

Iron Deficiency and the Role of Nutrition among Female Military Recruits

ERAN ISRAELI^{1,2}, DRORIT MERKEL³, NAAMA CONSTANTINI⁴, RAN YANOVICH^{5,6}, RACHEL K. EVANS⁷, DANIT SHAHAR⁸, and DANIEL S. MORAN^{5,6}

¹Division of Medicine, Department of Gastroenterology, Hebrew University-Hadassah Medical Center, Jerusalem, ISRAEL;

²Medical Corps, Israel Defense Forces, Tel-Hashomer, ISRAEL; ³Sheba Medical Center, Tel-Hashomer, ISRAEL;

⁴Department of Orthopedics, Hebrew University-Hadassah Medical Center, Jerusalem, ISRAEL; ⁵Heller Institute of Medical Research, Sheba Medical Center, Tel-Hashomer, ISRAEL; ⁶Sackler Faculty of Medicine, Tel Aviv University, ISRAEL; ⁷US Army Research Institute of Environmental Medicine, Natick, MA; and ⁸The S. Daniel Abraham International Center for Health and Nutrition, Ben-Gurion University of the Negev, Beer-Sheva, ISRAEL

ABSTRACT

ISRAELI, E., D. MERKEL, N. CONSTANTINI, R. YANOVICH, R. K. EVANS, D. SHAHAR, and D. S. MORAN. Iron Deficiency and the Role of Nutrition among Female Military Recruits. *Med. Sci. Sports Exerc.*, Vol. 40, No. 11S, pp. S685–S690, 2008. The impact of iron deficiency is considerable when enhanced physical fitness is required. Female military recruits represent a unique population faced with intense physical and cognitive demands. **Purpose:** To examine the prevalence of iron deficiency and the impact of dietary habits among female recruits in the Israel Defense Forces. **Methods:** Three hundred and forty-eight recruits completed the study (188 female combatants, 58 male combatants, and 92 noncombat females). Dietary intake was assessed using a Food Frequency Questionnaire. Blood samples were collected for complete blood cell count, iron indices, and vitamin B₁₂. The common definitions for anemia and iron store deficiency were used as follows: hemoglobin <12 g·dL⁻¹ for females and <14 g·dL⁻¹ for males; serum ferritin <12 mg·dL⁻¹. **Results:** The prevalence of iron deficiency and iron deficiency anemia was 29.8% and 12.8%, respectively, among female combatants. Similar data were found among noncombat females (27.2% and 17.4%, respectively) as compared with 5.2% and 0% among males. No significant difference in iron or total calorie intake was detected between subjects with iron deficiency (with or without anemia) when compared with subjects with normal iron status in the same study group. Plant sources constituted 85% of dietary iron source for females, in comparison to 73% for males. The contribution of red meat to the daily iron intake was 2% for females and 20% for males. **Conclusions:** A high prevalence of iron deficiency was found among female recruits. Coupled with the iron loss during menstruation, inadequate iron intake may have a permissive role for iron deficiency in female recruits and is an important issue facing females in the military. **Key Words:** ANEMIA, FEMALE SOLDIERS, FOOD FREQUENCY QUESTIONNAIRE

Iron deficiency anemia remains an enormous problem worldwide, with more than 500 million people suffering from this condition (5). Iron deficiency (with or without anemia) is the most prevalent micronutrient deficiency disease in the world, affecting up to two billion people (5,24), the most important causes being severe malnutrition and infection with hookworm. In developed countries, both of these causes rarely exist.

Menstrual blood loss is a significant cause of iron deficiency in women, and it has been shown that there is an inverse relationship between the amount of menstrual flow and serum ferritin levels (20). Thus, daily iron requirements for women are greater than for men, but energy intakes are lower. Therefore, it is hypothesized that women's iron in-

takes are also lower (16). Hence, the greater frequency of anemia among women is not surprising. Data from the 1999–2000 National Health and Nutrition Examination survey (NHANES) study indicate that the overall prevalence of iron deficiency is highest in females between the ages of 20 and 49 yr (15).

