of female athletes at a NCAA D1 school, 17 of the 70 athletes enrolled had low iron stores (<15 µg/L). Of these 17 athletes, 5 were on the soccer team, 3 on swim, 2 on basketball, 2 on softball, 2 on gymnastics, 2 on cross-country, and 1 on tennis.[11] Another study covering 100 female varsity athletes playing a variety of sports at two NCAA D1 schools showed 31% of the athletes as iron deficient at initial screening.[5] Unfortunately, this study did not provide data separating the prevalence by sport making it hard to draw concrete conclusions, but the purpose of the study was to test a variety of sports and not endurance athletes. A retrospective chart review which included 1536 female athletes on varsity rosters between 2002 and 2014 at one NCAA D1 university showed that nearly one-third of all female sFer values were under < 20 µg/L. No sport had a significantly higher prevalence of IDA at PPE compared to the group mean. When sports were pooled by their metabolic demands, phosphagen system, anaerobic glycolysis, or aerobic metabolism, the incidence of IDNA and IDA remained similar across groups. The results were also similar when the sports were paired sport group, ball sports, aesthetic or weight class sports, or endurance. Of these, only 2.2% indicated IDA while 30.9% indicated IDNA.[53] This supports several other studies also showing the prevalence of IDNA, 16%-59%, to be significantly higher than that of IDA, <1%-18%, in female athletes.[11,40,77-80] Similar results have been shown in female professional athletes where no significant difference was found in prevalence of IDNA or IDA across a variety of sports.[81] The same pattern across a variety of sports with different metabolic demands has also been shown in young female athletes.[40] The role of the primary metabolic demand in the prevalence of iron deficiency in female athletes is still open to debate, though, as other research has shown significant differences based on metabolic demand.[78] The prevalence of iron deficiency is high amongst female athletes. It appears that sub-clinical IDNA is the most prevalent in female athletes compared to their male counterparts and sedentary individuals. It affects most athletes regardless of sport and presumably diet since none of these studies classified the athletes by their diet.

Knowing this, the question is whether these prevalence rates are higher in vegetarians. Data looking at iron deficiency in vegetarian female athletes is extremely limited. In a study comparing 18 long-distance runners by documenting their iron stores based on their diet, 9 of the athletes consumed semi-vegetarian diets (<100g red meat/week) and the other 9 did not restrict meat intake. The 9 on semi-vegetarian diets had significantly lower sFer concentrations compared to the unrestricted group despite similar iron intake.[36] This finding suggests that meat restricted diets result in lower iron stores and bioavailability compared to unrestricted diets in female athletes. However, extracting available data from the study shows that even in the non-restricted group the average sFer value was only 19.8 µg/L which is low and would classify as IDNA based on criteria used for athletes in other studies. With only 9 athletes per group the results are also hard to generalize and draw many conclusions from. In Germany, a study of extreme endurance compared a lacto-ovo-vegetarian diet to a nonvegetarian diet. Fifty runners consumed a vegetarian diet and 60 consumed a traditional western diet before and during a 1000-km race over 20 days. Nutrient intake such as carbohydrates were controlled for and similar between the groups except that iron intake was higher in the vegetarian group. Over the course of the entire race, sFer concentrations were consistently lower in vegetarians compared to nonvegetarians, but no performance impairments were present.[82] To our knowledge these are the only studies directly comparing iron status in vegetarian female athletes to female athletes consuming a more traditional diet. Clearly, much more research is needed to draw firm conclusions on the prevalence of IDNA and IDA in female vegetarian athletes.

While not athletes, young adolescent females consuming a vegan diet showed no difference in iron deficiency compared to sex and age matched omnivores.[33] Also in Germany, a study of 75 vegan women showed an overall iron deficiency rate of 40% in young women, but only three women, 4%, had parameters defined as IDA.[83] One systematic review and meta-analysis has been published on the issue of iron status in vegetarians.[84] Females of any type of vegetarian diet were shown to have significantly lower ferritin levels when compared to nonvegetarians which supports other narrative reviews on iron status of vegetarian diets.[34,85] However, there was not a significant difference between cutoffs for females at the lowest level <10µg/L which would signify IDA. Other reviews have stated similar findings that while vegetarians tend to have lower iron stores than omnivores, they don't appear to have a greater prevalence of IDA.[26,28,34,85] However, most of these reviews do not cover vegetarian athletes specifically and the meta-analysis excluded data from vegetarian athletes because of the potentially increased iron demand. Therefore, it is hard to draw strong conclusions, but based on currently available data, IDA appears to remain relatively rare in female vegetarian athletes with prevalence rates like that of their omnivore counterparts. Other reviews covering vegetarian athletes have come to similar conclusions.[20,26]

