Incidence of Iron Deficiency and Iron Deficient Anemia in Elite Runners and Triathletes

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Objective: To assess the incidence of iron deficiency (ID), and iron deficient anemia (IDA) within a cohort of highly trained runners and triathletes, and to examine the association of oral iron supplementation history with serum ferritin (sFe) and hemoglobin (Hb) concentrations.

Methods: A retrospective analysis of routine blood test data taken from 2009 to 2015 from (n = 38) elite level runners and triathletes between the ages of 21 to 36 years. Oral iron supplement intake was assessed through a questionnaire.

Results: Triathletes (female, FT; male, MT) and runners (female, FR; male, MR) had higher incidence of at least 1 episode of ID (FT 60.0%, MT 37.5%, FR 55.6%, MR 31.3%) compared with values reported in the literature for endurance athletes (20%-50% females, 0%-17% males). Male triathletes and runners had a higher incidence of IDA than their female teammates (25% MT, 20% FT, 6.3% for MR, 0% FR), a finding which has previously not been reported. Hemoglobin concentrations were low, with incidence of Hb <140 g/L in men occurring at least once in 87.5% of triathletes, and 31.3% of runners, and Hb <120 g/L in women occurring at least once in 20% of triathletes, but 0% of runners. Although the athletes were appropriately treated with oral iron (mean 94 ± 115 mg/d), there was no observed correlation between iron intake and sFe or Hb.

Conclusions: Even with monitoring and treatment in place, ID and IDA are significant concerns for the health and performance of elite runners and triathletes, and this issue affects males and females.

Key Words: iron deficiency, anemia, serum ferritin, hemoglobin concentration, iron supplements, elite endurance athletes, hepcidin, performance, iron intake, blood

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INTRODUCTION

Elite endurance athletes are put under large training loads and experience immense physical stress, with the aim of enhancing athletic performance. This training stress, possibly combined with insufficient energy intake, inadequate recovery, and/or external stressors, may cause a wide range of negative health outcomes.1,2 Frequent metabolic dysfunctions seen in elite athletes are iron deficiency (ID) and iron deficient anemia (IDA), both of which can have detrimental effects on aerobic exercise performance and health.3

Iron is an important element that makes up the heme molecules of hemoglobin (Hb) within red blood cells, allowing for oxygen transportation and utilization.4 During anemia, defined as a deficiency of red blood cells, a decrease of Hb impairs oxygen delivery to the tissues, predisposing to performance decrements despite a compensatory increase of cardiac output.5 Endurance athletes are often thought to be at an increased risk of ID and anemia. Possible mechanisms for ID and IDA include intravascular/foot-strike hemolysis,3,4,6 ischemia to the viscera7,9 or frequent non-steroidal anti-inflammatory drug use8 which may promote gastric lesions,2 loss of iron through urine caused by renal ischemia,3 and iron losses through sweat.4

Iron balance may also be affected by an impairment of iron uptake, regulated through the peptide hormone hepcidin, with higher levels leading to a lower iron absorption rate.3 Hepcidin increases in response to inflammation or high iron concentrations in the body, and peaks 3 to 6 hours after an exercise bout. As such, exercise-induced inflammation could limit iron absorption. Oral iron supplementation also acutely increases hepcidin release,10 and as hepcidin has a circadian increase throughout the day, this may have implications for the optimal timing of supplementation and training to maximize bioavailability.10 Peeling et al.11 demonstrated that an increase in hepcidin because of inflammation was attenuated by very low iron status (sFe < 30 μg/L), suggesting that iron availability supersedes inflammation in its regulation.8 Finally, food restriction or specific diets may contribute to increased risk of ID and IDA in athletes.1
increased risk with up to 50% of distance runners presenting with sFe <20 µg/L.\(^{14}\) In the general population, ID is seen in close to 20% of females, 5% to 6% of postmenopausal women, and 1% to 4% of males.\(^{2}\) Causes of ID/IDA in the general population may be attributed to diet, blood loss, or insufficient uptake and exacerbated loss through the gut because of conditions such as colitis, helicobacter pylori infection, or celiac disease.\(^{3,12}\) In the literature to date, low sFe levels (<12 to <20 µg/L) are rare among male endurance athletes with reports of incidence from 0% to 17%.\(^{2}\) The discrepancy between males and females is usually attributed to loss of iron during menstruation in women, and differences in dietary intake.\(^{4}\)