Female military personnel represent a unique population exposed to intense physical and cognitive demands, particularly during field training or when operationally deployed. The functional consequences of iron deficiency and iron deficiency anemia are well documented and include reductions in the maximal work capacity, endurance, and voluntary activity (2,9). Most recently, it was reported that the overall prevalence of iron deficiency in US female military personnel was 13.4% upon initial entry into the army, whereas the prevalence of iron deficiency anemia was 5.8% (17). This is similar to the prevalence seen among lower income women in the general US population, as determined from the NHANES 1999–2000 study (15).

The objective of the present study was to determine and to compare the prevalence of iron deficiency and iron deficiency anemia among three populations of military recruits in the Israel Defense Forces (IDF), as well as to determine the

Address for correspondence: Eran Israeli, M.D., Department of Gastroenterology, Hadassah Medical Center, POB 12000, Jerusalem, 91120, Israel; E-mail: eran-i@bezeqint.net.

0195-9131/08/4011S-S685/0

MEDICINE & SCIENCE IN SPORTS & EXERCISE®

Copyright © 2008 by the American College of Sports Medicine

DOI: 10.1249/MSS.0b013e31818946ae

role of nutrition and, more specifically, the dietary intake of iron. All three groups included military recruits immediately after initial entry into the army. The first group (study group) included females recruited into an army combat unit (the “Karakal” unit). The second group (control group A) included males recruited into the same combat unit, in which basic and advanced training is performed uniformly and without gender segregation. The third group (control group B) was comprised of females recruited to a noncombat unit training to become military dental assistants (DA) and deployed in clinics in the home front. It is important to point out that the inclusion of females into combat units in the IDF is done on a voluntary basis, whereas noncombat service is compulsory for all nonreligious females. Because a selection bias might play a role in the study group (e.g., socioeconomic background, education), it was important to include the second control group of noncombatant females.

METHODS

This study was part of a larger study assessing health status of female combatants to the IDF during basic training. The study was approved by the Human Use Committees of the IDF Medical Corps and the US Army Research Institute of Environmental Medicine. Human subjects participated in these studies after giving their free and informed voluntary consent.

From a total of 414 recruits, 348 volunteers (84%) completed the study (188 female combatants, 58 male combatants, and 92 noncombat females). All volunteers were between the ages of 18 and 19 yr, were not pregnant, and had not exercised in the 8 h before blood collection. Volunteers were recruited to the study consecutively over a period of 15 months from three separate Karakal companies and three groups of female trainees in the IDF rear-clinic DA course. The recruitment period for the study was up to 1 wk after initial recruitment to the military and included blood sample collection and dietary assessment. During this period, the recruits did not undergo any intense physical activity.

Blood collection and analysis. Blood was collected by antecubital venipuncture into tubes (BD Vacutainer; Becton, Dickinson and Company, Franklin Lakes, NJ, ©2002 BD) containing the appropriate anticoagulant.

TABLE 1. Subject characteristics (mean ± SD).

Group	Female Combatants (n = 216)	Male Combatants (n = 78)	Female DA (n = 120)
Age	19.1 ± 0.6	19.3 ± 1.1	18.6 ± 0.4*
Height (cm)	162.3 ± 6.4	174.4 ± 6.8†	161.9 ± 6.6
Weight (kg)	60.6 ± 10.1	69.8 ± 13.1†	57.6 ± 9.5*
BMI (kg·m ⁻²)	23.1 ± 3.3	22.9 ± 4.1	21.9 ± 3.4*
% body fat (caliper)	30.7 ± 4.6	17.4 ± 5†	29 ± 4.2*
Lean body mass (kg)	41.7 ± 5.5	57.1 ± 8.1†	40.6 ± 5
$\dot{V}O_{2max}$ (mL·kg ⁻¹ ·min ⁻¹)	36.8 ± 6.4	50.4 ± 8†	33.9 ± 5.4*

* Differences ($P < 0.05$) between female combatants and DA.

† Differences ($P < 0.05$) between female and male combatants.

TABLE 2. Hematological indices of the study three groups.

