Impact of Iron Depletion Without Anemia on Performance in Trained Endurance Athletes at the Beginning of a Training Season: A Study of Female Collegiate Rowers

Diane M. DellaValle and Jere D. Haas

The objective of this study was to determine the impact of iron depletion without anemia on performance in a sample of female collegiate rowers at the beginning of a training season (August 2008, January 2009, and September 2009). One hundred sixty-five female collegiate rowers from 5 colleges and universities in central New York State participated in a screening of iron status. Blood hemoglobin (Hgb), serum ferritin (sFer), and soluble transferrin receptor were measured to determine prevalence of iron depletion and anemia. Rowers’ habitual moderate and vigorous physical activity, as well as their best time to complete a 2-km simulated race during the previous 3 months, were self-reported. Sixteen rowers (10%) were identified as anemic (Hgb <12.0 g/dl). Using a sFer cutoff of <20.0 μg/L, 30% (n = 44) of the nonanemic rowers were identified as iron depleted without anemia and reported 2-km times ~21 s slower (p < .004) than rowers with normal iron status. Given the high prevalence of iron depletion reported in this and other studies, screening for low iron stores at the start of a training program in female athletes involved in an endurance sport may be clinically useful. In this study, iron-depleted rowers (sFer <20–25 μg/L) reported a decrease in performance time compared with those with normal iron stores.

Keywords: iron deficiency, physical performance, serum ferritin, female athletes, rowing training

Iron deficiency is the most prevalent nutrient deficiency in the world. In the United States, iron deficiency with anemia affects 3–5%, and iron deficiency without anemia (IDNA), ~16%, of premenopausal women (Cogswell et al., 2009). Changes in energy metabolism and physical work capacity have been described in humans and animals with iron depletion (Beard, 2001; Haas & Brownlie, 2001; Willis, Brooks, Henderson, & Dallman, 1987). Compared with their sedentary counterparts, female athletes are more susceptible to IDNA (25–35%), which is 5–7 times more prevalent than iron deficiency with anemia (Constantini, Eliakim, Zigel, Yaaron, & Falk, 2000; Dubnov & Constantini, 2004; Dubnov et al., 2006; Malczewska, Blach, & Stupnicki, 2000; McClung, Marchitelli, Friedli, & Young, 2006; Sinclair & Hinton, 2005). Beyond the age-related factor of menstrual status, the increased prevalence of IDNA in active or training women may be a result of one or a combination of the following factors: hemolysis (foot strike, impact; Ehn, Carlmark, & Hoglund, 1980; Peeling, Dawson, Goodman, Landers, & Trinder, 2008), increased iron loss (gastrointestinal tract, hematuria, sweat; Weaver & Rajaram, 1992), poor dietary iron intake (Fogelholm et al., 1992; Hassapidou & Manstrantoni, 2001; McClung et al., 2006; Steen, Mayer, Brownell, & Wadden, 1995), or altered intestinal iron absorption, including the effects of inflammation resulting from training (Akabas & Dolins, 2005; Beard & Tobin, 2000; Collins, Wessling-Resnick, & Knutson, 2008; Peeling et al., 2008; Weight, Alexander, & Jacobs, 1991), although the exact mechanism is unknown.

Collegiate rowers are endurance athletes who train primarily at submaximal levels (75–85% of their VO2max), during which oxidative metabolism is the main energy pathway and throughout which iron plays an important role. It has been shown that the activity of iron-dependent enzymes and cytochromes needed for oxidative metabolism are decreased in animals (Willis, Dallman, & Brooks, 1988) and humans (Celsing, Ekblom, Sylvén, Everett, & Astrand, 1988) with IDNA, which leads to impaired endurance performance. Thus, consequences of IDNA particularly relevant to endurance athletes include reduced endurance capacity and energetic efficiency (Hinton, Giordano, Brownlie, & Haas, 2000) and increased local muscle fatigue (Brutsaert et al., 2003).

Serum ferritin (sFer) is the most common index of body-iron stores and reflects iron stored in the liver. sFer can be falsely elevated in an inflammatory state (e.g., infection, postexercise), in which case inflammatory markers such as C-reactive protein or α-1-acid glycoprotein can aid in the assessment of iron status (Beard, Murray-Kolb, Rosales, Solomons, & Angelilli, 2006; Northrop-Clewes, 2008; Thurnham et al., 2010). Soluble transferrin receptor (sTfR), a transmembrane protein regulated by cellular iron status, reflects iron deficiency at the tissue level and is a more sensitive index of functional iron deficiency than sFer. Unlike sFer, sTfR is unaffected by inflammation and has been shown to have lower within-subject variability in intensely training conditions.