Low Hb concentrations and IDA are less frequent than isolated ID. Several studies have shown that less than 8% of athletes have low Hb (<120 g/L for women and under <140 g/L for men).\(^{12}\) Differences in training status (elite vs sub-elite), sex, diagnostic cutoffs, and type of sport, should all play a role in the incidence and prevalence of ID and IDA.\(^{4}\)

Research on ID and IDA has defined their study population to female athletes because of the historically higher prevalence, and although we know men are also susceptible to these issues within endurance sport, they may be overlooked.\(^{1}\) Compounding this is the fact that many studies have not considered truly elite athletes within WC, world cup.

Furthermore, the efficacy of supplementation for preventing or reducing anemia is debatable.\(^{8,12}\) Thus, we sought to retrospectively assess the prevalence of ID and IDA within a cohort of elite, international caliber runners [male runners (MR)/female runners (FR), and triathletes [male triathletes (MT)/female triathletes (FT)]. As a secondary purpose, we sought to correlate iron supplementation history with incidence of ID and IDA to assess clinical efficacy in these endurance athletes.

**METHODS**

A retrospective study design was used using blood data from routine blood tests from spring 2009 until fall, 2015. Iron supplementation intake and history were obtained through questionnaire.

**Subjects**

Twenty-five (16m/9f) middle- (800 m-5 km) to long-distance (10 km to Marathon) runners and 13 (8m/5f) elite International Triathlon Union triathletes (sprint and Olympic distance), aged 21 to 36, were included in this study. Demographic information is presented in Table 1. Runners and triathletes were affiliated with the elite track and field or triathlon training centers, and all resided in Canada. The “elite” status of the athletes was based on the high standard of performance required to train with the centers, and the level of competition of the athletes. All athletes competed minimally at a national level (n = 3), and the majority competed internationally (n = 35).

**Blood Samples**

Under the supervision of a sports medicine doctor, venous blood samples were used for evaluation of ID and IDA with measurement of sFe and Hb concentration. All tests were taken in the morning, preworkout. White blood cell count was measured to screen for acute infection, which could increase sFe concentrations as iron is an acute phase reactant.\(^{1}\) Iron deficiency was evaluated based on 2 criteria: complete medical ID as <15 µg/L as defined by the WHO,\(^{16}\) and ID that impacts performance as <25 µg/L.\(^{17}\) Low Hb was also evaluated using 2 criteria for men, with Hb <140 g/L being “moderate anemia,”\(^{15}\) and <130 g/L being “anemia” as indicated by the WHO.\(^{16}\) For women, low Hb was designated as <120 g/L.\(^{3,16}\) Iron deficient anemia status was defined by concurrent low iron and low Hb within a single blood test, as defined by <25 µg/L sFe, and <120 g/L Hb for women, and both <130 and <140 g/L Hb for men. As blood tests for Hb concentration can be affected by plasma volume, (hemoconcentration or dilutional pseudo-anemia\(^{3}\)), low Hb concentration and low sFe together were required for a designation of IDA.

