Advancing the Knowledge and Practice of Nutrition in Canada

NIN Review

National Institute of Nutrition

No. 31 2002

Iron for Health – *for All Ages*

Une santé en fer—*à tout âge* **RÉSUMÉ**

Durant le cycle de la vie, le fer est un nutriment essentiel. Dans d'importants sous-groupes, la carence en fer demeure un souci grave, mentionnons les bébés et les enfants, les adolescentes et les femmes adultes ainsi que les végétariens qui ne mangent ni viande ni poisson ni volaille. En même temps, les apports recommandés pour ces sous-groupes ont été révisés à la hausse.

Aux non-végétariens, il faut souligner l'importance de consommer de la viande, du poisson et de la volaille en tant que sources de fer. Les Canadiens ont aussi besoin de conseils pratiques pour augmenter la disponibilité de fer de sources nonhéminiques. Pour une biodisponibilité optimale de fer nonhéminique, il faudrait les inciter à consommer au moins une source de vitamine C, surtout quand le repas est sans viande.

Une surveillance nationale des apports alimentaires des Canadiens s'impose. Ces données devront être complétées par des précisions sur le statut en fer recueillies grâce à un dépistage des carences ciblant les segments de la population à risque maximal.

Iron is an essential nutrient for individuals of all ages. Iron deficiency is the most common nutrient deficiency worldwide. Are Canadians able to get enough iron for health?

Recently published information on iron warrants a revisit of this essential nutrient by health professionals. Specifically:

- A review of iron needs in the population has resulted in increased intake recommendations for most individuals, especially infants, adolescent females, women aged 18 to 49 years, and individuals who do not consume meat, fish or poultry; and reduced intake recommendations for men and postmenopausal women.[1]
- A review of Canadian literature indicates that iron deficiency may occur in up to 65% of infants 6 to 12 months of age,[2–8] up to 37% of toddlers 13 to 36 months of age,[6–12] and up to 39% of teenage girls.[13,14]
- New Canadian intake recall data indicate that 57% of teenage girls and 46% of women aged 18 to 49 years do not consume the minimum number of servings from the Meat and Alternatives food group.[15]

This review provides information on the role of iron in health, the risks of insufficient and excess iron consumption, and the prevalence of iron deficiency throughout the lifecycle. Where available, Canadian data are presented.

An Essential Nutrient

Iron in the Body

The body has two compartments of iron: functional and non-functional. Most of the body iron is considered essential or functional iron, involved in biochemical functions in the form of hemoglobin, myoglobin, and in enzymes. A small amount of iron is transported attached to the protein transferrin.[16] Non-functional or storage iron is found in the liver, spleen, muscle, or bone marrow.[16,17] Ferritin accounts for some 95% of the stored iron in liver under normal conditions, with the balance being in the form of hemosiderin.[17] The minimal concentration of ferritin in the serum is an index of body iron stores and it is unknown whether it serves a specific role.

One of the main roles of iron is in the transfer and storage of oxygen, in the form of hemoglobin and myoglobin. Hemoglobin, a major component of red blood cells (erythrocytes), is a protein consisting of four subunits. Each subunit holds one heme molecule, which consists of one atom of ferrous iron (Fe^{2+}) attached to a protoporphyrin molecule. The ferrous iron can bind oxygen and transport it throughout the body. Myoglobin is similar to one subunit of hemoglobin and stores oxygen exclusively in muscle tissue. Iron and the iron-containing heme group of hemoglobin and myoglobin are involved as cofactors of enzymes that assist in the oxidation of nutrients for energy and in the proper functioning of cells.[16]

Iron Deficiency

As iron is depleted, a gradual sequence of changes occurs. Three levels of iron deficiency are commonly identified:[1]

- ***Depleted iron stores***—bone marrow iron is absent, the serum ferritin level is below 12 µg/L, and total iron-binding capacity is above 400 µg/dL, but there is no effect on functional iron;
- ***Early functional iron deficiency***—the supply of iron to the functional compartment is sub-optimal but not low enough to identify anemia; biochemical measures indicate that percent transferrin saturation is low, and free erythrocyte protoporphyrin and serum transferrin receptor levels are elevated;
- ***Iron deficiency anemia***—hemoglobin is below 130 g/L in males and 120 g/L in females and mean cell volume is decreased.

These classifications are similar to the Stage 1–3 iron deficiency definitions used in the *Manual of Clinical Dietetics*.[18]

The onset of iron deficiency is often gradual. When anemia is not present, the changes may be less readily recognized and thus more insidious.

Iron deficiency occurs when iron intake fails to meet the body's iron needs and iron stores are depleted. Iron absorption becomes more efficient to compensate for insufficient intake. However, over time, if intake does not increase, iron deficiency can progress to iron deficiency anemia.

Many published studies interchange iron depletion and iron deficiency. In most of the studies reviewed, serum ferritin was the primary measurement used to determine iron deficiency. Because no consensus exists in the literature, depleted iron stores and iron deficiency will be regarded as the same in this document.