The authors are with the Div. of Nutritional Sciences, Cornell University, Ithaca, NY.
athletes (Malczewska et al., 2000). sFer and sTfR respond to iron supplementation in opposite directions (sTfR decreases and sFer increases with supplementation or repletion of iron stores). Total body iron (mg/kg) can be calculated using a ratio of sTfR to sFer (Cook, Flowers, & Skikne, 2003), but in a population with a low prevalence of anemia, calculated total body iron is driven by sFer.

The purpose of this study was to examine the iron status of female collegiate rowers at the beginning of a training season and determine the association between IDNA and reported rowing performance.

**Methods**

**Recruitment of Subjects**

This study was approved by the institutional review boards of Cornell University, Binghamton University, Syracuse University, Hobart & William Smith Colleges, and Ithaca College. Rowers were recruited over a period of 3 years (spring 2006, fall 2008, spring 2009, and fall 2009). Varsity and second-semester novice female rowers who were >18 years of age and able to begin regular training for their sport were eligible to participate in the screening. Subjects were recruited at the beginning of the conditioning phases of their competitive rowing seasons (on arrival on campus postsummer and postwinter break). Training activities during this time included general aerobic conditioning (cycling, running, rowing on ergometer), resistance training, and high-intensity rowing training.

Team coaches were instrumental in recruitment and screening efforts. A medical screening (NCAA-required) before our screening excluded all athletes not healthy enough to participate in their rowing training (current, acute, or chronic illness; severe asthma; musculoskeletal problems). All rowers provided written voluntary informed consent before participating in the study. Out of 199 eligible female rowers, 165 completed the iron-status screening. Subjects received iron-status results as a benefit of participation, along with referral or recommendations to improve iron status if necessary.

**Measurements**

After NCAA medical clearance, iron-status variables were measured for each subject and demographic, as well as information on current dietary supplement use, health and menstrual status, and habitual physical activity. Height and weight were self-reported and later validated with measured height and weight in a subsample of 48 subjects who participated in an intervention trial (height \( r = .98, p < .001 \); weight \( r = .99, p < .001 \); no systematic bias). Time spent in light to moderate and vigorous physical activity was quantified via self-report (habitual endurance training and leisure-time physical activity frequency, intensity, and duration; Craig et al., 2003). Performance was assessed via self-reported best times to complete a 2-km simulated race on the ergometer from the previous season (2–3 months before iron-status screening). Reported 2-km times were also later validated with measured performance in the aforementioned subsample of 48 rowers (VO\(_{2\text{peak}}\) L/min: \( r = -.69, p < .001 \); 4-km time, min: \( r = .64, p < .001 \)).

Iron-status variables measured immediately after nonfasting venous blood sampling (antecubital venipuncture into two evacuated tubes with EDTA and serum separator) included hemoglobin, hematocrit, red blood cell count (Beckman Coulter, Fullerton, CA), sFer (Immulate 2000), sTfR (ELISA, Ramco Laboratories, Stafford, TX), and α-1-acid glycoprotein (radial immunodiffusion plate, Kent Laboratories, OR). Rowers were classified as either iron depleted (sFer <20 μg/L) or normal (sFer ≥20 μg/L). All anemic subjects (n = 16) were notified of their status immediately after blood test results (within 1 week of analysis) and referred to their respective campus health services for further instruction and monitoring or treatment.

**Data Analysis**

All data analysis was conducted using SPSS (version 18.0, SPSS Inc., Chicago, IL). Data were examined to verify normality of distribution, and skewed distributions were log-transformed as appropriate. Descriptive statistics are presented as \( M \pm SD \). Student’s t test and ANOVA were used to analyze differences between groups for iron status (iron depleted vs. normal) with respect to all variables measured. When a significant overall difference was detected, Bonferroni’s post hoc analysis was used. Pearson’s correlations were used to examine associations between variables. To investigate the effects of iron status on physical performance, multiple-regression analysis was conducted between physical performance (2-km time) and sFer group status (based on sFer cutoff of 20.0 μg/L) with potential confounders included as covariates in the regression models (height, time spent training, and years of rowing experience). A significance level of \( p < .05 \) was used to test the main effect of iron status on reported performance, and \( p < .10 \) was the level of statistical significance used to test the interaction effects.