Group	Female Combatants (n = 188)	Male Combatants (n = 58)	Female DA (n = 92)
Hgb (g·dL ⁻¹)	12.7 ± 1.1	15.3 ± 1*	12.8 ± 1.1
MCV (fL)	83.4 ± 5	84.6 ± 4.2	84.3 ± 5.1
Serum iron (ng·dL ⁻¹)	67.3 ± 45	100.4 ± 45.3*	79.3 ± 45.5†
Serum transferrin (mg·dL ⁻¹)	307.5 ± 59.7	266.8 ± 55.2*	331.8 ± 53.6†
Serum ferritin (ng·mL ⁻¹)	17.4 ± 12.7	52.9 ± 36.3*	21.6 ± 19.9†
Serum vitamin B ₁₂ (pg·mL ⁻¹)	368.1 ± 225.3	331 ± 146.1	367.4 ± 140.5
Serum folate (ng·mL ⁻¹)	7 ± 3.5	5.4 ± 3*	6.2 ± 3.4†
Serum IL-6 (pg·mL ⁻¹)	43.4 ± 87	48.7 ± 82	34.3 ± 101

* Differences ($P < 0.05$) between female and male combatants.

† Differences ($P < 0.05$) between female combatants and DA.

Samples were put in ice and sent within 6 h to be processed and analyzed in the Tel-Hashomer Hospital Central Laboratories (Hematology and Biochemistry). Hemoglobin (Hgb) was determined with fresh blood using a hematology analyzer (Cell-Dyn[®] 3000; Abbott Diagnostics, Abbott Park, IL). Serum ferritin was measured with an electrochemiluminescence immunoassay (Roche Elecsys[®] 2010; Roche Diagnostics GmbH, Mannheim, Germany) and serum transferrin with an immunoturbidimetric assay (Tina-quant[®] with Roche Diagnostics GmbH); vitamin B₁₂ and folate levels were determined with an automated analyzer (Architect Abbott Diagnostics). Interleukin 6 (IL-6) was measured by ELISA from Linco (Linco Research Inc., St. Charles, MO) on the Luminex Labmap 100 (Luminex Corp., Austin, TX). Interassay CV is 12.7%. The sensitivity of this assay is 3.2 pg·mL⁻¹, and the reference range for IL-6 is <3.2–263 pg·mL⁻¹.

Classification of iron deficiency. The loss of iron can be classified into two stages according to their impact on red cell synthesis. Iron deficiency occurs as iron stores decline and a decrease in transport iron occurs (4). In this stage, there is an isolated decrease in serum ferritin levels (or low transferrin saturation). Iron deficiency anemia occurs as the synthesis of iron-containing proteins, such as Hgb, become compromised to the point at which values fall below a specific cutoff (9). In the present study, we used a *stringent* cutoff value of a serum ferritin <12 ng·mL⁻¹ for iron deficiency, a Hgb level <12 g·dL⁻¹ for females and <14 g·dL⁻¹ for males for anemia, and a serum vitamin B₁₂ <180 μg·mL⁻¹ for vitamin B₁₂ deficiency.

Dietary assessment. Subjects were interviewed at site regarding their dietary intake using a Food Frequency Questionnaire (FFQ) developed specifically for the Israeli population. This is a common method used to assess individual long-term dietary intake of foods and nutrients. The questionnaires elicit a subjectively reported “usual frequency” of consuming an item from a list of 126 foods (22,25). To assess differences in the sources of iron in the diet, we first sorted the foods by their iron content and then divided them into plant or animal sources. Foods that contain less than 1 mg of iron per 100 g were coded separately.

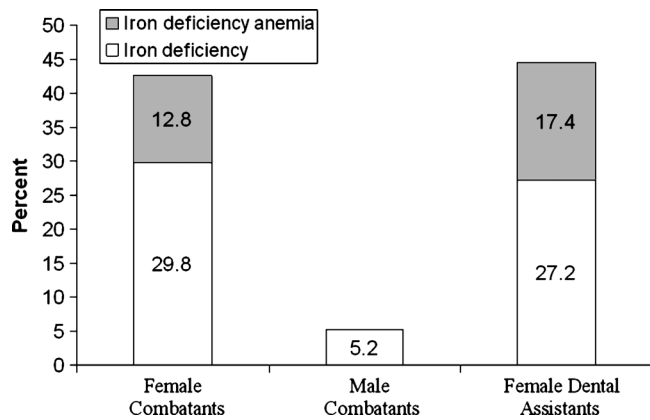


FIGURE 1—Prevalence of iron deficiency and iron deficiency anemia among three populations of IDF recruits. Iron deficiency was defined as serum ferritin $<12 \text{ ng}\cdot\text{mL}^{-1}$. Iron deficiency anemia was defined as serum ferritin $<12 \text{ ng}\cdot\text{mL}^{-1}$ as well as Hgb level $<12 \text{ g}\cdot\text{dL}^{-1}$ for females and $<14 \text{ g}\cdot\text{dL}^{-1}$ for males.

