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# Iron Nutriture in Adolescence (1976)

Pages
14

Size
5 x 9

ISBN
0309335884

Committee on Nutrition of the Mother and Preschool Child; Food and Nutrition Board; Division of Biological Sciences; Assembly of Life Sciences; National Research Council

# Iron Nutriture in Adolescence

COMMITTEE ON NUTRITION OF THE MOTHER AND PRESCHOOL CHILD

FOOD AND NUTRITION BOARD
Division of Biological Sciences
Assembly of Life Sciences
National Research Council

NATIONAL ACADEMY OF SCIENCES
Washington, D.C.
1976

DHEW Publication No. (HSA) 77-5100

U.S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE

PUBLIC HEALTH SERVICE
Health Services Administration
Bureau of Community Health Services
Rockville, Maryland 20857

# *Foreword*

ONE OF THE MOST COMMON CAUSES of anemia in the world today is a dietary deficiency of iron. Since adolescence is an accelerated period of growth, it is associated with an increased need for iron, and iron deficiency is a common finding among adolescents of both sexes. This deficiency is more prevalent, by currently used standards, in boys than in girls and occurs in all races and at all levels of economic status.

Because of its concern with adolescent health and nutrition services, the Bureau of Community Health Services asked the experts of the National Academy of Sciences to clarify the dimensions and nature of the problem of iron deficiency anemia. The research project was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The study was conducted by the Committee on Nutrition of the Mother and Preschool Child, with support in part from Grant No. MC–R–110354–03, under the maternal and child health provisions of title V, Social Security Act. Committee members who participated were chosen for their special competencies and with regard for appropriate balance. Alvin M. Mauer, M.D., carried major responsibility for the report. Slight editorial modifications of the text submitted by the committee have been made by BCHS.

"Iron Nutriture in Adolescence" provides current information about iron metabolism and factors influencing iron balance as well as recommended iron intakes. Methods for identification of the state of iron nutrition are described and prevalence data are presented. Of major importance to health care providers are the recommendations and conclusions about iron nutriture of teenagers.

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IRON IS AN ESSENTIAL NUTRIENT, and a dietary deficiency of iron represents the most common cause of anemia in the world today. At birth the normal-term infant contains about 275 milligrams (mg) of iron (Widdowson and Spray, 1951), about three-fourths of which is present in circulating hemoglobin and most of the remainder in liver stores. The adult woman and man contain about 2.3 and 3.5 grams (g) of iron, respectively (AMA Committee on Iron Deficiency, 1968). Thus, between infancy and maturity, a positive iron balance must exist.

Iron is distributed in the body in two general groups of compounds. One group is important metabolically, and the other group is primarily responsible for iron storage and transport. The most important component of the metabolic group is hemoglobin which accounts for about 70 percent of the body iron. Myoglobin in muscle accounts for about 4 percent of body iron, and tissue iron enzymes (cytochromes, catalase, peroxidase, and some other nonheme-enzymes) represent about 1 percent of body iron. In the normal adult man approximately 25 percent of total iron is in storage form, whereas in the woman storage iron represents about 10 percent of total iron. Iron storage compounds (ferritin and hemosiderin) are present in roughly equal amounts, approximately one-third in liver, one-third in bone, and one-third in the spleen and other tissues. Iron is transported in the blood in the form of a protein compound called transferrin, which accounts for only a very small fraction of total body iron.

If the body is severely deficient in iron, anemia develops because of the inability to make sufficient amounts of hemoglobin for red blood cells. As the anemia progresses in severity, the affected person exhibits symptoms of tiredness, fatigue, and weakness. In severe anemia, the function of the heart can be impaired and heart failure may occur.

Iron deficiency can also occur without being severe enough to produce significant anemia. It is more difficult to demonstrate any disability for the nonanemic iron-deficient individual. However, there are some indications that moderate iron deficiency can be associated with fatigue (Beutler et al., 1960) and impaired school performance (Webb and Oski, 1973).

## FACTORS INFLUENCING IRON BALANCE

The three factors influencing the status of iron nutrition through adolescence are the amount and availability of iron ingested, rate of body growth, and iron loss. Each is a major contributing factor in determining the amounts of iron available for both the metabolic and storage iron.

*Intake and Absorption.* Although absorption of dietary iron is generally low, iron from heme compounds is better absorbed than nonheme iron (Bjorn-Rasmussen et al., 1974). In fact, the ratio of the rates of absorption of heme and nonheme iron is about 7:1. Thus, the amount of heme iron-containing foods in the diet is an important factor in determining the amount of iron absorbed. Another important factor influencing absorption of iron from food is the nature of the iron-containing food (Martinez-Torres and Layrisse, 1974). Absorption of iron from plant sources ranges from a low of 1 percent from rice and spinach to 4 to 6 percent from lettuce, wheat, and soybeans. Absorption of iron from meat is about 10 to 15 percent. Less than half that amount, however, is absorbed from eggs. Iron absorption from vegetable foods can also be enhanced when the food is eaten with meat (Martinez-Torres and Layrisse, 1974). The rate of iron absorption is inversely related to the status of iron stores and may be twice as great in the iron-depleted as in the normal subject (Martinez-Torres et al., 1974).