Individual needs differ and depend on the amount of iron losses (e.g. menstruation), periods of rapid growth, and times of greater requirements (e.g. pregnancy). The onset of iron deficiency is often gradual. Early symptoms of iron deficiency leading to anemia may be tiredness, headache, irritability or depression. Some physical symptoms would be a change in pallor, fatigue, difficulty breathing, palpitations and a reduced "work capacity".[16]

In addition to the well-known symptoms of iron deficiency anemia, iron deficiency may lead to a number of nonhematological manifestations including changes in cellular function, growth, motor development, behaviour and cognitive function. When anemia is not present, these changes may be less readily recognized and thus more insidious. There may also be an increased risk for infection, as well as altered fetal outcome and premature labour in pregnant women.[19]

Testing for depleted iron stores or iron deficiency anemia is not routinely recommended in *The Canadian Guide to Clinical Preventive Health Care*,[20] except for high-risk infants and disadvantaged children. As a result, the true prevalence of iron deficiency in Canada is not known. A number of small-scale studies have reported iron deficiency in 3% to 65% of infants and/or young children.[2–12] In addition, two small studies on adolescents, measuring serum ferritin levels, found that 12.5%[13] and 25%[14] of adolescent females had depleted iron stores.

National Policies on Intake

New recommendations for iron—Dietary Reference Intakes (DRIs)—have been established recently.[1] These numbers, published in 2001, are higher for most individuals, especially infants, adolescent and adult females, and individuals who do not consume meat, fish or poultry, compared to the Recommended Nutrient Intakes (RNIs) set out in the 1990 *Nutrition Recommendations* for Canadians.[21] The higher recommendations result from the modelling approach used to estimate the requirement distribution, and they reflect a greater understanding of individual variability within the population.

The DRIs consist of four values: Estimated Average Requirement (EAR), Recommended Dietary Allowance (RDA), Adequate Intake (AI), and Tolerable Upper Intake Level (UL).[1] Each value refers to the dietary intake of healthy individuals. The definitions of the DRI values and their uses for assessing intakes are summarized in Table 1.

The availability of these new DRI values has implications for planning and assessing diets for healthy individuals and populations, the creation of nutrition guidelines and education, and many other applications including judging the need for public health interventions such as food fortification.

Table 1: Definitions and Uses of DRIs

DRI	Definition[1]	Uses for Assessing Intakes[22]	
		Individuals	Groups
Estimated Average Requirement (EAR)	– the average daily nutrient intake level estimated to meet the requirement of half the healthy individuals in a particular life stage and gender group – the intake at which the risk of inadequacy is 50% to an individual	– to examine the probability that an individual's usual intake is inadequate	– to estimate the prevalence of inadequate intakes within a group
Recommended Dietary Allowance (RDA)	– the average daily nutrient intake level sufficient to meet the nutrient requirement of nearly all (97% to 98%) healthy individuals in a particular life stage and gender group – the intake at which the risk of inadequacy to the individual is very small (only 2% to 3%)	– a goal for usual intake of individuals – an individual's usual intake at or above this level is almost certainly adequate	– cannot be used to assess intakes of groups
Adequate Intake (AI)	– a recommended average daily nutrient intake level based on observed or experimentally determined approximations or estimates of nutrient intake, by a group (or groups) of apparently healthy people, that are assumed to be adequate – used when an RDA cannot be determined	– when an RDA is not available for a nutrient (when no EAR has been determined), the AI can be used as the goal for an individual's intake	– mean usual intake at or above this level implies a low prevalence of inadequate intakes among a group
Tolerable Upper Intake Level (UL)	– the highest average daily nutrient intake level likely to pose no risk of adverse health effects to almost all individuals in the general population – as intake increases above the UL, the potential risk of adverse effects increases – at intakes between the RDA and the UL, the risks to the individual of inadequacy and of excess are both close to zero	– usual intake above this level may place an individual at risk of adverse effects from excessive nutrient intake	– to estimate the percentage of the population at potential risk of adverse effects from excessive nutrient intake

The DRIs for most nutrients, including iron, have been established and are beginning to be implemented into education programs. As the RNIs are still being used, information on both sets of recommendations is provided (Tables 2 and 3).

Table 2: Recommended Nutrient Intakes (RNIs) for Iron (mg/d)[21]

Age	Recommended Nutrient Intakes (RNIs)	
	Males	Females
5–12 months	7	7
1–3 years	6	6
4–9 years	8	8
10–12 years	8	10
13–15 years	10	13
16–18 years	10	12
19–24 years	9	13
25–49 years	9	13
50–74 years	9	8
> 75 years	9	8
Pregnant (2nd trimester, 3rd trimester)	–	+5, +10

Bioavailability

Forms of Dietary Iron

Iron is present in food in two forms: (1) heme iron, as found in the hemoglobin or myoglobin of animals, or (2) nonheme iron, which is found in both animal and plant foods, primarily as iron-containing salts.

The main source of heme iron in the Canadian diet is the Meat and Alternatives food group, particularly meat, fish, poultry and seafood. Beef liver and chicken liver contain the largest quantities of heme iron; beef represents the best source in non-organ cuts of meat. Raw oysters and shrimp also contain a high level of heme iron.

Nonheme iron is found in either the ferrous iron (Fe^{2+}) or ferric iron (Fe^{3+}) form in many foods. The primary source of nonheme iron in the Canadian diet is Grain Products, many of which are enriched or fortified with iron. Other sources of nonheme iron include beans (e.g. white or kidney beans), lentils, tofu, dried apricots, raisins, nuts, eggs, meat, fish and poultry. Based on a conservative estimate, the average adult Canadian diet includes 10% heme and 90% nonheme iron.[1]

Method of Absorption

Two pathways for iron absorption exist. One controls the absorption of heme iron from the hemoglobin and myoglobin in meat. The other regulates the absorption of nonheme iron, primarily as iron-containing salts.[16]

Table 3: Dietary Reference Intakes (DRIs) for Iron (mg/d)[1]

Age	Recommended Dietary Allowance (RDA)		Estimated Average Requirement (EAR)		Tolerable Upper Intake Level (UL)
	Males	Females	Males	Females	All
7–12 months	11	11	6.9	6.9	40
1–3 years	7	7	3	3	40
4–8 years	10	10	4.1	4.1	40
9–13 years	8	8	5.9	5.7	40
14–18 years	11	15	7.7	7.9	45
19–30 years	8	18	6	8.1	45
31–50 years	8	18	6	8.1	45
51–70 years	8	8	6	5	45
> 70 years	8	8	6	5	45
< 18 years, pregnant	—	27	—	23	45
19–50 years, pregnant	—	27	—	22	45

Note: RDAs for vegetarians (those who do not include meat, fish or poultry in their diet) are 1.8 times greater than for individuals consuming a mixed diet.