Statistical analysis. Statistical analysis was performed using commercially available statistical software (SAS 9.13 Software, SAS for personal computers Rel 9.1.3; SAS Institute Inc., Cary, NC). Means and SD were computed for continuous variables, proportion out of total for discrete variables. Differences between means were computed by Student *t*-test and differences between proportions by chi-square test. Descriptive statistics are presented as means \pm SD, and statistical significances were determined as $P < 0.05$.

RESULTS

Male recruits to the Karakal unit differed ($P < 0.05$) from females in height, weight, percent body fat, and baseline $\dot{V}O_{2\text{max}}$ in accordance with the expected gender differences in anthropometric and physiological parameters. The DA were slightly younger, with a lower average weight, body

mass index (BMI), and percent body fat when compared with the female combatants. The baseline $\dot{V}O_{2\text{max}}$ of this group was also slightly lower than that of the female combatants (although reaching statistical significance). Characteristics of each of the three populations appear in Table 1.

As can be seen in Table 2, the mean Hgb was significantly higher in the male group versus the two female groups. This was also observed for the indices reflecting iron stores (e.g., serum ferritin). Interestingly, mean ferritin levels were slightly, although significantly, higher among the DA when compared with the female combatants. Mean serum folate levels were lowest among the male group, whereas serum vitamin B₁₂ levels were comparable among the three groups (Table 2).

Among female combatants, the prevalence of iron deficiency was 29.8% and that of iron deficiency anemia was 12.8%. These figures were similar for the DA group. The overall prevalence of iron deficiency was 5.2% among male combatants, and no cases of iron deficiency anemia were found in this group (Fig. 1). Elevated levels of serum IL-6 were found in seven of the female combatants (2/7 had iron deficiency and 1/7 had iron deficiency anemia), in three from the DA group (all with normal iron status), and in one of the male combatant group (with normal iron status). These subjects were included in the data analysis. Low levels of vitamin B₁₂ deficiency were detected in 12.8% of the female combatants and in 10.3% and 2.9% for the male combatants and DA, respectively.

Table 3 represents a comparison of dietary intakes between the three study groups. BMI, age, and physical activity were not significantly different between the groups (see Table 1). Therefore, there was no need for adjustment of these parameters, which may act as potential confounders when comparing different populations. The male combatants differed significantly in most parameters of daily nutrient intake from the female combatants. Nonetheless, no significant difference was detected for carbohydrates, fiber,

TABLE 3. Comparison of selected nutrient intake among the three study groups, female and male combatants and female dental assistants (DA).

Group	Female Combatants (n = 220)	% DRI	Male Combatants (n = 78)	% DRI	Female DA (n = 115)	% DRI
Energy (kcal)	2210 \pm 946	80	2656 \pm 1068*	87	2206 \pm 881	92
Carbohydrates (g)	295 \pm 140	227	333 \pm 143	256	295 \pm 131	227
Total fat (g)	81 \pm 37	ND	98 \pm 41*	ND	78 \pm 33	ND
Protein (g)	82 \pm 38	178	106 \pm 47*	189	88 \pm 37	191
Dietary fiber (g)	26 \pm 14	104	28 \pm 13	74	26 \pm 13	104
Iron (mg)	15.3 \pm 7	85	19.0 \pm 8*	238	15.5 \pm 7	86
Folic acid (mg)	353 \pm 246	88	431 \pm 277*	108	344 \pm 230	86
Vitamin B ₁₂ (pg·mL ⁻¹)	6.1 \pm 7	254	9.1 \pm 13	379	8.9 \pm 10†	371
Calcium (mg)	874 \pm 519	87	978 \pm 623	98	840 \pm 440	84
Magnesium (mg)	353 \pm 160	114	268 \pm 208*	67	342 \pm 142	110
Zinc (mg)	10.6 \pm 5	133	13.2 \pm 6*	120	11.2 \pm 5	140
Thiamin (mg)	1.6 \pm 0.8	146	1.9 \pm 0.9*	158	1.6 \pm 0.7	146
Riboflavin (mg)	2.3 \pm 1.1	209	2.8 \pm 1.4*	215	2.3 \pm 1.1	209
Niacin (mg)	20.2 \pm 9	144	25.7 \pm 12*	161	21.9 \pm 9	156
Vitamin B ₆ (mg)	2.3 \pm 1.2	177	2.5 \pm 1.2	192	2.3 \pm 1.1	177
Vitamin C (mg)	277 \pm 280	369	211 \pm 197*	234	256 \pm 185	341
Vitamin E (mg)	11.1 \pm 7	74	11.4 \pm 6	76	10.0 \pm 5	67

DRI, dietary reference intake.