With potentially increased prevalence of IDNA, but not IDA in female vegetarian athletes, the focus can turn to whether vegetarian diets impair physical performance. The same study by Snyder et al comparing the female endurance runners showed no difference in aerobic performance despite the difference in sFer levels.[36] Another study comparing 49 Israeli vegetarian athletes to 49 age, sex, body size, and sport matched nonvegetarian athletes showed no significant difference in pulmonary function, aerobic capacity, or anaerobic capacity.[86] At the 1000-km race over 20 days in Germany the average running time for vegetarians was not significantly different from that of the nonvegetarians, the order of finishing was not influenced by diet, and only half of each group finished the race.[82,87] Performance did not seem to be affected by a vegetarian diet even under extreme endurance conditions. A review on physical performance and vegetarian diets concluded that a vegetarian diet, even when practiced for decades, is not detrimental or beneficial to cardiorespiratory endurance.[20] The type of vegetarian diet was not controlled for in this review, but other cofounders such as carbohydrate intake, age, training status, and body weight were controlled for. A recent cross-sectional study of 27 vegetarian athletes and 43 omnivore athletes found that VO_{2max} was significantly higher in female vegetarians; however, there was no difference in peak torque.[88] Athletes had a relatively loose definition in this study as a participant could be anyone on a NCAA D1 club sports team or training for a major endurance race. Previous training routine and status was not controlled for and could explain the differences seen between groups. A systematic review[89] from January 2015 took data from all studies that directly compared physical performance between vegetarian diets and omnivore diets. Only 8 studies matched this inclusion criteria and most were well dated. From these 8 studies, there was no difference in physical performance from vegetarian based diets to omnivorous diets. This held true for strength and power and anaerobic and aerobic performance. Despite usually lower iron stores, most available literature to date suggests that vegetarian diets do not decrease athletic performance. This indirectly supports that IDA is not more common in vegetarians than nonvegetarians as IDA would likely lead to clear performance deficits.

Iron Supplementation for Vegetarian Diets

If vegetarian female athletes were to follow recommendations for increased iron intake in athletes[22] and vegetarians,[10] they would need to consume 38 mg of iron per day. This would be nearly impossible through normal dietary intake. The typical western diet, which includes meat, has an iron density of 6mg/1,000 kcal.[9,48] This means a typical meat eater would have to consume roughly 6,300 kcal/day to reach that iron goal. As discussed previously, vegetarian diets have the same to slightly greater dietary iron intake which would imply similar iron density. Thus, vegetarian female athletes would need to consume significantly more and arguably unreasonable amounts of kcal per day to reach that goal. Instead, the athletes should focus on increasing iron density. While not completed in vegetarians, a recent study showed that in female athletes when iron density was higher than 6mg/1,000kcal the relative risk for low ferritin was 2.3 times lower.[40] In the same study, female athletes with normal ferritin levels had an iron density 0.66 mg/1,000 kcal greater than female athletes with low ferritin concentrations. Dietary iron density could prove important when assessing and managing the risk of vegetarian female athletes for IDNA and IDA.

