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Pumping Dietary Iron: Implications for Aerobic Endurance Exercise

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Implications for Aerobic Endurance Exercise

by Melvin H. Williams, Ph.D., FACSM

In an earlier issue of *ACSM's Health & Fitness Journal*® (Sept/Oct, 1998), Barry A. Franklin, Ph.D., FACSM, president of ACSM, authored an article called, "Pumping Iron: Rationale, Benefits, Safety, and Prescription" where he presented evidence supporting the health benefits of resistance training an anaerobic type of exercise training. As we all know, aerobic endurance exercise training also conveys multiple health benefits.

The energy needed for aerobic endurance exercise tasks is derived from the oxidation of carbohydrate and fat, necessitating a well-developed cardiovascular system to deliver oxygen, and aerobically-trained muscles to use the oxygen. Aerobic exercise training enhances cardiovascular efficiency and induces body fat losses, two of its many health benefits. While many of your clients exercise aerobically for these health benefits, others may also train to compete in aerobic endurance events, such as 10K road races, marathons, and ironically (no pun intended), even Ironman-type triathlons.

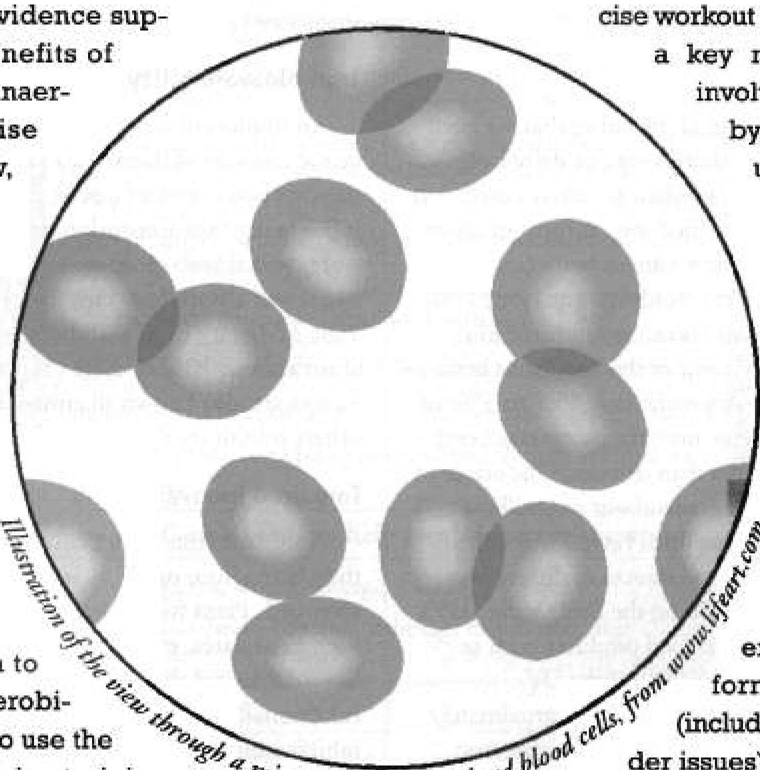


Illustration of the view through a microscope of normal red blood cells, from www.lifeart.com

For your clients who may want to perform at their best, either during a typical aerobic exercise workout or in competition, iron is a key nutrient because it is involved in oxygen delivery by the blood and oxygen utilization in the muscle.

This article presents the concept of iron balance involving:

- the interaction of dietary iron intake and body iron losses
- the role of iron in body functions
- the effects of both iron deficiency and iron excess on exercise performance and health (including some important gender issues)
- prudent guidelines relative to obtaining optimal iron nutrition

Table 1 provides brief definitions of terminology used in reference to iron.

Table 1. Iron terminology

Apoferritin — protein in the intestinal cell that combines with iron compounds to form ferritin
Ferritin — iron bound to the protein apoferritin; major storage form of iron in the body
Hematocrit — the total blood volume that consists of red blood cells (RBCs)
Heme iron — iron combined with protoporphyrin
Hemoglobin — an iron-containing pigment in RBC that transports oxygen
Hemosiderin — an aqueous-insoluble form of storage iron
Hereditary hemochromatosis — a genetic disorder characterized by excess accumulation of body iron stores
Iron depletion — low levels of bone marrow iron stores
Iron deficiency anemia — anemia characterized with below normal hemoglobin concentrations and microcytic (small) and hypochromic (pale) RBC
Iron deficiency without anemia — condition with low body iron stores but normal hemoglobin levels
Myoglobin — iron-containing compound in the muscles; similar to hemoglobin
Nonheme iron — simple elemental iron
Serum ferritin — ferritin stores in the blood
Serum iron — the amount of iron actually bound to transferrin in the blood
Sports anemia — a false anemia; normal iron stores with low-normal hemoglobin levels often observed in aerobic endurance athletes
Transferrin — a blood protein that binds with iron; normally serum transferrin is one-third saturated with iron