* Differences ($P < 0.05$) between female and male combatants.

† Differences ($P < 0.05$) between female combatants and DA.

calcium, and vitamins B₁₂, B₆, and E. The nutrient intakes between the two female groups were similar, apart for a higher intake of vitamin B₁₂ in the DA group.

Table 4 presents a comparison of the dietary intake of selected nutrients in each of the study groups according to iron or vitamin B₁₂ status. No significant difference in total iron intake was detected between subjects with iron deficiency (with or without anemia) when compared with normal subjects in the same study group, nor did we find differences in the intake of other nutrients such as energy, folic acid, or vitamin B₁₂ between these groups. We then assessed the sources for iron in the diet. For both female groups, 85% of iron intake was from plant sources (nonheme iron), whereas animal products (which are rich in heme iron) contributed to only 15% of the total iron intake. In comparison, the sources for iron intake in the male combatant group were 27% from animal products and only 73% from plant sources. It is important to note that the contribution of red meat to the daily iron intake was 2% for females and 20% for males.

Among the 24/164 female combatants with low-levels of vitamin B₁₂, there was a trend for a lower intake of vitamin B₁₂ (5.4 ± 7 vs 6.3 ± 7 μg , $P = 0.52$), although this did not reach statistical difference. Comparative data were observed for the male combatants (5/53 with vitamin B₁₂ deficiency). Among the DA with low-levels of vitamin B₁₂, the mean vitamin B₁₂ intake was actually higher than those with

normal vitamin B₁₂ levels (22.0 ± 18 vs 8.1 ± 8 μg , $P < 0.05$), but only a small number (3/99) were found among this group.

DISCUSSION

The main findings of this cross-sectional study indicate that the overall prevalence of iron deficiency among female recruits to the IDF is surprisingly high: 29.8% for iron deficiency and an additional 12.8% of iron deficiency anemia; thus, a total of over 40% showed iron deficiency. These data were corroborated in previous studies in the IDF in similar populations (6). A recent report (17) determined that iron deficiency among female recruits to the US military is similar to that seen among lower income women in the general US population but is less than a third of what we have found (13.4% for iron deficiency including 5.8% iron deficiency anemia). The authors categorized iron deficiency when two out of three indicators were positive: serum ferritin <12 $\text{ng}\cdot\text{mL}^{-1}$, transferrin saturation $<16\%$, or red cell distribution width (RDW) $>15\%$. We chose to categorize iron deficiency using serum ferritin <12 $\text{ng}\cdot\text{mL}^{-1}$ as the sole parameter. Although the different categorizations could partially account for the difference of reported iron deficiency between populations, it would certainly not explain the threefold increase in the IDF recruits. Because we chose stringent criteria for ferritin and Hgb cutoff levels, our data are actually a minimal estimation of the prevalence of iron deficiency and anemia. Among US military personnel, the prevalence of iron deficiency increased to 32.8% after an 8-wk basic combat training (BCT) period, which included both aerobic and muscle strength training. After an additional 6-month period of permanent duty assignments, it then decreased to 9.6%. The authors postulated that an inadequate iron intake during the BCT period could be the cause for the increase in iron deficiency, although no direct data on iron or total energy intake was collected in that study.

Serum ferritin is an acute-phase reactant and may be elevated in chronic inflammatory conditions, thus masking iron deficiency. Strenuous physical activity has been found to cause an acute-phase response increasing the levels of various immunologically active agents, for example, plasma concentrations of interleukin (IL)-6, 5-lipoxygenase, leukotriene B₄, and leukotriene C₄ (LTC-4) (12,19). IL-6 is an important inducer of hepcidin synthesis, and hepcidin is the main mediator of iron deficiency of inflammation. In anemia of inflammation, iron retention by duodenal enterocytes and by reticuloendothelial macrophages leads to markedly low transferrin saturation, iron-restricted erythropoiesis, and mild-to-moderate anemia (8,26). Strenuous physical activity can also induce iron deficiency by blood loss through the gastrointestinal tract (due to temporary ischemia) and urine (3); increased iron loss in the sweat (3); exercise-induced increases in red blood cell fragility (18); and plasma expansion (21). Although some of the IDF recruits designated for combat duties reported increased physical training

TABLE 4. Intragroup comparisons of selected nutrient intake, according to iron or vitamin B₁₂ status.