Absorption depends on the body's iron status or level of iron stores and on iron bioavailability from the diet. Heme iron is the most usable form of iron; it is more easily absorbed than nonheme iron (15% to 35% vs. 2% to 20%, respectively).[23] Although not yet isolated, it is believed that a receptor exists that binds the heme molecule and is not affected by other dietary factors. The absorption of nonheme iron, on the other hand, is dependent on the level of body iron stores, its solubility and interaction with other dietary components.[24]

Enhancers and Inhibitors

Certain components of the diet can enhance or inhibit the absorption of nonheme iron when consumed in the same meal.

Enhancers make the nonheme iron in the diet more soluble or form compounds that are more easily absorbed. Enhancers include ascorbic acid (vitamin C) and meat, fish and poultry (MFP factor). With little or no meat, fish or poultry or vitamin C in the meal, and zero body stores, nonheme iron absorption would be 5%. With 30 g to 90 g of MFP factor or 25 mg to 75 mg of vitamin C present, the absorption of nonheme iron increases to 10%.[23] The exact mechanism by which the MFP factor increases iron absorption is not clear. However, if the MFP factor and/or vitamin C–rich foods such as citrus fruit are consumed with the nonheme iron, absorption can increase by up to a maximum of four times.

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Inhibitors decrease the amount of nonheme iron absorbed by binding the iron into insoluble complexes that are then excreted from the gastrointestinal tract. The strongest inhibitors are polyphenols, found in many food products. They are especially high in black tea, which can decrease absorption of nonheme iron by up to 70%.[24] A recent study showed that many polyphenol-containing beverages, such as herb teas, can inhibit iron absorption from a simple bread meal; these have not been tested when consumed with complex meals.[25] To a lesser extent, phytates, found in legumes, rice and grains, can inhibit the absorption of nonheme iron. Additional inhibitors of nonheme iron are listed in Table 4. Consuming tea or coffee between meals has a much smaller effect, decreasing the amount of iron absorbed by 20%.[24] Consuming vitamin C at the same meal has the ability to neutralize the inhibitory effect of polyphenols and phytates from other foods.[24]

Calcium is the only factor that may play a role in inhibiting absorption of heme iron as well as nonheme iron.[24,26] However, its long-term effect does not seem to be consistent. In one study, a daily supplement of 1000 mg of calcium was given to 11-year-old girls. No effect on their iron status was seen.[27] In another study, calcium intake of both girls and women was measured. A weak inverse association between dietary calcium intake and iron status was found.[28]

Total Iron vs. Absorbed Iron

Recommendations for iron intake are based on total dietary iron. However, the amount of iron that is actually absorbed is very difficult to determine, as absorption is affected by the quantity of inhibitors and enhancers, as well as the level of body iron stores. Several models and algorithms have been proposed to determine the amount of iron actually absorbed.[23,24,26,29] Although these calculations are based on experiments involving one meal, not the entire diet, they provide valuable information on absorption.

Table 4: Factors that Influence Nonheme Iron Absorption

	Examples
Enhancers	
MFP Factor	meat, fish and poultry
Vitamin C (ascorbic acid)	sweet peppers, broccoli, brussels sprouts, cabbage, oranges, strawberries, papaya, fruit juices
Inhibitors	
Polyphenols	black tea, herb teas, coffee, cocoa, some grain products, red wine
Phytate	legumes (peas, beans and lentils), soybeans, whole grains, rice
Oxalate	spinach, chard, beet greens, rhubarb, sweet potato
Non-phytate component of soy protein	soy protein
Calcium	food and supplements

In establishing the DRIs for iron, an average bioavailability of 18% was assumed, considering the mixed diet typical in Canada and the United States.[1] In other words, 18% of the dietary iron consumed is absorbed. This value is based on two assumptions: (1) at least 10% of the dietary iron is heme iron and 90% is nonheme, and (2) body iron stores are minimal, so that absorption is maximized.

The availability of iron in diets with restricted intakes of meat, fish or poultry is estimated to be 10%. That is why the new DRI recommendations (RDAs) for individuals who limit those foods are 1.8 times greater than for individuals consuming a mixed diet.[1]

The amount of dietary iron that is actually absorbed by the body is the most important factor in determining whether an individual is consuming sufficient amounts of iron. For individual foods, Figures 1 and 2 show the total content of iron and the absorbed iron, assuming no enhancers present and zero body stores. Although a bowl of bran flakes has more total iron compared to most heme sources, less iron is absorbed. The presence of enhancers can increase the amount of nonheme iron absorbed from the cereal (e.g. >75 mg vitamin C from a glass of orange juice increases the absorption from 0.245 mg to 0.98 mg).[30]

Safety of Iron

In the absence of hereditary hemochromatosis, iron overload or toxicity is almost impossible through diet alone because absorption of nonheme iron decreases as body stores increase. Iron toxicity typically occurs through inappropriate intake of iron supplements[31–33] or as secondary iron overload resulting from parenteral iron administration, repeated blood transfusions, hereditary hemochromatosis or hematological disorders.[1]