Iron balance and dietary sources

Iron is an essential trace mineral, meaning that we need to obtain adequate iron in our diet to replace daily iron losses. Iron is one of the most abundant metals on earth but other than the iron found in the food we eat most exists in a form that can not be used by the human body (1).

Dietary iron exists in two forms, nonheme and heme iron. Iron is present in plants in a form known as nonheme iron. When animals consume plants, some of the iron forms heme iron in the blood and muscles. Approximately 35% to 55% of iron found in animal flesh is heme iron, the percentage being somewhat higher in beef and ham than chicken. One ounce of lean beef, such as round steak, contains about one milligram (1 mg) of iron, 55% of which is heme iron. Table 2 highlights plant and animal foods that are good sources of dietary iron. Food labels also provide information on the Daily Value (DV) for iron content. Some commercial food products, such as cereals, may be fortified to provide 100% of the DV.

The typical Western mixed diet contains approximately 5 to 7 mg of iron per 1,000 kilocalories, with heme iron providing about 10% to 15% of the total food iron. Diets with high meat content may provide 25% or more of iron requirements. The little iron that is available for biological needs exists in both a ferric (Fe^{3+}) and a more readily absorbable ferrous (Fe^{2+}) state.

Iron bioavailability

An important aspect of iron nutrition is bioavailability, or the amount of dietary iron absorbed into the body. A person's body store of iron is the most important factor influencing iron absorption. Individuals with low body stores will absorb more iron and those with high body stores will absorb less. Healthy people absorb about 5% to 10% of dietary iron, and those who are iron deficient absorb about 10% to 20% (1). Furthermore, some dietary factors are also known to enhance iron absorption, while others inhibit its absorption.

Impaired bioavailability

Nonheme iron from plant foods has lower bioavailability than heme iron; only 1% to 2% of nonheme iron is absorbed. Plant foods also contain a variety of substances, such as oxalates, phytates, and tannates that may make iron less soluble and thus reduce its bioavailabilty (2). Additionally, calcium-rich foods or supplements may inhibit iron absorption when consumed together.

Enhanced bioavailability

Animal foods rich in heme iron may improve iron balance in several ways. First, heme iron is taken up directly by the intestinal cells, with approximately 20% to 30%

absorbed. Second, apart from this direct contribution of dietary iron, even small amounts of meat when eaten with plant foods may improve iron balance by enhancing nonheme iron absorption. For example, iron absorption from either maize or black beans is almost doubled when these foods are mixed with animal meat, such as beef, veal, poultry or fish (2). Organic acids such as vitamin C (ascorbic acid) also help to facilitate nonheme iron absorption, primarily by preventing the oxidation of ferrous iron to the less absorbable ferric form.

Normal body losses and increased needs

With iron being a trace element, our bodies zealously defend the few grams of iron that are within each of us (1). For example, basal iron losses for the typical adult male average about 0.90 to 1.05 mg of iron per day. These losses are primarily via small amounts of blood, unabsorbed iron in bile and shedded intestinal cells in the feces, and minute amounts excreted by the kidneys and skin (1).

Basal iron losses in adult women are approximately 0.8 mg per day. Before menopause, teenage and adult females lose more iron because of menstrual blood loss; one ml of blood contains 0.5 mg of iron, so iron loss is influenced by menstrual blood loss. Actual blood loss during menses may range from 30–60 ml or more per cycle (1, 3), which when averaged over the menstrual cycle accounts for a daily iron loss of about 0.5 to 1.0 mg above basal iron losses.