In the most recent position statement from the American College of Sports Medicine on nutrition and athletic performance, well planned, varied, and appropriately-supplemented vegetarian diets were stated to appear to successfully and effectively support parameters that influence athletic performance.[90] This position has been supported by numerous reviews stating properly planned vegetarian diets can meet the macro and micro nutritional needs of an athlete.[7,26,27,76,87] Some research has supported this by showing that a properly balanced vegetarian diet can be successfully used by world-class athletes.[25] Several studies have shown that nutritional deficits observed in vegetarian diets are commonly due to poor meal planning and low total caloric intake.[16,28] For female athletes not experiencing IDNA or IDA, a diet high in bioavailable iron sources, such as legumes, bok choy, and tofu for vegetarians, paired with foods high in iron enhancers may be sufficient for maintaining iron stores. It has been suggested that vegetarian athletes include a vitamin C source with every meal to help increase iron absorption.[20] Athletes should be educated on foods with high iron bioavailability and vegetarian athletes need to be especially conscious of their daily food choices. Iron fortified foods have mostly been shown to have a positive impact on iron status.[14] A study using iron-rich Teff bread showed a significant increase in iron intake, but no difference in iron stores in female athletes.[91] The dietary intervention lasted only 6 weeks which could explain why the difference in iron stores was not significant. Changes in iron stores can take 2-3 months to show significant changes.[92] Vegetarian athletes can increase their total iron intake by including more leafy green vegetables such as spinach, asparagus and broccoli along with soy foods, legumes, Swiss chard, dried beans, whole grains, nuts and seeds, bok choy, and tofu.[26,93] One pound of kale provides nearly 8 mg of iron.[93] Increasing dietary knowledge in vegetarian female athletes should be a main and early goal of any intervention. A positive correlation has been shown between total nutrition knowledge and dietary iron intake.[94] While the correlation was only moderate, women with a higher total nutrition knowledge, as measured by survey, had consistently higher iron intake than those with lower food knowledge. Interestingly, though, in this study no link was found between dietary iron intake and iron stores.[94] Thus, the higher dietary intake did not appear to translate to better iron status. Regardless, the importance of meal planning for iron rich foods and iron enhancers cannot be understated for athletes consuming a vegetarian diet.

Eating whole foods is also vital to maintaining a healthy nutritional status for vegetarians as food processing can lead to major nutrient losses. For example, the milling of whole grains to white flour leads to a 75-95% loss of minerals, vitamins, phytochemicals and dietary fibers.[28] This includes an approximately 62% reduction in iron content during the process.[19] Cooking, industrial processing, and storage degrade ascorbic acid and remove its enhancing effect on iron absorption.[42] Converting a potato to potato chips causes a 40% decrease in mineral content and 50% loss of vitamin C while increasing fat content from 0.1 g to 40 g per 100 g.[28] Even frozen fruits and vegetables lose some of their nutrients when they are washed prior to deep freezing.[28] On the opposite side of the spectrum, iron-fortified foods have shown strong ability to improve iron status. A systematic review of 60 trials found that iron-fortified not only significantly improved sFer, but also significantly lowered risk of IDNA and IDA. The fortification even proved efficacious in cereal containing high amounts of phytic acid.[95] The type of iron used for fortification matters, though, and many cereals have been found to use low-cost elemental irons which have extremely low bioavailability.[44] Therefore, care needs to be taken to identified foods fortified with irons high in bioavailability. Along with proper meal planning, food selection much be a conscious decision for vegetarian athletes.

While a well-planned and proper diet can nutritionally provide everything, including micronutrients, a vegetarian female athlete needs, iron supplementation may be needed to return iron stores to proper levels if already deficient. Oral and intramuscular iron supplementation had a large effect in female athletes on improving sFer according to a recent meta-analysis of 17 studies covering iron treatment in endurance athletes.[55] Iron treatment can improve sFer levels in athletes with mild IDNA before they reach IDA. Studies have shown that even moderate doses as small as 1-2 times the RDA can lead to improvements in sFer in athletes with mildly compromised iron stores.[52] Unfortunately, there are currently no evidence-based guidelines for the treatment of athletes with IDA.[55] A wide variety of protocols have been used in the literature for iron supplementation making it vital to determine a relationship between dose and response. Supplementation should occur using the most bioavailable forms iron sulfate, iron gluconate, or iron fumarate.[4] All these ferrous salts have comparable rates of absorption and incidence of gastrointestinal adverse events. They should be provided in a quick release form to allow for large quantities of soluble iron in the duodenum.[48] Doses can be broken up into smaller amounts more frequently to reduce gastrointestinal issues.[52] Larger doses of iron given less frequently, 60 mg of elemental iron once a week, are also effective at treating IDNA and IDA and some have reported better compliance with this regimen.[52] Oral supplementation should be taken with iron enhancers such as vitamin C and drinks containing inhibitors such as coffee, tea, and milk should be avoided. It has also been suggested that for endurance athletes, supplementation should aim to restore sFer levels to approximately 60 μg/L.[48] Iron supplementation in female athletes with reduced iron stores has shown consistent aerobic performance improvement.[92,96-99] For athletes without IDNA or IDA there is no benefit to athletic performance by iron supplementation and it can lead to iron overload.[14,52]