	Normal Iron Stores	Iron Deficiency	Iron Deficiency Anemia	Low-Level Vitamin B ₁₂ ^a
Female combatants (n = 188)	n = 108	n = 56	n = 24	n = 24
Energy (kcal)	2185 ± 941	2323 ± 1014	2181 ± 998	2531 ± 1006
Carbohydrates (g)	288 ± 142	315 ± 144	287 ± 144	353 ± 162
Total fat (g)	80 ± 37	83 ± 38	83 ± 39	93 ± 42
Protein (g)	81 ± 37	87 ± 45	80 ± 38	84 ± 30
Dietary fiber (g)	26 ± 14	29 ± 16	26 ± 16	35 ± 23
Iron (mg)	15.2 ± 7	15.9 ± 7	14.9 ± 7	17.4 ± 7
Vitamin B ₁₂ (μg)	6.6 ± 8	5.0 ± 5	6.2 ± 7	5.4 ± 7 ^b
Folic acid (mg)	373 ± 264	347 ± 227	302 ± 229	414 ± 337
Male combatants (n = 58)	n = 55	n = 3	n = 0	n = 5
Energy (kcal)	2667 ± 1081	3446 ± 1347		2334 ± 831
Carbohydrates (g)	338 ± 153	373 ± 96		268 ± 85
Total fat (g)	99 ± 40	117 ± 34		92 ± 33
Protein (g)	107 ± 48	134 ± 42		103 ± 33
Dietary fiber (g)	29 ± 13	33 ± 6		25 ± 8
Iron (mg)	19.2 ± 9	23.2 ± 6		19.3 ± 11
Vitamin B ₁₂ (μg)	8.9 ± 14	12.5 ± 12		5.8 ± 5 ^b
Folic acid (mg)	410 ± 289	602 ± 231		338 ± 221
Female DA (n = 102)	n = 61	n = 25	n = 16	n = 3
Energy (kcal)	2220 ± 811	2132 ± 871	2092 ± 1065	2402 ± 981
Carbohydrates (g)	299 ± 137	283 ± 117	286 ± 145	295 ± 123
Total fat (g)	78 ± 31	76 ± 31	75 ± 38	94 ± 40
Protein (g)	87 ± 31	86 ± 38	82 ± 42	97 ± 42
Fiber (g)	26 ± 13	27 ± 14	22 ± 13	28 ± 14
Iron (mg)	15.5 ± 6	14.9 ± 6	14.7 ± 8	18.4 ± 9
Vitamin B ₁₂ (μg)	7.6 ± 6	7.7 ± 7	8.8 ± 10	22.0 ± 18
Folic acid (mg)	364 ± 232	325 ± 279	296 ± 208	240 ± 394

^a Low-level vitamin B₁₂ was defined when serum vitamin B₁₂ <180 $\text{pg}\cdot\text{mL}^{-1}$, irrespective of the presence or absence of anemia.

^b The daily intake of vitamin B₁₂ in female combatants with normal vitamin B₁₂ (n = 164) was 6.3 ± 7 μg , $P = 0.52$; for male combatants with normal vitamin B₁₂ (n = 53), 7.1 ± 6 μg , $P = 0.62$; and for DA with normal vitamin B₁₂ (n = 99), 8.1 ± 8 μg , $P < 0.05$.

at home in preparation for military service, we found that IL-6 was elevated in only seven female combatants. Thus, whereas strenuous physical activity of BCT could theoretically explain the increased prevalence of iron deficiency in the US recruits, this was not the case in our population.