**Results**

Sixteen rowers (10%) were identified as anemic (hemoglobin <12.0 g/dl; Cogswell et al., 2009) and eliminated from subsequent analyses. Results of the iron-status screening of nonanemic rowers are presented in Table 1. Thirty percent (n = 44) of the nonanemic rowers were found to be iron depleted (sFer <20.0 μg/L), and 12% (n = 18) were clinically iron deficient (sFer <12.0 μg/L). There were no significant differences between rowers with depleted or deficient iron status and those with normal iron status in any demographic variable. Twenty-eight nonanemic rowers (19%) had high values of sTfR (>8.0 mg/L; Brownlie, Utermohlen, Hinton, Giordano, & Haas, 2002), and 10% had total body iron <0 mg/kg, indicating severe iron deficiency. Three rowers had an α-1-acid glycoprotein value >140 mg/dl, indicating inflammation.
Nineteen percent of screened subjects had a previous history of anemia or physician-diagnosed iron deficiency.

On average, rowers were 19.7 ± 1.2 years of age and 170.7 ± 7.3 cm tall and weighed 69.5 ± 8.1 kg (BMI 23.7 ± 3.3 kg/m²). Across the sample, rowers had 3.0 ± 2.3 years rowing experience and a previous-season 2-km time of 7 min and 48 s (469 ± 25 s) and spent 6.4 ± 2.2 hr/week in combined moderate and vigorous physical activity. Thirty-three percent of the sample reported consuming a multivitamin/mineral supplement either intermittently or regularly. Reported time spent in light to moderate physical activity per week was positively associated with years of rowing experience ($r = .29$, $p = .03$), and height and weight were negatively correlated with 2-km performance time ($r = -.51$ and $-.39$, respectively, $p < .001$), with taller and heavier rowers reporting faster times.

Multiple-regression analyses revealed that sFer group, height, and years of rowing experience were each a significant predictor of 2-km performance time ($p < .05$). For these nonanemic subjects, hemoglobin was not a significant predictor of 2-km time and was not included in the multiple-regression models, and there were no significant interactions between iron status and the amount of time spent in physical activity. For rowers with sFer $<20.0$ μg/L, 2-km times were 21 s slower than for rowers with normal iron status ($p = .004$; see Figure 1). As expected, the relationship between sFer status and 2-km time was stronger for those with sFer $<15$ μg/L ($\beta = -29.4$ s, $p = .002$). This relationship remained significant

### Table 1 Iron Status of Nonanemic Female Collegiate Rowers (Between Schools) at the Beginning of Training Season, $N = 149$

<table>
<thead>
<tr>
<th>Iron-status index</th>
<th>$M \pm SD$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serum ferritin (μg/L)</td>
<td>33.6 ± 22.1</td>
</tr>
<tr>
<td>Log serum ferritin (μg/L)</td>
<td>1.4 ± 0.3</td>
</tr>
<tr>
<td>Hemoglobin (g/dl)</td>
<td>13.2 ± 0.7</td>
</tr>
<tr>
<td>Red cell distribution width (%)</td>
<td>13.0 ± 1.2</td>
</tr>
<tr>
<td>Hematocrit (%)</td>
<td>40.7 ± 2.2</td>
</tr>
<tr>
<td>Mean cell volume (fl)</td>
<td>88.8 ± 3.5</td>
</tr>
<tr>
<td>Soluble transferrin receptor (mg/L)</td>
<td>6.5 ± 1.9</td>
</tr>
<tr>
<td>Total body iron (mg/kg)</td>
<td>3.8 ± 3.0</td>
</tr>
</tbody>
</table>

*Note. fl = femtoliter.*

![Figure 1](image-url) — The impact of iron deficiency without anemia on rowers’ reported 2-km performance (means adjusted for years of rowing experience and height, $p = .004$). *Depleted rowers (serum ferritin $<20.0$ μg/L) significantly different from nondepleted rowers (serum ferritin $>20.0$ μg/L), $p = .004$.
using a higher sFer cutoff of 25 μg/L (β = –17.4 s, p = .01) but was no longer significant using a sFer cutoff of 30 μg/L (β = –6.7 s, p = .38).

**Discussion**

The 30% prevalence of IDNA in the female rowers in this study was similar to that previously reported for other female athletes participating in endurance sports, as well as female soldiers (Constantini et al., 2000; Dubnov & Constantini, 2004; Dubnov et al., 2006; Malczewska et al., 2000; McClung et al., 2006; Sinclair & Hinton, 2005). It is possible that the prevalence of IDNA in our study may have been affected by either chronic or intermittent intake of multivitamin or mineral supplements, some of which contain iron. Furthermore, the sFer cutoff of 20 μg/L may have misclassified rowers as normal, and examination of optimal sFer levels for female athletes is warranted.