Based on these differences, and using the assumption that only about 10 percent of dietary iron is absorbed, the Recommended Dietary Allowances (RDA) of iron for adult males and teenage and premenopausal adult females, respectively, are 10 and 15 mg per day. Other factors may also influence iron requirements, including puberty (increasing blood volume), pregnancy (iron needs of the fetus), and blood donations (replace blood iron losses). The RDA for teenage males is 12 mg, and the National Research Council now recommends 30 mg of elemental iron during the second and third trimesters of pregnancy. As discussed below, aerobic endurance athletes may have increased iron requirements. In general, the body adapts to increased losses or needs by absorbing more dietary iron.

Functional Iron

More than any other metal, iron is a key element in the metabolism of living organisms (1). The total amount of iron in the body varies among individuals, but it averages approximately 3450 mg in adult males and 2450 mg in adult females. About 30% of total body iron is storage iron, while 70% is functional iron (2).

Iron in excess of need is stored intracellularly in the form of either ferritin or hemosiderin. Some of the absorbed dietary iron is stored in the mucosal cells as ferritin but most is transported in the plasma by an iron-binding glycoprotein called transferrin. Transferrin delivers iron to the liver, spleen, bone marrow, and skeletal

Table 2. Food sources for iron

Good plant sources (nonheme iron)
Leafy greens of the cabbage family, such as broccoli, kale, spinach, collards
Legumes, such as lima beans and green peas; dry beans and peas, such as pinto beans, black-eyed peas, and canned baked beans; nuts
Grain products — whole wheat and iron enriched breads, cereals, rice and pasta
Good animal sources (heme and nonheme iron)
Meats — beef, pork, lamb, and liver and other organ meats
Poultry — chicken, duck, and turkey, especially dark meat
Fish — shellfish, like clams, mussels, and oysters; sardines and other fish
Vitamin C-rich foods to help nonheme iron absorption
Fruits — guava, lemon, orange, tomato
Vegetables — beets, broccoli, cabbage, cauliflower, and pumpkin
Food labels
Food labels are required to list iron content. The label contains the percent of the Daily Value (DV). The Reference Daily Intake used for the DV is 18 mg; thus, a food serving containing 10% of the daily value contains 1.8 mg of iron.

muscle where it is stored as ferritin. Small amounts of ferritin normally circulate in the plasma, and since the plasma ferritin is derived largely from the storage pool of body iron, its level is a good indicator of the adequacy of body iron stores (2). With increasing amounts of tissue iron, the ferritin is stored in an aqueous-insoluble form as hemosiderin. When needed, both storage forms may be released into the blood.

Iron as an essential ingredient for aerobic endurance exercise

In its functional form, iron is one of the most essential nutrients with implications for aerobic endurance exercise. In the body, some iron forms heme. Heme is a component of hemoglobin in the red blood cell (RBC), myoglobin in the muscle cell, and several oxidative enzymes within the mitochondria.

Hemoglobin is formed in the RBC in the bone marrow and comprises about 85% of the functional iron in the body. Hemoglobin combines with oxygen in the lungs for transport via the blood to the muscles and other tissues. The average blood hemoglobin concentration in adult males and females is, respectively, 14 to 16 and 13 to 15 grams per deciliter (g/dl). When fully saturated, each gram of hemoglobin can transport 1.34 ml of oxygen.

Myoglobin (myohemoglobin) is the counterpart of hemoglobin in the muscle cells. Myoglobin constitutes about 12% of the functional iron and transports oxygen within the muscle cell. Total myoglobin levels are lower in females than in males.

Oxidative enzymes comprise the remaining 2% to 3% of functional iron. These heme and nonheme enzymes, such as the cytochromes, are involved in oxidative reactions producing ATP from the metabolism of carbohydrate and lipids.

Compared to females, males have greater amounts of functional iron, particularly hemoglobin and myoglobin, a factor that may confer an advantage relative to aerobic endurance exercise performance.

Iron deficiency

Iron deficiency affects an estimated 40% of the world's population (1) and is the most common known form of nutritional deficiency in the United States (4). Iron deficiency may occur because of an increased need for iron, a decreased intake of iron, or because of increased losses of iron.

Several natural life occurrences may increase iron needs. At the onset of puberty, for example, the increase in lean body mass, particularly muscle, and associated expansion of the blood volume increase iron needs (5). Iron needs are also increased during pregnancy for nutrition of the developing fetus. Moving to high altitude will stimulate RBC production to compensate for the decreased oxygen content in the air, thus increasing iron needs.