The average dietary intake of iron for female recruits was $15 \text{ mg}\cdot\text{d}^{-1}$, which is 83% of the dietary reference intake (DRI) for iron of $18 \text{ mg}\cdot\text{d}^{-1}$ (14). An unexpected finding of our study was that overall, the mean dietary iron intake did not differ between subjects with normal iron stores and those with iron deficiency or iron deficiency anemia. Heme iron, which constitutes 30–70% of all iron found in meat, is more readily absorbable than nonheme iron found in both meat and plant foods. Although heme iron represents only 10–15% of dietary iron intake in meat-rich diets, it may contribute 40% or more of the total absorbed iron in omnivores (1). In the female groups, only 15% of the total iron intake was contributed by animal products mainly poultry (relatively low in heme iron as compared with red meat). This pattern of eating is common in the Israeli population who consume relatively low intakes of red meat and high intakes of plant foods (23).

A recent report from the United Kingdom investigated the impact of habitual dietary iron intake and menstrual blood loss on iron deficiency among 90 healthy premenopausal women (10). Linear regression model indicated that menstrual iron loss and dietary group (red meat vs poultry/fish vs vegetarian) were important predictors of iron status. On the other hand, total iron intake *per se* was not related to iron status.

Heath et al. (11) used a validated FFQ and a menstrual recall method to assess iron intake and menstrual blood loss in 384 premenopausal women in New Zealand. Twenty-three percent of the study population had iron deficiency (serum ferritin $<20 \text{ ng}\cdot\text{mL}^{-1}$). The factors associated with iron deficiency included low meat/fish/poultry intake, high menstrual blood loss, recent blood donation, nose bleeds, and low BMI. Similarly, there was no correlation between total iron intake and iron deficiency in this study as well. Of note, an interaction effect between meat/fish/poultry intake and menstrual blood loss was apparent. A relatively high nutritional intake was associated with decreased risk of iron deficiency in individuals with low menstrual blood loss but not in those with high levels of menstrual loss.

Thus, a direct correlation between total dietary iron intake and iron deficiency is not apparent. Rather, the dietary source of iron may be more important in this regard. Based on our study as well as on those cited above, an individualized assessment is required to delineate the relative weight of each factor as a cause for iron deficiency as well as to individualize effective treatment (e.g., iron supplementation vs oral contraceptive use to decrease menstrual blood loss). Our study is limited by the fact that we did not measure menstrual blood loss.

The possibility of primary GI disease as a cause for iron deficiency was also not investigated (e.g., decrease in ab-

sorption of iron and folic acid due to celiac disease, or blood loss due to other gastrointestinal pathologies.). We found a prevalence of 1.3% of latent celiac disease in asymptomatic military recruits (unpublished), and other GI diseases have been reported to be quite rare as a cause for iron deficiency in this age group (7).

The functional consequences of iron deficiency and its anemia are well documented and affect physical as well as cognitive functions (2,4,9). Iron deficiency, even without anemia, impairs favorable adaptation to aerobic exercise (2). In this study, iron deficiency was similar among both female groups. However, female combatants are more exposed to various physical and cognitive challenges, especially during field training or when operationally deployed. In the case of training without gender segregation, women are subjected to the same physical and mental demands as men. Due to the fundamental disadvantage women have in terms of strength and aerobic capacity, iron deficiency could have an even greater impact on their response to these challenges.

In summary, we report a high prevalence of iron deficiency and iron deficiency anemia in female military recruits (eight times that of males). We did not find a decrease in the total iron intake in subjects with iron deficiency. Heme iron constituted only a fraction of the total iron intake (15%) for both female groups and in this regard may have a permissive role for iron deficiency. Iron supplementation has been shown to improve physical and cognitive performance (13). Our data demonstrate a high prevalence of iron deficiency in military female recruits and therefore warrant interventional trials to examine the protective role of iron supplementation in this high-risk group.

The opinions and assertions in this article are those of the authors and do not necessarily represent official interpretation, policy, or views of the US Department of Defense or the Israeli Defense Forces.