Figure 1: Total and Absorbed Iron in Heme Foods

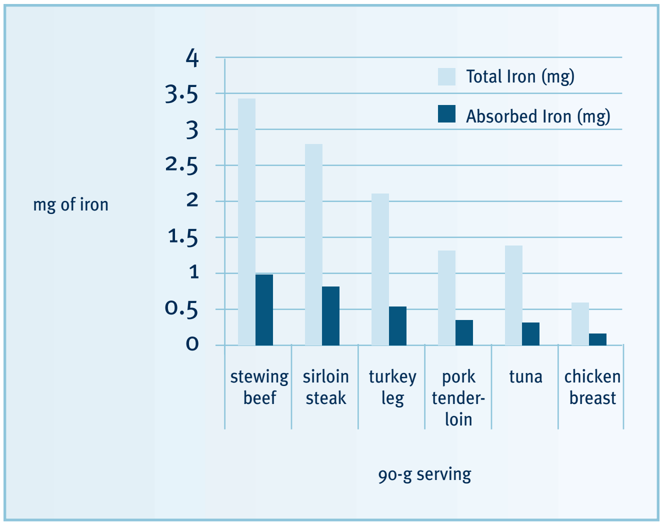
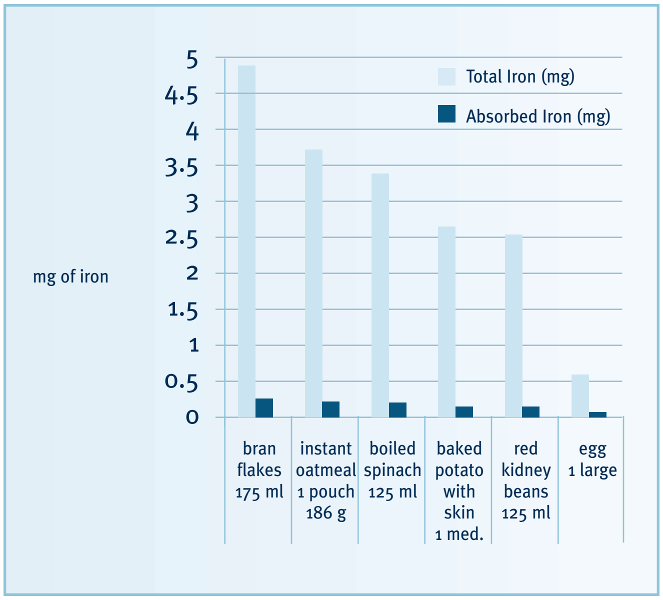


Figure 2: Total and Absorbed Iron in Nonheme Foods



Note: Values for absorbed iron were calculated based on Reference 30, assuming no enhancers present and zero body iron stores.

Supplement Use

The rate of supplement use in Canada has been determined based on intake recall and a questionnaire: approximately 15% of men and 19% of women take a multivitamin that contains iron; less than 2% of the population consume a single iron supplement.[34] Common side effects of supplement use include constipation and other gastrointestinal effects. Such side effects can be reduced through consumption of supplements with or after meals, or in smaller doses more frequently.[1] New DRIs for adults provide a UL of 45 mg/day, which takes into account supplement intake. Intakes above this level put the individual at increasing risk of adverse effects.

Hemochromatosis

A genetic disorder that can cause iron toxicity is hereditary hemochromatosis.[‡] It is an autosomal recessive disorder that results in excessive absorption of iron from food. The excess iron is deposited in the cells of the liver, heart, pancreas, joints and pituitary gland. If left untreated, organ damage can result. The disorder affects about 1 in 300 Canadians, and is more common in those of northern European descent and in males (likely because males do not experience menstrual iron losses). The treatment includes regular removal of blood (phlebotomy) and avoidance of vitamin/mineral supplements containing iron.[35]

Risk of Disease

An increased risk for liver cancer has been found in individuals with hereditary hemochromatosis.[1] Although some studies have identified a positive correlation between iron status and cancer in the general population, others have not.[36–38]

Research over the past 20 years has examined the relationship between body iron stores and coronary heart disease. A cohort study in Finland was the first to provide evidence that high serum ferritin levels (>200 µg/L) were associated with an increase (2.2-fold) in acute myocardial infarction.[39,40] Follow-up research identified a relationship between the gene for hemochromatosis and coronary heart disease in men and women.[41,42] Although some studies have found a relationship between other measures of iron status and the rate of coronary heart disease, several large prospective cohort studies do not support this relationship.[1,43,44] Such studies can be difficult to interpret because of other factors. For example, aspirin and exercise can decrease coronary heart disease risk independently; both also cause a decrease in serum ferritin levels.[45,46] As a result, current data do not support a causal relationship between body iron levels and coronary heart disease.[1]

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Population Sub-Groups

Infants and Children

It is thought that healthy, full-term breastfed infants have sufficient iron stores and circulating hemoglobin to meet their needs until 4 to 6 months of age.[47] If an infant is not breastfed, iron-fortified formulas are recommended until 9 to 12 months of age.[47] After about 6 months of age, iron stores are determined by such factors as intake of iron-fortified infant cereal, meat and iron-fortified formula.[48] To prevent iron deficiency, it is also recommended that all infants should receive iron-containing foods such as iron-fortified cereals as their first foods.[47]

Factors that influence iron status in infancy continue in early childhood, with diet playing a major role. Meat intake, more often than any other food group, has been associated with better iron status in children from 6 months to 5 years of age.[49–54] In addition, the intake of cereals—iron-fortified infant cereal in infants and ready-to-eat breakfast cereals in older children—especially when combined with vitamin C, has been effective in maintaining iron status.[50,51] A Canadian study that examined the dietary intake of preschool children by food groups indicated that most children who ate fortified cereals, the primary source of iron in their diets, would have been expected to meet their iron needs more easily than those who did not.[55]

About a dozen studies have shown that iron depletion and iron deficiency anemia are present in Canadian infants and children (Table 5).