In addition to rowers’ physical characteristics, sFer status was significantly related to reported 2-km performance times. We found a degree of association between sFer status and reported performance times comparable to what has been reported in iron-supplementation trials (Brownlie et al., 2002; Brownlie, Utermohlen, Hinton, & Haas, 2003; Brutsaert et al., 2003; Hinton et al., 2000), confirming our sFer cutoff of 20 μg/L as sensitive. Again, using the cutoff of 20 μg/L may have misclassified IDNA rowers as normal, affecting this relationship. In this study, 42% of rowers had sFer <25 μg/L, and the relationship between sFer and reported 2-km performance time remained significant using this cutoff.

It is biologically plausible that rowers’ 2-km time is associated with poor iron status. As mentioned previously, there are several iron-dependent enzymes involved in the transformation of chemical to mechanical energy during oxidative metabolism, which is the main energy pathway used by rowers during endurance training and most competitive events performed submaximally, around the lactate threshold. During high-intensity activities such as a 2-km ergometer time trial, impaired O₂ transport capacity, even in the absence of frank anemia, may result in increased reliance on anaerobic metabolism to produce energy (greater lactate production at an earlier stage of exercise; Schoene et al., 1983; Zhu & Haas, 1998b). Because of the nature of this survey and our self-reported performance variable, we did not have a measure of maximal oxygen consumption or blood lactate in these rowers, but this would be important to confirm in the laboratory.

Our sample of collegiate female rowers is one at high risk for iron depletion because of their menstrual status and high training load, among other factors mentioned herein. With the exception of the acute-phase protein α-1-acid glycoprotein as a marker of inflammation (which was not used to exclude subjects from the analysis), these factors were not measured in the current study.

Strategies to easily screen and improve iron status may be useful for female endurance athletes at the beginning of a training season, because data suggest that iron status of very active women may decrease with increased levels of physical training over time (Ashenden, Martin, Dobson, Mackintosh, & Hahn, 1998; Brigham, Beard, Krimmel, & Kenney, 1993; Diehl, Lohman, Smith, & Kertz, 1986; McClung et al., 2009). In a recent study, McClung et al. (2009) examined 94 female U.S. Army recruits before and after 9 weeks of basic combat training and found that sFer decreased by 20% (p < .01). In other studies of female athletes, decreases in sFer (~25%) were associated with training (Ashenden et al., 1998; Brigham et al., 1993).

Early screening and iron supplementation, both of which have been shown to improve resistance to fatigue and endurance capacity in IDNA nonathletes (Brutsaert et al., 2003; Hinton et al., 2000), may be beneficial to female endurance athletes at the beginning of a season to help prevent further decrements in iron status throughout the training and competitive seasons. Given the modest relationship between early-season iron status and recent performance observed in this study, improving iron status may improve endurance athletes’ adaptation to training, as well as their performance in competition.

Not all potential confounders such as pre- and postseason VO₂peak and fat-free mass could be measured in this cross-sectional study. As a result of logistic considerations of the current survey, a self-reported measure of performance (2-km self-reported best time) during the previous 2–3 months was used as an outcome. Although the self-reported measure was highly correlated with laboratory-derived values in a subsample of 48 rowers, results should be interpreted with caution. The observed association between IDNA and reported 2-km performance time is consistent with laboratory data showing that IDNA impaired 15-km cycling time-trial performance in nonathletic women (Hinton et al., 2000; Zhu & Haas, 1998a). It would be important to confirm these results in a longitudinal study, preferably following the same rowers periodically throughout both competitive seasons of the academic year. Future research should examine the dietary risk factors for IDNA, including iron intake and bioavailability, as well as other markers of iron metabolism, such as hepcidin.

**Conclusions**

Results from this study add to the evidence that iron status is an important issue facing female endurance athletes at the beginning of a training season. The prevalence of iron depletion is higher in this population than in the general population of young women because of many factors. Female endurance athletes should be screened using a sFer cutoff between 20.0 and 25.0 μg/L to identify iron depletion, which is likely to impair performance. Athletes with a history of anemia or iron deficiency should
receive counseling regarding supplementation and food choices, as well as serial monitoring of their iron status (hemoglobin, sFer).

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References