Inadequate dietary intake appears to be the main factor underlying iron deficiency in Western diets. Most men, including male athletes (6), consume more than adequate dietary iron. Although Western-type diets with good bioavailability can cover iron requirements in most women, the high prevalency of iron deficiency in menstruating Western women is mainly related to the low iron bioavailability in present diets (7). In the United States, the diet has evolved to consist predominantly of iron-poor dairy products, snack foods, white bread, and soft drinks (1). Additionally, the caloric energy intake of many female athletes is less than might be anticipated based on their training loads, and some may have disordered eating patterns (3) or consume vegetarian-type diets with low iron bioavailability (high fiber content and low heme iron) (8). As a result, intakes of iron in athletic females are often below the RDA (6).

Excess iron loss from the body occurs primarily through excess blood loss. For example, a 500 ml blood donation represents the loss of approximately 250 mg of iron. Lactating females and those with heavy menstrual losses also lose excess iron. Blood may also be lost in the urine and feces.

The scientific literature is mixed relative to the effect of exercise on iron loss. A key factor may be exercise intensity. Several studies (9, 10) have shown that three to six months of *moderate-intensity* aerobic exercise in previously untrained adult females had no effect on selected measures of iron status. However, *very strenuous* aerobic exercise training, such as we see in competitive athletes may induce iron loss, possibly by (3, 11):

- increasing gastrointestinal blood losses, particularly in people who take nonsteroidal antiinflammatory drugs
- producing hematuria (blood in urine) through mechanical rupture of RBCs by footstrikes in runners or by jarring of the urinary bladder
- minor sweat losses

One of the effects of aerobic endurance training is an increase in both plasma volume and RBCs. However, the plasma expansion is usually greater and leads to hemodilution and decreased hemoglobin concentration. Thus, many aerobic endurance athletes may have normal iron stores, but low-normal hemoglobin concentrations. This condition is not a true anemia; it has been referred to as sports anemia. As a matter of fact, it is believed to be a favorable adaptation to endurance training. The increased blood volume can compensate for the moderate reductions in hemoglobin concentration through increases in cardiac output, allowing for $\dot{V}O_{2max}$ to remain unchanged or even increase (12). Nevertheless, although most cases of sports anemia are due to hemodilution, evidence now emerging supports the view that exercise training, particularly distance running, may increase RBC turnover (13).

Stages of iron deficiency

At the outset of negative iron balance, storage iron reserves may be adequate to maintain normal hemoglobin and hematocrit levels as well as normal serum iron (2). However, depletion of these reserves progresses through three stages of iron deficiency (2, 3, 14):

1. Iron depletion is associated with decreased bone marrow iron stores and is characterized by low serum ferritin levels.

2. When iron stores are depleted, heme synthesis is impaired and immature RBC are released.

Stages 1 and 2 are often referred to as iron deficiency, or iron deficiency without anemia.

3. Iron deficiency anemia is associated with small, pale RBC characterized by low hemoglobin concentrations (<12 g/dl in women and <13 g/dl in men) (2).

Prevalence

In a recent study of iron deficiency in the United States involving approximately 25,000 persons, iron deficiency occurred in no more than 1% of teenage boys and young men. However, iron deficiency (9% to 11%) and iron-deficiency anemia (2% to 5%) are still relatively common in adolescent girls and women of childbearing age. In raw numbers, about 7.9 million women have iron deficiency and 3.3 million women have iron-deficiency anemia (15). Despite the recognition of iron deficiency as a major nutritional problem in the United States and despite efforts to ameliorate it, the prevalence of iron-deficiency anemia seems to have remained essentially unchanged or perhaps increased during the past 30 years (1).

Iron deficiency may be more prevalent in some athletes. As evaluated by various blood markers of iron status, many male and female endurance runners, although not anemic, are at risk for depletion of the iron stores. Various studies published in the 1980s have reported that 8% to 58% of male athletes and 40% to 80% of female athletes are iron deficient; the reported number of athletes with true anemia in these studies is low, although significant (16). Given the continuing prevalence of iron deficiency in the general population, a similar situation may exist among endurance athletes.

Supplementation

Should aerobic endurance athletes supplement with iron? The answer depends on the iron status of the athlete. Research indicates that individuals with adequate iron stores will not benefit from iron supplementation and, as noted below, may be subject to adverse health effects. Conversely, remediation of iron-deficiency anemia with the return to normal hemoglobin levels helps return exercise performance to normal. The benefit of iron supplementation in athletes with iron-deficiency anemia is well established (17).