[‡]Information: Canadian Hemochromatosis Society (www.cdnhemochromatosis.ca); U.S. Centers for Disease Control and Prevention (www.cdc.gov/nccdphp/dnpa/hemochromatosis/index.htm).

Link with Cognitive Function

The direct impact of compromised iron status is not fully known. However, human and animal studies have shown a direct relationship between iron status and cognitive function.[56–58] A recent review indicates that correlation studies support an association between iron treatment and reversal of developmental delay. However, the review concludes that more randomized control trials are needed to verify the benefits of iron treatment.[59] Longitudinal studies indicate that children who were anemic in early childhood continue to have poor cognitive and motor development and school achievement into middle childhood. In several studies, iron treatment did not result in anemic children catching up to non-anemic children; however, one study did show a clear benefit of long-term treatment.[59] A factor that influences outcome is the length of time the infants were anemic. Anemia for longer than 3 months resulted in significantly lower results in mental and motor development.[60]

In children older than 2 years, evidence suggests that iron treatment can improve cognition but not necessarily school achievement. In three preventive trials, some improvement was observed in motor development and attention skills. Interpretation of many cognition studies is difficult because anemic children may have more psychosocial, economic and biomedical disadvantages than non-anemic children. It is difficult to control for these other variables when studying iron status.[59]

The research on cognitive function and iron status has been expanded to examine the relationship in school-aged children, adolescents and dieting adult females. Children and adolescents 6 to 16 years of age

Table 5: Iron Status of Canadian Infants and Children

Age	n	Iron Depletion (%)	Iron Deficiency Anemia (%)	Location or Group	Reference
2 months 6 months 12 months	213	1–5 35–52 32–65	1.3 24.4 26.3	Inuit, Northern QC	7
6–18 months	320	10.6	3.5	Ottawa-Carleton, ON	4
9 months	433	24	7	Vancouver, BC	2
9 months	344	—	5.6–10.8	Cree, Northern QC	6
8–15 months	428	34	4.3	Toronto, ON Halifax, NS Montreal, QC Edmonton, AB	3
12–20 months	25	62.5	24	Charlevoix, QC	12
6–12 months 13–18 months 19–36 months	372	11.4 9.9 16.5	— — —	Chinese children, Montreal, QC	5
1 year	218	37	25	Children of disadvantaged families, Montreal, QC	8
18 months (BF)* 18 months (EM)	59	32 37	4 17	St. John's, NF	11
18 months 24 months 36 months	425	29.2 7.8 2.0	— — —	Montreal, QC	10
1–4 years 5–9 years	87 117	29 20	— —	Canada	9
5 years	106	3	—	Guelph, ON	9

* BF = breastfed; EM = fed evaporated milk

in the United States who were participating in the third National Health and Nutrition Examination Survey (NHANES III) were given standardized tests. Math scores were lower in those with iron deficiency compared to those without.[61] In a randomized, double-blind, placebo-controlled clinical trial, adolescent girls with depleted iron stores who were supplemented with iron performed better on a test of memory and verbal learning than the placebo group.[62] In another study, a number of obese women on weight-reducing diets who received sufficient dietary iron had decreased iron measures (hemoglobin and transferrin saturation). The women with the decreased hemoglobin levels had altered cognitive function measured by their ability to concentrate.[63] These studies indicate that iron status throughout life may have an impact on cognitive function.

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Adolescents

The increased iron requirement during adolescence is due to the growth spurt and the expansion of blood volume in both sexes, and the onset of menarche in females. Peak growth in males occurs between 11.7 and 15.3 years, preceded by the onset of sexual maturation. Females have a longer period of increased iron needs due to an earlier peak growth period followed by a more gradual sexual maturation period.[48] Requirements for female adolescents are almost double the pre-adolescent level. Dietary data suggest that adolescent girls are unlikely to acquire any iron stores because intakes are low.[64] In addition, those who skip one or more meals per day are more likely to have a low iron intake.[65]

The recent Food Habits of Canadians study indicated that adolescent males and females appear to consume adequate intakes of iron, as their mean intake is well above the EAR.[66] Although two of the main sources of iron in the diet are Grain Products and Meat and Alternatives, almost 30% and 45% of male teens and female teens, respectively, do not consume the minimum number of servings from the Grain Products food group. In addition, almost 40% of male teens and 57% of female teens do not consume the minimum number of servings from the Meat and Alternatives food group.[15] In the United States, only 23% of males and 18% of females 2 to 18 years of age are meeting the recommended servings in the Meat, Poultry, Fish, Dry Beans, Eggs and Nuts group.[67]

A Quebec study in the mid-1980s estimated that 39% of the adolescent female population was iron deficient, measured by serum ferritin.[68] In addition, 25% had low serum ferritin levels even though their iron intakes were above recommended levels, and 23% of those with low intakes had normal serum ferritin levels. This suggests that bioavailability of food iron, as well as quantity consumed, could be a determining factor in iron status. More recently, considering only serum ferritin values, iron deficiency was identified in 12.5% of females in a study completed in Edmonton, Alberta,[13] and 25% of adolescent females in Guelph, Ontario.[14]

Similar prevalence rates for iron deficiency have been reported in other countries:

- Sweden—23.6% of female teens and 3.7% of male teens;[69]
- United States—14.2% of adolescent girls;[1]
- Australia—9% of 15-year-old females;[70] and
- Northern Europe—15% to 24% of adolescent girls and 2% to 5% of adolescent boys.[71]

A study in Poland found 12.7% of 10- to 12-year-olds to be iron deficient, using two measures of iron status. In this population, the females attempting to lose weight or those avoiding animal products had lower iron status than the other females.[72]

Adults 19 to 50 Years of Age

Several provincial and national studies have measured the intake among adults of total dietary iron and/or foods consumed from the four food groups.