**Iron Intake**

Iron supplementation history was assessed through written questionnaire after the collection of blood data. Athletes were asked if and/or when they first began taking iron supplements. Participants were also asked what brand of iron supplement they use, what dose they take, and what dose they have previously taken. Finally, reports of any iron infusions or injections and approximate dates of those procedures were collected. Average weekly supplemental iron intake, measured in elemental iron (milligram), was calculated for each athlete, because many athletes did not take iron everyday. Most athletes maintained weekly iron supplementation intake over time (2009-2015), and so the effect of

**TABLE 1. Descriptive Characteristics of Elite Runners and Triathletes in a Study of the Incidence of ID and IDA**

<table>
<thead>
<tr>
<th></th>
<th>Sex (n)</th>
<th>Age (Mean ± SD)</th>
<th>Competition Level (n)</th>
<th>Type of Athlete (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Runners</td>
<td>Male (16)</td>
<td>26.6 ± 4.7</td>
<td>O (4), IC (10), NC (2)</td>
<td>M (3), 5-10k (4), 3k SC (5), 800-1500 m (4)</td>
</tr>
<tr>
<td></td>
<td>Female (9)</td>
<td>23.3 ± 3.5</td>
<td>IC (8), NC (1)</td>
<td>5-10k (3), 3k SC (2), 800-1500 m (4)</td>
</tr>
<tr>
<td>Triathletes</td>
<td>Male (8)</td>
<td>22.4 ± 2.6</td>
<td>ITU WC (4), ITU CC (4)</td>
<td>ITU sprint/olympic DL (8)</td>
</tr>
<tr>
<td></td>
<td>Female (5)</td>
<td>23.0 ± 11</td>
<td>ITU WC (4), ITU CC (1)</td>
<td>ITU sprint/olympic DL (5)</td>
</tr>
</tbody>
</table>

CC, continental cup; DL, draft legal; IC, international competition; ITU, International Triathlon Union; M, marathon; NC, national competition; O, olympics; SC, steeplechase; WC, world cup.
changes in iron intake and subsequent sFe or Hb status could not be measured.

Statistics
Statistical analysis was performed using SPSS (SPSS v.23.0; IBM, Inc, Chicago, IL). Descriptive statistics are presented as mean ± SD. For comparison of mean sFe and Hb between groups, independent sample Student t tests were used, with significance set a priori at P < 0.05. Linear regression was used to assess the association of individual elemental iron intake with mean individual sFe and Hb.

RESULTS
Ferritin and Hemoglobin Status
Mean sFe and Hb concentrations from all blood tests are displayed in Table 2. There were significant Hb differences (P < 0.01) between males and females for both sports, as expected. Mean Hb levels were significantly lower in MT than in MR (P < 0.01), however, mean sFe levels were higher in MT (P < 0.05). Females had similar sFe and Hb levels across sports.

Incidence of Iron Deficiency and/or Anemia
The incidence of at least 1 episode of either ID (sFe <15 and <25 μg), low Hb (Hb concentrations <140 and <130 g/L for males, and <120 g/L for females), and a diagnosis of anemia are displayed in Table 3. Recognizing the necessity of establishing cutoff values, it is interesting to note that although 20% of FT had Hb <120 g/L at 1 or multiple points in time, a full 60% experienced Hb concentrations <125 g/L. None of the FR had a Hb concentration <120 g/L; however, 2 of the 9 (22.2%) had a Hb concentration <125 g/L. Of the MT, 87.5% had at least 1 occurrence of Hb concentrations <140 g/L, and although 25% had an occurrence of Hb <130 g/L, this increased to 50% if the cutoff was 135 g/L. The MR had the lowest incidence of low Hb at 31.3% <140 g/L, and 12.5% <135 g/L, but none <130 g/L. Of the triathletes who had sFe <25 μg once, 83% of them (5/6) had a second episode, and 67% (4/6) had it 3 times or more. Of the 4 who experienced IDA, 2 (50%) had subsequent episodes. The runners did not have enough individual blood tests to perform this analysis.

Iron Intake
The weekly intake of elemental iron (milligram) is displayed by group in Figure 1. Most athletes did not change their iron supplementation protocol over time, precluding comparison of alterations in iron intake with blood markers of ID and IDA. In cases where iron intake did change significantly (n = 2), the most temporally relevant value was used. The FT reported the highest oral supplemental iron intake, however, all groups had a wide intersubject range. Mean elemental iron intake for all the groups was 560 ± 549 mg/wk or 80 ± 78 mg/d (excluding infusions). Four athletes had 1 session of iron intravenous infusions throughout the testing period (n = 3 MT, and n = 1 FR). The triathletes who had multiple episodes of ID (n = 5) were taking 1410 ± 477 mg/wk on average. Supplement intake was not correlated to individual mean sFe or Hb concentrations, as can be seen in Figure 2.