REFERENCES

1. Bjorn-Ramussen E, Hallberg L, Isaksson B, Arridon B. Food iron absorption in man. *J Clin Invest.* 1974;53:247–55.
2. Brownlie T 4th, Utermohlen V, Hinton PS, Giordano C, Haas JD. Marginal iron deficiency without anemia impairs aerobic adaptation among previously untrained women. *Am J Clin Nutr.* 2002; 75:734–42.
3. Chatard JC, Inigo M, Claire G, Lacour JR. Anemia and iron deficiency in athletes. Practical recommendations for treatment. *Sports Med.* 1999;27:229–40.
4. Dallman PR. Biochemical basis for the manifestations of iron deficiency. *Annu Rev Nutr.* 1986;6:13–40.
5. De Mayer E, Adiels-Tegman M. The prevalence of anaemia in the world. *World Health Stat Q.* 1985;38:302–16.
6. Dubnov G, Foldes AJ, Mann G, Magazanik A, Siderer M, Constantini N. High prevalence of iron deficiency and anemia in female military recruits. *Mil Med.* 2006;171:866–9.
7. Ferrara M, Coppola L, Coppola A, Capozzi L. Iron deficiency in childhood and adolescence: retrospective review. *Hematology.* 2006;11:183–6.

8. Ganz T. Hepsidin—a peptide hormone at the interface of innate immunity and iron metabolism. *Curr Top Microbiol Immunol*. 2006;306:183–98.
9. Haas JD, Brownlie T 4th. Iron-deficiency anemia and reduced work capacity: a critical review of the research to determine a causal relationship. *J Nutr*. 2001;131:S676–90.
10. Harvey LJ, Armah CN, Dainty JR, et al. Impact of menstrual blood loss and diet on iron deficiency among women in the UK. *Br J Nutr*. 2005;94:557–64.
11. Heath ALM, Skeaff CM, Williams S, Gibson RS. The role of blood loss and diet in the aetiology of mild iron deficiency in premenopausal adult New Zealand women. *Public Health Nutr*. 2001;4:197–206.
12. Hilberg T, Deigner HP, Moller E, et al. Transcription in response to physical stress—clues to the molecular mechanisms of exercise-induced asthma. *FASEB J*. 2005;19:1492–4.
13. Hinton PS, Giordano C, Brownlie T, Haas JD. Iron supplementation improves endurance after training in iron-depleted, non-anemic women. *J Appl Physiol*. 2000;88:1103–11.
14. Institute of Medicine. *Dietary References Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium and Zinc*. Washington (DC): National Academy Press; 2001.
15. Looker AC, Cogswell ME, Gunter MT. Iron deficiency—United States, 1999–2000. *MMWR Morb Mortal Wkly Rep*. 2002;51:897–9.
16. Lukaski HC, Hall CB, Siders WA. Altered metabolic response of iron-deficient women during graded, maximal exercise. *Eur J Appl Physiol*. 1991;63:140–5.
17. McClung JP, Marchitelli LJ, Friedl KE, Young AJ. Prevalence of iron deficiency and iron deficiency anemia among three populations of female military personnel in the US army. *J Am Coll Nutr*. 2006;25:64–9.
18. Radomski MW, Sabiston BH, Isoard P. Development of “sports anemia” in physically fit men after daily sustained submaximal exercise. *Aviat Space Environ Med*. 1980;51:41–5.
19. Robson-Ansley PJ, Blannin A, Gleeson M. Elevated plasma interleukin-6 levels in trained male triathletes following an acute period of intense interval training. *Eur J Appl Physiol*. 2007;99:353–60.
20. Rowland TW, Kelleher JF. Iron deficiency in athletes. Insights from high school swimmers. *Am J Dis Child*. 1989;143:197–200.
21. Schumacher YO, Schmid A, Grathwohl D, Bultermann D, Berg A. Hematological indices and iron status in athletes of various sports and performances. *Med Sci Sports Exerc*. 2002;34(5):869–75.
22. Shahar D, Shai I, Brenner-Azrad A, Vardi H, Fraser D. Development of a semi-quantitative Food Frequency Questionnaire (FFQ) to assess dietary intake of multiethnic populations. *Eur J Epidemiol*. 2003;18:855–61.
23. Shai I, Shahar DR, Vardi H, Fraser D. Selection of food items for inclusion in a newly developed food-frequency questionnaire. *Public Health Nutr*. 2004;7:745–9.
24. Stoltzfus RJ. Defining iron-deficiency anemia in public health terms: time for reflection. *J Nutr*. 2001;131:S565–7.
25. Willet W. Food frequency methods. In: *Nutrition Epidemiology*. New York (NY): Oxford University Press; 1998. p. 69–91.
26. Wrighting DM, Andrews NC. Interleukin-6 induces hepcidin expression through STAT3. *Blood*. 2006;108:3204–9.