- In the Food Habits of Canadians study, 46% of adult females did not consume the minimum number of servings from the Meat and Alternatives food group, and 30% did not consume the minimum number of servings from the Grain Products food group on the day of the survey.[15] These two food groups represent the main sources of heme and nonheme iron in the Canadian diet, respectively. Individuals who consumed red meat were more likely to reach the recommended intake for iron.[66]
- In the Food Habits of Canadians study, the Ontario Health Survey, and the Saskatchewan Provincial Survey, at least two thirds of women 18 to 49 years of age had iron intakes less than the RNIs.[66,73,74]
- The Santé Quebec data indicate that 24% of women 19 to 50 years of age had intakes below the EAR, and that 72% of women had available iron intakes below the EAR for absorbed iron.[30]

- In the United States, 11% of women 20 to 49 years of age were iron deficient based on two out of three laboratory tests being abnormal (transferrin saturation, serum ferritin, erythrocyte protoporphyrin).[75]

Measurements of iron status for adult Canadians are greatly lacking. A single study in Thunder Bay, Ontario, on 111 women 18 to 40 years of age found iron deficiency anemia (measured by hemoglobin <120 g/L) in 3.6% of individuals and iron depletion (measured by ferritin levels <20 μg/L) in 39% of individuals.[76] However, studies in other developed countries have found the incidence of iron deficiency in women to be between 5% and 16%, with anemia in about 4% of women.[77,78] Factors that influence iron deficiency include blood loss due to increased menstrual flow, and consumption of meat, fish and poultry.[79] In addition, rates of iron deficiency increase due to pregnancy or blood donation. Data from NHANES III indicate that the mean intake of iron for adults is above the EAR in all groups except pregnant women.[1] Similar results were found in the Continuing Survey of Food Intakes of Individuals and the Total Diet Study.[1] However, iron deficiency was identified, using three measures of iron status, in 11% of females 20 to 49 years of age.[75] Individuals of Mexican descent and those in the lowest poverty level had higher rates of iron deficiency anemia than the non-Hispanic white females of the same age.[80]

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Pregnant Women

The Canadian Task Force on the Periodic Health Examination states that, currently, insufficient evidence exists for or against routine iron supplementation of all pregnant women.[20] However, it is recognized that iron deficiency and iron deficiency anemia are common in pregnancy.[20] Health Canada and the Centers for Disease Control and Prevention in the United States base their recommendations on the premise that many women have insufficient pre-pregnancy iron stores. They recommend consumption of a low-dose iron supplement (30 mg/day) during the second and third trimesters, in addition to a diet rich in iron and factors that enhance nonheme iron absorption.[81,82] When iron deficiency, with or without anemia, is diagnosed, larger doses of iron supplements may be advised to improve iron status as early in the pregnancy as possible.[82]

In a U.S. study, 90% of the pregnant women had iron intakes below two thirds of the former US-RDA (Recommended Daily Allowance) for pregnancy; 41% had iron deficiency and 22% had iron deficiency anemia.[83] This is not surprising, as very few women have sufficient iron stores prior to pregnancy to meet the needs of pregnancy.[84] Very little data, however, are available in Canada. One study in a northern Canadian population observed that 32% of women had iron deficiency in the first and second trimesters, 25% at delivery and 52% at 4 months postpartum.[85] The study found that iron supplementation during pregnancy can be effective in preventing iron deficiency postpartum.[85]

It has been reported that during pregnancy, adolescents and adults have similar low intakes of key nutrients, including iron.[86] Iron balance in the second and third trimesters may depend more on adequate intakes of bioavailable iron than on the size of the iron stores at conception.[87] Even so, a symposium held in the United States on improving adolescent iron status before childbearing identified the importance of iron status before and early into pregnancy. The main findings of the various papers presented at the symposium are:[88]

- Iron status early in pregnancy appears to have a stronger influence on birth outcomes than status later in pregnancy, suggesting the importance of improving iron status before childbearing.
- The prevalence of anemia, requirements for iron and rate of iron absorption into the blood are particularly high in the third trimester of pregnancy, suggesting continued need to provide iron supplementation throughout the entire pregnancy.
- Iron supplementation increases fetal growth significantly in terms of both weight and body mass.
- Schools, community kitchens, low-income communities and marriage registries are important examples of avenues through which to reach adolescent girls before pregnancy, and thereby reduce anemia.
- Dietary iron intake can be increased greatly among adolescent girls.