DISCUSSION
The major novel findings of this study are that the elite triathletes and runners demonstrated a higher prevalence of ID than previously reported in the literature, and most groups had significantly higher occurrences of low Hb than expected, despite high-quality monitoring and medical care. Furthermore, MR and MT had higher incidences of IDA than their female teammates, which have not previously been reported in the literature. Finally, triathletes may be at an increased risk for low Hb and IDA compared with runners. Although the athletes in this study took very high doses of supplemental iron, there was no correlation between their supplemental oral iron intake and sFe or Hb concentrations.

Serum Ferritin and Hemoglobin Concentrations
The mean sFe and Hb for each group of athletes in this study fell within the clinically healthy ranges of 35 to 200 μg/L for sFe,7,18 Hb of 120 to 160 g/L in females, and Hb of 140 to 180 g/L in males,19 with the female athletes having lower mean

<p>| TABLE 2. Serum Ferritin and Hemoglobin Concentrations of Elite Triathletes and Runners From Routine Blood Tests Taken from 2009 to 2015 |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|</p>
<table>
<thead>
<tr>
<th><strong>Sex</strong> (&lt;i&gt;n&lt;/i&gt;)</th>
<th><strong>sFe Tests (&lt;i&gt;n&lt;/i&gt;)</strong></th>
<th><strong>Hb Tests (&lt;i&gt;n&lt;/i&gt;)</strong></th>
<th><strong>Mean Ferritin ± SD (μg/L)</strong></th>
<th><strong>Mean Hb ± SD (g/L)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Runners</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male (16)</td>
<td>59</td>
<td>56</td>
<td>61.0 ± 31.8*</td>
<td>148 ± 87††</td>
</tr>
<tr>
<td>Female (9)</td>
<td>43</td>
<td>44</td>
<td>54.2 ± 61.4*</td>
<td>133 ± 64‡‡</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>---------------------------------</td>
<td>---------------------------------</td>
<td>---------------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>Triathletes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male (8)</td>
<td>68</td>
<td>70</td>
<td>84.1 ± 62.1*‡</td>
<td>141 ± 84‡‡</td>
</tr>
<tr>
<td>Female (5)</td>
<td>56</td>
<td>66</td>
<td>57.3 ± 40.6‡</td>
<td>133 ± 78‡‡</td>
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<tr>
<td>---------------------------------</td>
<td>---------------------------------</td>
<td>---------------------------------</td>
<td>---------------------------------</td>
<td>---------------------------------</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female (14)</td>
<td>99</td>
<td>110</td>
<td>55.9 ± 50.48§</td>
<td>133 ± 78‡‡</td>
</tr>
<tr>
<td>Male (24)</td>
<td>127</td>
<td>126</td>
<td>73.4 ± 51.5§</td>
<td>144 ± 94§‡</td>
</tr>
</tbody>
</table>

*Significant difference between triathletes and runners of same sex P < 0.05.
†Significant difference between triathletes and runners of same sex P < 0.01.
‡Significant difference between females and males of same sport P < 0.01.
§Significant difference between females and males for both sports P < 0.05.
sFe concentrations compared with male athletes (Table 2). This is consistent with previous mean sFe and Hb values among athletes.20 Although females tend to have lower sFe values than men because of menstruation,13 it is unlikely that the women athletes in our study were all eumenorrheic; however, the common use of hormonal birth control in our sample did not allow us to determine menstrual history or health. Furthermore, while men did have a mean sFe in the healthy range, 3/8 MT had received an intravenous iron infusion at least once, which was followed by a large increase in their sFe in the following blood test, and then a consequent return to previous levels over a number of months. These data were not removed, because it was difficult to ascertain how long the infusion would have affected the following tests. Furthermore, one of the MT had consistently high sFe values (mean sFe 211.7 μg/L), which caused the mean sFe levels of the group to be greatly increased. When the mean from the individual was removed, the group mean for MT sFe was reduced from 84.1 ± 62.1 to 53.8 ± 25.6, which was less than the mean sFe of the female athletes.