Replenishing iron stores can take 2-3 months when using 100 mg ferrous iron/day.[22,48,55,92] Because of this, sFer testing should only be completed once time for proper improvements has occurred. The International Olympic Committee recommends iron screening be a part of health evaluations for elite athletes.[100] However, in one survey of 55 NCAA D1 schools, only 43% of athletic programs performed routine screening for iron deficiency.[101] Of the 24 schools that screened female athletes, only 13 included screening of all female athletes. Screening of female athletes for iron deficiency is not a routine practice. Even amongst the institutions that did perform screening, testing varied significantly. Different biochemical indices and a wide range of cutoffs were used to define iron deficiency. Treatment response also varied widely between institutions. Clear procedures for testing iron status in elite female athletes need to be defined as screening should become common practice for all athletes, especially vegetarians.

Considerations for Future Research

Several areas of athletic nutrition and vegetarian diets still need more research. There is a paucity of data looking at rates of IDNA and IDA in vegetarian athletes, male or female. Beyond anecdotal evidence of athletes succeeding at athletic endeavors while maintaining a vegetarian diet,[20] there are almost no controlled studies examining iron deficiency in athletes. This makes it difficult to assess whether vegetarian diets are truly suitable for athletes because there is no data to compare to what is known about nonvegetarian athletes. This is partly due to the difficult nature of controlling for diet in studies and the difficulties of a retrospective review since dietary recall is unreliable, but new research using sound methods could provide significant insight into the interaction between vegetarian diets and iron in athletes. Better research is also needed to compare athletic performance in vegetarian and nonvegetarian athletes. Barr and Rideout noted that since 1999 few studies have looked at the effects of vegetarian diets on athletic performance.[27] Well controlled and amply powered studies are needed to further directly compare athletic performance between the two diets. This lack of data and call for more research has been noted by several other reviews.[20,26,27]

Appropriate cutoff values when using sTfR to measure iron status in athletes also need to be determined. This is especially important because significant ethnic differences in sTfR suggest separate cutoffs are need for different races.[7] There is currently a lack of an international standard,[55] which makes clinical use of sTfR values difficult. There is also variability in the performance of commercially available assay,[55] which further makes comparisons of sTfR values hard. Without an international standard and comparable units, it is not possible to make comparisons between the different assay kits. An international standard needs to be recognized for sTfR concentration so appropriate cutoff values can be determined for athletes and implementation of sTfR testing of athletes can become standard.

The effects from the rise of hepcidin to exercise and inflammation on iron metabolism are well documented.[62,68,102-104] An interesting area of research could look at whether vegetarian diets alter the response of hepcidin to exercise or alter its interaction with iron metabolism. Currently there appears to be no research exploring this interaction. Low ferritin is also associated with oxidative stress, so research on potential effects from vegetarian diets could prove useful. Vegetarian diets are known for their high antioxidant intake,[16,93] so they theoretically could alter that relationship compared to an omnivore diet.

Discussion

Despite limited research, enough preliminary data is available to begin untangling the interactions between vegetarian diets, iron, and athletic performance. Vegetarian diets do not generally lead to decreased iron intake compared to traditional omnivore diets. In fact, they commonly lead to an increase in iron intake. However, this has not translated into better iron status in vegetarians due to the lower bioavailability of non-heme iron commonly found plant-based diets. This holds true regardless of gender or athletic participation. As a result, some consensus statements and other reviews have recommended higher dietary iron intake values for vegetarians and athletes. When looking closer at the data, though, even with higher intakes, female vegetarians still do not usually reach the current RDA for iron. The implication of this is that it could be premature to recommend higher iron intake for athletic females consuming a vegetarian diet. There is currently a lack of data on iron stores and status in females who meet the RDA for iron. Reaching the RDA for pre-menopausal women seems to be difficult regardless of diet. While current data shows high rates of iron deficiency, it is almost exclusively from subjects not consuming the recommended amount. It is not currently possible to say that a vegetarian consuming the RDA for iron is at greater risk of IDNA as no data are currently available is able to suggest that the RDA is inadequate for vegetarians or athletes. These recommendations so far are only based on theoretical iron loss and balance not supported by literature. Thus, it is possible that consuming the normal RDA for iron is enough to maintain iron stores even in vegetarian female athletes. The focus should not be on trying to raise recommendations for iron intake on female vegetarians and athletes, but rather on the importance of reaching the RDA. Not enough data is available to confidently recommend higher iron intakes for vegetarian female athletes when it is unknown if the RDA is adequate already.