Older Adults

Adults over 50 years of age in general, and postmenopausal women in particular, do not appear to be at risk of iron deficiency. Their dietary intakes are adequate[66] and their requirements are lower than those of younger adults.[1] Ferritin levels in women over 50 years of age participating in NHANES III were much higher than among premenopausal women. This is not unexpected; an intake of 8 mg/day of dietary iron would imply that the probability of inadequate intake in a premenopausal woman not taking oral contraceptives is 50%; taking oral contraceptives, 15%; and in a postmenopausal woman, 0% due to changes in iron loss through menses.[1] The mean intakes of iron, hemoglobin levels and serum transferrin saturation levels are not different in females under 50 years of age compared to those 50 to 70 years of age and those over 70 from NHANES III.[1]

The prevalence of anemia in elderly people living at home in Chile was very low (4.8% in men and 1.3% in women) compared to people over 65 years of age in Great Britain (based on low hemoglobin levels: 23% in males and 16% in females).[89,90] In some groups of free-living elderly people (67 to 96 years of age), a greater percentage had elevated iron stores than depleted iron stores.[91]

Almost 40% of male teens and 57% of female teens do not consume the minimum number of servings from the Meat and Alternatives food group.

Individuals Who Avoid Meat

The complete avoidance of meat, fish or poultry can be a concern in maintaining iron stores, as its bioavailability is much higher than that of nonheme iron. The National Institute of Nutrition's Tracking Nutrition Trends study found little change between 1989 and 2001 in the proportion of adult Canadians who indicate being vegetarian (4%).[92,93] As in previous years, in 2001 almost all vegetarians reported consuming some animal protein: 70% indicated eating fish or seafood, 51% poultry and 32% red meat.[93]

A study in Vancouver comparing vegetarian diets to non-vegetarian diets found no difference in average iron intake; however, iron status was not measured.[94] In East Indian Punjabi immigrants to Canada, who consume a primarily lacto-ovo vegetarian diet (inclusion of milk products and eggs), intake of absorbable iron in males and premenopausal females was 23% and 64% below recommended levels, respectively.[95] As well, 5.1% of males and 15.7% of females had iron deficiency anemia.[95]

In Australia, no differences were observed in the median iron intake of vegetarians and omnivores, or in the prevalence of iron deficiency.[96] Similar results were found in New Zealand comparing vegetarian and non-vegetarian Seventh-day Adventists to the rest of the population.[97] In China, the rate of iron depletion and anemia were higher among female Buddhist vegetarians than among non-vegetarians (iron depletion: 50% vs. 22.5%, respectively; anemia 30% vs. 12.5%).[98] In France, vegetarian males had iron intakes above the RDAs for the French population while the median iron intake of vegetarian females was below the recommendations; however, no iron status measurements were taken.[99] The bioavailability of dietary iron and the presence of enhancers in the diet of the people in this study may explain some of the differences observed.

Very little is known about the impact of a vegetarian diet on the iron status of adolescents. However, children consuming no meat, fish or poultry have an increased risk of low iron intake.[100] Of the students surveyed in an Edmonton study, approximately 2% indicated that they were vegetarian and 25% indicated that they were dieting. No differences were seen in iron intakes or iron status between vegetarians and non-vegetarians; however, the number of vegetarians was small. Both a low intake of iron and a lack of heme iron may have an impact on iron status in this population. Although non-dieters had higher iron intakes than dieters, both groups had mean intakes above the RNI.[13]

Athletes

Female athletes, distance runners and vegetarian athletes are at increased risk for developing iron deficiency. Vegetarian female athletes are at greatest risk, due to lack of heme iron intake, expanded plasma volume and increased iron loss through sweat, gastrointestinal bleeding, menstruation, and occasionally hematuria (blood in the urine).[101] The prevalence of low serum ferritin levels is greater in female endurance athletes than among females in the general U.S. population.[102] This has been seen in other countries as well.[103] Hemoglobin levels also can be low; when this occurs, the maximum oxygen consumption (VO_2 max) is reduced.[102,104] Short-term moderate exercise can result in compromised iron status that can be offset by ingesting iron supplements or meat. Muscle food sources (meats) were shown to be more effective than other foods in protecting hemoglobin and ferritin status in female athletes.[101,105]

A study in Finland compared pubescent athletes with control subjects. Although intake of the athletic boys was greater than that of the control subjects, no difference was found in the females. A similar number of girls (7/71) and boys (7/64) had depleted iron stores, as measured by serum ferritin below 7 µg/L (most studies use 12 µg/L as the cut-off). No difference due to exercise was observed.[106] However, these athletes were not involved in endurance sport; endurance sport can result in greater iron losses and higher iron requirements.[1]

Improving Iron Nutrition

A variety of approaches have been used to improve iron nutrition throughout the world. In many countries, education and health promotion programs to improve health have been established, with some proving to be very successful in changing eating habits. A major problem in these programs is the lack of evaluation to determine the impact on health. It is also difficult to assess whether the specific program or other factors have changed eating habits.

Addition of Iron to Foods

Addition of iron to staple foods has been used in various countries, including Canada. The addition of vitamins and minerals to foods in Canada—either restoration, nutritional equivalence or fortification—is controlled under the Food and Drug Regulations.‡

- Iron and B vitamins are added to cereal products. For example, iron is added to enriched precooked rice and enriched pasta at levels necessary to **restore losses** due to milling, and added to enriched cornmeal to increase the level to that of whole wheat flour. Iron is added to white flour to raise the content to 24% above levels in whole wheat flour. The levels of iron per 100 g are as follows: enriched pre-cooked rice, 1.6 mg; enriched pasta, 2.9–4.3 mg; enriched bread, 2.76 mg; cornmeal, 2.9 mg; flour, 4.4 mg (Part B, Division 13 of the Regulations).
- The principle of **nutritional equivalence** of substitute foods has also been applied in setting requirements for nutrient addition to products simulating meat, egg and poultry products. For example, iron is added to simulated meat and poultry products (0.25 mg/g protein) and egg products (2.3 mg/100 g).
- **Fortification** is also used in Canada and other countries as a public health intervention to correct and/or prevent nutritional problems of public health significance. For example, iron may be added to breakfast cereals at levels higher than processing losses; they contain 13.3 mg/100 g or 4 mg/30 g serving size, which equates to 29% of the Recommended Daily Intake (used for labelling purposes) of 14 mg for iron (B.13.060 of the Regulations). Iron is also added to infant formula and infant cereal products for similar reasons and to a variety of special purpose foods such as meal replacements and instant breakfasts.