Although the mean sFe for all groups were clinically healthy compared with most reference ranges, they were on the low end because some studies suggest that sFe levels can still be considered low at <99 μg/L.7 Verdon et al21 demonstrated that nonanemic women with sFe <50 μg/L improved mood and fatigue with iron supplementation demonstrating that the women in our study, whose mean sFe was 55.9 ± 50.4, could likely benefit from additional iron. The mean Hb concentrations of the male athletes in this study, and in particular the MT, were also quite low. Some studies suggest that Hb <140 g/L defines anemia in males,12 and there are data to suggest that the low end of anemia defined as <130 g/L by the WHO should be revised to a minimum of <136 g/L.22 Because the MT had a mean Hb of only 141 ± 8 g/L with iron infusions and outliers included in the data, it is likely that many of the MT are consistently at risk for anemia. Furthermore, while symptoms of anemia may not yet be occurring in these athletes, performance may be compromised. It is clear that increased Hb will improve performance through increased oxygen delivery to the tissues, as is seen when athletes increase Hb mass through erythropoietin stimulation from altitude training or through banned exogenous methods.23

Athlete’s pseudoanemia, or the expansion in plasma volume that occurs with endurance training, could explain some of the low Hb values seen in these athletes.24 Ideally, Hb would have been measured as hemoglobin mass, which is not affected by plasma volume expansion,25 however, this is not yet practical for routine testing. As sFe is not influenced by plasma volume a combination of low sFe and Hb was required for a diagnosis of IDA in this article.

### Incidence of Iron Deficiency and Iron Deficient Anemia

In previous literature, the prevalence of ID in endurance athletes is variable, with 20% to 50% of female athletes presenting with low iron6,14,18 and 0% to 17% of male athletes presenting with low sFe.4 Iron deficient anemia remains fairly infrequent in the sports literature, with up to 10% to 15% of female athletes having IDA, but with males rarely presenting.4 Furthermore, Zoller and Vogel12 suggested that low Hb concentrations (<140 and <120 g/L, indicative of anemia) occur in fewer than 8% of conditioned elite athletes. In this investigation, we observed a much higher incidence of ID and IDA than previously suggested. Twenty-five percent of MT, 60% of FT, and 1 FR had sFe <15 μg/L indicative of complete iron store depletion.16 This increased to 31.3% of MR, 37.5% of MT, 55.6% of FR, and 60% of FT, who had at least 1 episode of sFe <25 μg/L, which has been shown to be detrimental to aerobic performance.17 As some research is now using <30 μg/L as the cutoff for absolute ID, the incidence of low sFe may be even higher in our population of elite endurance athletes. In addition, 87.5% of the MT, and 31.3% of the MR had Hb values <140 g/L, which is significantly higher than the 8% of athletes suggested by Zoller and

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### TABLE 3. Incidence of at Least One Episode of ID, Low Hb, or IDA From Routine Blood Tests Taken From 2009 to 2015 in Elite Triathletes and Runners