While rates of IDNA can be high in vegetarian female athletes, incidence of IDA remains low. Vegetarian female athletes do not currently show an increased risk for IDA compared to female athletes consuming traditional Western diets. This holds true even with the data coming from subjects not consuming the RDA for iron. Therefore, it is possible that consuming the RDA could be adequate for vegetarian female athletes to improve and maintain proper iron stores and status. This review also found that, while limited, available data shows no decrements in athletic performance in vegetarian female athletes. Implications of this are that vegetarian diets are improperly discouraged among female athletes and can sustain high levels of athletic performance when properly planned. Support communities, such as coaches and parents, around female athletes should not focus on discouraging vegetarian diets. Instead, they should concentrate efforts on encouraging the athlete to approach the vegetarian diet in a well-rounded way including support from medical and nutritional specialists.

When iron deficiency does present itself, there are effective means of iron supplementation to restore proper iron levels. The current approach is to suggest oral iron supplementation to most vegetarian as a precaution. However, the findings from this review suggest that iron supplementation does not have to only refer to pills or shots. Foods fortified with iron or high in iron enhancers have consistently shown improvements in iron in female vegetarians. Both should also be considered as acceptable means of iron supplementation. The definition of what is considered iron supplementation should include approaches that are not just pharmaceutical. In fact, oral iron supplementation should not be used with vegetarian female athletes until iron stores are checked and iron deficiency is present. Proactive oral supplementation is unnecessary for vegetarian athletes and should only be used when IDNA or IDA are present, similar to the approach with athletes consuming traditional omnivore diets.

Current research appears to focus around the current reactive approach in athletics to IDNA and IDA in female athletes, especially those consuming a vegetarian diet. Iron status is only checked when symptoms of IDA begin to present themselves and then iron treatment is implemented. Despite only requiring months to restore iron levels, this reactive approach does not appear to be the best. Combining available data on vegetarian diets, iron bioavailability, and iron status in females a proactive approach to preventing IDNA presents as plausible. Early and proper dietary education to vegetarian female athletes could prevent much of the IDNA and IDA seen as much of these incidences are linked to improper overall dietary intake than specifically vegetarian diets. To start, the approach should focus on consuming the RDA for iron. Once this is met, then monitoring iron status would be beneficial. A proactive approach should also include testing iron status in all female athletes, regardless of diet, at regularly designated intervals. This can help with the early detection of low iron signs and allow for milder interventions such as diet modifications for correction. It would also provide insight to whether the RDA is already adequate for vegetarian female athletes. Less reliance on oral supplementation and injections could then be necessary, as a shift to other means of supplementation would be possible. Despite what is commonly thought, vegetarian female athletes do not show limitations in athletic performance and it is not a given for them to develop of iron deficiency.

Despite commonly being classified as high-risk in literature, most current data shows no increase in prevalence of IDA in females or female athletes consuming a vegetarian diet compared to their omnivorous counterparts. Vegetarian female athletes can compete at the highest levels. While iron stores appear to be lower, little to no impact has been noted on athletic performance of vegetarian female athletes. The importance of a proper, wholesome diet and meal planning including iron-fortified foods should be stressed to the athlete. There is less room for error when consuming a vegetarian diet to satisfy nutrient requirements. Proper screening needs to be in place for all elite athletes. Supplementation can be used as needed to replenish iron stores, but increasing dietary knowledge should be the main intervention.

Media-Friendly Summary

While some insight on the effects of vegetarian diets on iron metabolism in female athletes is available in current literature, more research is needed to fully understand the effects a vegetarian diet can have on iron metabolism and athletic performance in female athletes.

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