The benefits of iron supplementation to athletic individuals with iron deficiency without anemia are less well defined. In a comparison of nonanemic women who were either iron-depleted or iron-sufficient, those who were iron-sufficient had significantly higher hemoglobin levels. It was also noted that the iron-depleted women had a significantly lower $\dot{V}O_{2max}$, which the researchers attributed to factors related to reduced body iron storage, but not to decreased oxygen-transport capacity of the blood (18). Several studies have noted that the return of normal iron status in nonanemic female athletes following iron supplementation was associated with improved markers of enhanced oxidative metabolism in the muscle during exercise and improved running performance. In one study (10), nonanemic women with low iron status undergoing six months of aerobic training experienced a decline in hemoglobin, while women taking a 50 mg iron supplement did not. Nevertheless, a recent critical review (19) noted that although iron supplementation can raise serum ferritin levels, increases in ferritin concentration unaccompanied by increases in hemoglobin concentration have not been shown to improve endurance performance. Other reviewers (17) agree with this finding, but indicate that the treatment protocols used in some of these studies do not meet the general recommendations for the optimal clinical management of iron deficiency. Additional research with more appropriate supplementation protocols is needed to help resolve this issue.

Some researchers believe that there are sufficient arguments to support controlled iron supplementation in all athletes with low serum ferritin levels to prevent development of iron deficiency (17). Others suggest that athletes having hemoglobin in the low-normal range associated with low ferritin levels may have iron deficiency anemia responsive to iron supplementation (19). For example, a hemoglobin level of 12 g/dl may be in the normal range, but may be subnormal for a female athlete who previously had a level of 14 g/dl. Several sports-oriented physicians have proposed experimental trials of iron supplementation. If iron therapy corrects a mild anemia, such as increasing hemoglobin levels by 1 g/dl, odds are that exercise performance will improve (3, 20).

Excess

Daily iron supplementation in amounts no larger than the RDA appears to be safe. Even larger amounts may not lead to excess body iron accumulation because intestinal cells tends to protect normal persons from the adverse effects of excessive iron ingestion by decreasing iron absorption (1). However, black stools are common, and either constipation or diarrhea may occur.

Conversely, even a large single dose can be highly toxic or lethal to small children who ingest a small handful of iron tablets that look like candy. Moreover, inappropriate and prolonged supplementation with iron to adults who are not iron deficient may needlessly expose them to serious health risks (1). Iron gradually accumulates in the body to dangerous amounts, especially in the liver, but some accumulates in the heart, pancreas and muscles. Excessive iron appears to be directly toxic to host tissues by several mechanisms and may lead to liver cancer or death (2).

Recent epidemiological research from Finland has noted an association between high levels of serum ferritin and risk of coronary heart disease (CHD). One hypothesis suggests that excess iron may generate oxygen free radicals and possibly oxidize LDL-cholesterol, making it more dangerously atherogenic (20). However, a recent meta-analysis based on 12 prospective studies with 7,800 cases indicated that there is no good evidence supporting an association between iron status and CHD (21).

The most serious complication associated with iron overload is hereditary hemochromatosis (HH), a genetic disorder that increases the activity of iron-binding proteins in the intestinal mucosa and liver, effectively increasing iron absorption and storage. Approximately one of every 220 individuals (primarily white males of northern European extraction) is genetically susceptible. The iron accumulates slowly so the disease rarely becomes evident before age 40 (1, 2).

HH is characterized by the excessive accumulation of body iron, primarily as hemosiderin, which can cause severe organ damage, especially in the liver, pancreas and heart. The disorder can lead to liver cirrhosis, liver cancer, diabetes, or cardiac disease (2). A classical sign of HH is a bronze pigmentation of the skin.

Given the prevalence of HH, some physicians recommend a more aggressive screening program beginning at age 20 and repeated every few decades. Testing for high levels of serum ferritin and iron may screen for HH, and removal of excess iron by repetitive blood withdrawals over time promotes recovery of tissue function and prevents irreversible tissue damage so that affected individuals can lead healthier lives (2).