Children who do not consume fortified breakfast cereals have lower iron intakes and are less likely to meet the recommendations for iron.

The fortification of breakfast cereals represents an important source of iron in the diet of children. Those who do not consume fortified breakfast cereals have lower dietary iron intakes and are less likely to meet the recommendations for iron.[55,107,108]

If an infant is not breastfed, iron-fortified formulas are recommended until 9 to 12 months of age. To prevent iron deficiency, it is also recommended that all infants should receive iron-containing foods such as iron-fortified cereals as their first foods.[47] Fortification of infant formula seems to improve the status of low birth weight infants, premature infants and those not consuming sufficient iron-fortified infant cereal or meat.[109]

Although fortification has been shown to be a major source of dietary iron, the impact on iron status is unknown. In Denmark, removing iron fortification of flour had no negative impact on iron status in the adult population.[110] One of the challenges of fortification is to select the appropriate food item to fortify to ensure that the groups needing the iron will be consuming it.[109]

‡www.hc-sc.gc.ca/food-aliment/english/publications/acts_and_regulations/food_and_drugs_acts/index.html

Supplementation

Many individuals choose to take supplements, as "insurance", in lieu of a healthy diet, or as a result of clinical assessment indicating iron deficiency or anemia. Although confirmed as beneficial in clinical settings, supplement use has not proven to be effective as a public health intervention.[111] This may be due to lack of compliance, side effects of taking a supplement, cost, or poor bioavailability from the supplements. There is concern for the toxicity of excess iron intake, and some individuals are at risk of iron overload.[112]

Improving Iron Availability

The best approach to increase iron nutrition in a population is through selection of iron-rich foods including sources of heme iron, consumption of enhancers and avoidance of large quantities of inhibitors.[111] Table 6 highlights some of the practical ways to improve iron bioavailability.

Table 6: Practical Ways to Improve Iron Availability

• Consume a variety of foods from all four food groups in *Canada's Food Guide to Healthy Eating*.
• Include meat, fish and poultry in the diet as a source of heme iron and to enhance the absorption of nonheme iron. Red meat has the highest amount of heme iron.
• Focus on good food sources of nonheme iron, especially foods such as fortified cereals and whole grain or enriched breads.
• Consume vitamin C–rich foods with the meal to increase absorption of nonheme iron up to four-fold (e.g. vegetables and fruit, especially sweet peppers, broccoli, brussels sprouts, cabbage, oranges, strawberries, papaya and fruit juices).
• Avoid tea and coffee during meals.
• Include enhancers of iron absorption along with foods that have known inhibitors (e.g. orange juice or strawberries along with a high fibre cereal).
• Individuals whose diet is restricted in meat, fish and poultry should focus on iron-rich plant foods and foods rich in vitamin C, and avoid tea, coffee and other polyphenol-containing beverages when eating iron-rich foods.
• Offer iron-fortified infant cereal from 4 to 6 months until 2 years of age.

A Case for Screening

Educating the Canadian population to improve intake of nutrients, including iron, can be beneficial. However, knowledge of the true impact of this and other strategies to improve iron nutrition is limited without knowledge of iron status. Continued monitoring of food and nutrient intake is valuable and needed. However, screening for iron deficiency may be especially beneficial in certain groups.[113] These include:

- rapidly growing individuals, such as infants, preschool children and teenagers;
- pregnant women, especially early in the pregnancy;
- people undergoing endurance training, specifically distance runners; and
- vegetarians, especially those in the above three groups and those who avoid meat, fish and poultry (heme iron) entirely.

Conclusion

Iron is an essential nutrient throughout the lifecycle. Iron deficiency remains a serious nutrition concern among important sub-groups of the population, including infants and children, adolescent and adult females, and vegetarians who do not eat meat, fish or poultry. At the same time, recommended intakes for these groups have increased.

For non-vegetarians, the importance of meat, fish and poultry as good sources of iron should be emphasized. Canadians also need practical advice on enhancing the iron availability from nonheme sources. For optimum nonheme iron bioavailability, people should be encouraged to consume at least one source of vitamin C, particularly with meatless meals.

A nation-wide process to monitor the dietary intakes of Canadians is needed. These data should be complemented with information on iron status through a screening process for iron deficiency that targets segments of the population at highest risk.

Acknowledgements

This review was written for NIN by **Laura Pasut**, MSc, RD, Nutridata Consulting Services.

NIN gratefully acknowledges the contributions of the following reviewers:

- **Mary L'Abbé**, Ph.D., Nutrition Research Division, Food Directorate, Health Canada;
- **Huguette Turgeon O'Brien**, Dt.p. Ph.D., Département des sciences des aliments et de nutrition, Université Laval; and
- the **NIN Scientific Advisory Council**.

NIN thanks the Beef Information Centre for an educational grant to support the development and printing of this paper.

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A series of concise statements on nutrition, NIN Reviews are written for NIN by Canadian experts and reviewed by both NIN's Scientific Advisory Council and external specialists.

ISSN 0840-5085.

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