<table>
<thead>
<tr>
<th>Subjects (n)</th>
<th>sFe &lt; 15 μg/L (L (%))</th>
<th>sFe &lt; 25 μg/L (L (%))</th>
<th>Hb M &lt; 140 g/L (%)</th>
<th>Hb M &lt; 130 g/L (%)</th>
<th>Hb F &lt; 120 g/L (%)</th>
<th>&lt;130/♀ &lt;120 g/L and sFe &lt;25 μg/L (%)</th>
<th>&lt;140 g/L and sFe &lt;25 μg/L (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FT (5)</td>
<td>60.0</td>
<td>60.0</td>
<td>—</td>
<td>—</td>
<td>20.0</td>
<td>20.0</td>
<td>25.0</td>
</tr>
<tr>
<td>MT (8)</td>
<td>25.0</td>
<td>37.5</td>
<td>87.5</td>
<td>25.0</td>
<td>—</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td>FR (9)</td>
<td>11.1</td>
<td>55.6</td>
<td>—</td>
<td>—</td>
<td>0.0</td>
<td>0.0</td>
<td>—</td>
</tr>
<tr>
<td>MR (16)</td>
<td>0.0</td>
<td>31.5</td>
<td>31.3</td>
<td>0.0</td>
<td>—</td>
<td>0.0</td>
<td>6.3</td>
</tr>
</tbody>
</table>

♂, males; ♀, females.
The incidence of IDA within our study occurred primarily in triathletes, as 20% of the FT and 25% of the MT had at least 1 occurrence of IDA. The increased occurrence of IDA in triathletes compared with runners, and compared with values seen in the literature, suggests that the increased training volume, or multiple high-intensity workouts within the same day could be blocking iron absorption. Inadequate iron intake combined with extremely high

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FIGURE 2. Mean individual sFe and Hb in relation to reported weekly elemental iron supplement intake for elite triathletes and runners.

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levels of training, causing increased inflammation, intravascular hemolysis, ischemia to visceral and kidney tissues, and loss through sweat, could explain these differences. There may also be differences in monitoring or supplementation protocols between groups. It is uncertain why the men in this study had increased occurrence of IDA over females.

Iron Supplementation

In our study, iron supplementation was not correlated with mean individual sFe or Hb levels. Although the recommended daily allowance for iron supplementation is 18 mg/d for women, and 8 mg/d for men, and the upper limit set at 45 mg/d, our athletes were taking on average 80 mg/d for women, and 8 mg/d for men, and the upper limit with mean individual sFe or Hb levels. Although the highest fractional absorption was achieved with doses between 40 and 80 mg, and the subsequent increase in hepcidin over 48 hours from doses over 40 mg resulted in significantly lower absorption rates. This suggests that low-dose iron supplementation (40-60 mg) taken on alternate days may increase iron absorption while limiting gastrointestinal exposure to unabsorbed iron.

This research is not without limitations. Owing to the retrospective nature of our study, we could not accurately assess dietary iron intake, quantify training loads and/or performance, or assess menstrual history or health in the female athletes, but it is worth noting that all athletes had access to the highest level athlete support teams to optimize the training response to each of these factors. We did not have markers of inflammation in our blood tests such as C-reactive protein or interleukin-6 (IL-6) to assess states of inflammation which acutely raise sFe and may increase hepcidin levels, but this offers a promising area for future research. We also did not have data on soluble transferrin receptor (sTfR), which is regulated by cellular iron status and is unaffected by inflammation. Total body iron (milligram per kilogram) can be calculated using a ratio of sTfR to sFe, which would have strengthened our analysis. Finally, the assessment of oral iron supplement intake using a questionnaire must be regarded as an estimation of what the athletes were taking and insight into supplementation patterns, because the longevity of the study and recall bias does not allow for an accurate assessment of what the athletes actually took, which may have differed slightly over time or from their prescription.

Recommendations

It is clear that ID and IDA are common issues in elite endurance sport, and are quite difficult to treat and prevent. Ensuring sufficient dietary intake of heme iron, as well as adequate calories from a nutrient rich diet to ensure energy balance as often as possible, is likely the best form of prevention. Oral iron supplementation is often necessary for the prevention of IDA, however, lower doses (<60 mg/d) taken on alternate days, and preferably in the morning before training may optimize iron absorption and limit gastrointestinal damage. Further research into optimal oral iron supplementation doses and timing in elite endurance athletes is necessary to determine the ideal supplementation protocol.

REFERENCES