Getting enough iron: Prudent guidelines

Aerobic endurance athletes of both sexes, especially developing adolescent males and adolescent/adult females who undergo prolonged, intense training are susceptible to iron deficiency, with or without anemia. Impaired performance may result (16). At the elite level, the Sports Medicine and Science Division of the United States Olympic Committee recommends screening for hemoglobin and hematocrit twice yearly, and other tests of iron stores might be recommended for menstruating female athletes. Prevention of iron deficiency is an important consideration for all individuals involved in aerobic endurance exercise, and treatment may be necessary for some.

Dietary considerations

Ideally, most physically active individuals should obtain adequate iron through their diets, selecting foods rich in heme and nonheme iron as noted in Table 2. Individuals attempting to lose excess body fat should select foods with high iron density (i.e., foods with a high ratio of iron content to kilocalories). Some examples are presented in Table 3. The following are key points for obtaining adequate dietary iron and prevent iron deficiency:

1. Consume heme-rich iron foods, such as meat, with nonheme-rich foods, such as dried beans and peas, whole wheat bread, and enriched grain products.

2. Consume foods rich in vitamin C with nonheme-rich foods. Drinking orange juice in the morning with iron-enriched toast or cereal will enhance nonheme iron absorption. Many fruits and vegetables are rich in vitamin C.

3. Cook acidic foods, such as tomato sauce, in cast iron cookware; some iron may be leached from the container to the food.

4. Consume fortified breakfast cereals, some of which contain 100% of the DV for iron.

5. Become aware of iron-rich foods and make attempts to incorporate them in the daily diet. Check food labels for iron content. A DV of 10% indicates one serving of the food is a

good iron source (1.8 mg iron), while a DV of 20% or higher indicates it is a high iron source (≥3.6 mg iron).

Supplement considerations

Iron supplements may be recommended for some aerobic endurance athletes, such as athletes who initiate altitude training, athletes who are on restricted caloric intake, female athletes with heavy menstrual blood flow or those who do not eat meat, and those who have low body iron stores. The following guidelines appear to be prudent:

1. Decisions regarding iron supplementation are best made based on the needs of an individual athlete (17).

2. Athletes concerned about their iron status should have an appropriate blood test. According to a leading sports hematologist only two inexpensive tests (a complete blood count (CBC) that includes hemoglobin and hematocrit and a serum ferritin check) are needed to diagnose anemia (20).

3. Individuals with iron-deficiency anemia should consult a physician for iron therapy. Correcting the anemia should enhance aerobic endurance performance.

4. Aerobic endurance athletes with iron deficiency without anemia also may benefit from iron supplementation. An empiric trial of iron supplementation, in amounts similar to those used with iron-deficiency anemia, under the guidance of a health professional is prudent.

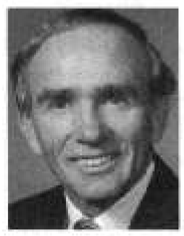
5. Calcium supplements, if used, should not be taken with an iron rich meal, but rather on an empty stomach; do not take calcium and iron supplements at the same time of day.

6. It should be reemphasized that iron supplementation should not be done indiscriminately, but only after determination of one's iron status. There should also be adequate follow-up to evaluate the effectiveness of the therapy and to prevent excess accumulation of iron.

Table 3. Selected foods with high iron density. The numbers in parentheses represent milligrams of iron per 100 kilocalories of food energy.

Almonds (0.8)
Beans, kidney (1.5)
Bread (1.1)
Cereal, Grape Nuts (1.2)
Cereal, Total (18)
Chicken, dark meat (0.8)*
Chicken, white meat (0.6)*
Clams, cooked (18)*
Oysters, cooked (9.6)*
Pasta, cooked (0.8)
Peas, fresh green (5)
Peppers, sweet (1.5)
Raisins (0.9)
Seeds, sunflower (1.2)
Shrimp, cooked (3.1)*
Spinach (15)
Tuna, light (2.4)*
Turkey, dark (1.2)*

*Contains heme iron



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The Condensed Version & Bottom Line

Iron is a key nutrient for aerobic endurance exercise performance. In general, performance differences between male and female aerobic endurance athletes favor the male by approximately 10%. Other physiological or biomechanical factors may help explain these differences, but it is interesting to note that the difference between males and females in functional iron compounds also approximates 10%. Although aerobic endurance athletes of both sexes need to optimize their iron nutrition, it is especially important for female athletes who are more at risk for iron deficiency.