Iron can also be absorbed from the diet in inorganic form, providing the opportunity for enriching diets with iron. Absorption of inorganic iron, however, varies according to the type of iron salt used (Fritz et al., 1970). Ferrous sulfate is well absorbed and is generally regarded as the standard iron salt for comparison of absorption values. Ferrous fumarate and gluconate are also well absorbed. Other compounds, such as sodium iron pyrophosphate are much less well absorbed (Cook et al., 1973). Absorption characteristics become important when iron fortification of foodstuffs is considered. However, other problems such as induction of rancidity or discoloration of the foods may limit the use of iron compounds with maximal availability. In unfortified foods, iron salts comprise only a small part of the iron intake and absorption.

*Rate of Growth.* Two periods in a child's life are characterized by particularly rapid growth. Both periods involve a risk of iron deficiency since during these periods of growth, blood volume and muscle mass are increased. Thus, the need for iron for hemoglobin and myoglobin synthesis is increased.

The first period of rapid growth begins in utero, reaches a peak of acceleration late in fetal life, then decelerates until about 2 to 3 years of age when the annual growth rate becomes constant. Though growth during the first year of life is slower than that of late fetal life, total body iron increases twofold from birth to age 1.

The second period of accelerated growth begins between 8 and 10 years and is usually completed by 14 to 16 years of age. This period of rapid growth is characteristic of adolescence and is associated with an increased need for iron. Increases in blood volume and muscle mass associated with growth are considerably greater in boys than in girls (Hepner, 1975). Boys gain an average of 19 g per day at age 15 years, whereas girls at the same age gain an average of 12.6 g per day. Because boys gain proportionately more in lean body mass, for each additional kilogram of weight, boys require 42 mg of iron, as compared with 31 mg for girls. Furthermore, great individual variation exists in respect to the rate with which lean body mass is added (Hepner, 1975). For example, the requirements for dietary iron for a boy growing at the 97th percentile for body weight may be double that of a boy growing at the 3rd percentile. Therefore, the changing need for iron during adolescence will vary from individual to individual as to time of onset and degree of need. The age of onset of puberty, the velocity of growth, and the time required to complete the process of adolescent maturation are extremely variable. To compensate for this variability, it has been suggested that adolescence be judged by a sexual maturity rating based on secondary sex characteristics. Changes in the need for iron during this period appear to be better correlated with sexual maturity rating than with chronological age (Daniel et al., 1975). Thus, in any consideration of the iron nutriture of adolescents, biological variability must be taken into account.

*Loss.* Iron loss of adolescents is presumed to be similar to that of adults. The normal adult man loses about 0.5 to 1 mg of iron each day. Most of this iron is lost from the intestinal tract through desquamation of epithelial cells; only small amounts are lost in the urine or from the skin. Normal adult women who are menstruating have an additional loss equivalent to about 0.5 mg per day (AMA Committee on Iron Deficiency, 1968). Menstrual blood loss averages 40 to 50 milliliters (ml) per period but may vary widely from individual to individual (Hallberg et al., 1966). Since each ml contains about 0.4 mg of iron, menorrhagia is associated with an increasing risk of iron deficiency (AMA Committee on Iron Deficiency, 1968). The mean loss by girls may be less than that of adult women, but the wide variability in menstrual blood loss is an important factor in iron nutriture in adolescent girls. Moreover, anovulation is of relatively high prevalence in the immediate post-menarchal years and is known to be associated in some instances with increased uterine blood loss.

Pregnancy in the adolescent girl poses a particular problem of iron nutriture. Not only is the requirement for iron further increased by pregnancy, but the adolescent girl frequently has little, if any, iron stores to draw upon during gestation (Scott and Pritchard, 1967). It is important, therefore, that iron nutriture be evaluated carefully in the pregnant adolescent.

## RECOMMENDED IRON INTAKES OF ADOLESCENTS

The recommended daily allowance for iron during adolescence is 18 mg, according to "Recommended Dietary Allowances" issued by the National Academy of Sciences in 1974. Assuming an absorption rate of 10 percent, this would allow for an increment of 1.8 mg of iron per day. Assuming losses of 0.5 to 1 mg daily, the recommended intake should promote a positive iron balance and provide for the increased amounts of body iron needed for the increasing blood volume and muscle mass. The 18 mg RDA for iron would seem adequate for both boys and girls. Although the girl has an additional iron loss from menstruation, her needs for iron to provide for increasing blood volume and muscle mass are proportionately less than for an adolescent boy.

This increase in the RDA for dietary iron should begin at about 10 years and be continued through 18 years. However, as has been mentioned, there is considerable variability in the onset of the adolescent growth spurt, its rate, and its time of cessation. Furthermore, among girls there is considerable variability in the age of onset of menstruation. Therefore, the precise timing of this need for any individual for an increased RDA for iron will vary and only general recommendations can be made for the timing and duration of the increased dietary intake.

## IDENTIFICATION OF THE STATE OF IRON NUTRITURE

Before considering the prevalence of iron deficiency in adolescence, it is important to review the methods used in assessing the state of iron nutriture. Based on the degree of effect of progressive states of iron lack, three categories have been proposed (AMA Committee on Iron Deficiency, 1968). The term "iron depletion" is used to characterize a deficiency in storage iron only. "Iron deficiency without anemia" refers to the situation in which there is both an absence of iron stores and a decrease in the saturation of transferrin to 15 percent or less. "Iron deficiency with anemia" is the most severe state of iron depletion and indicates that there is insufficient iron for the production of hemoglobin in the bone marrow.

The most sensitive indicator of iron depletion is the determinaton of iron stores. This assessment can be made by examining smears of bone marrow aspirate stained by Prussian blue dye for hemosiderin granules within the reticuloendothelial cells. Also visible on this preparation is the stainable iron within the erythroblast. These iron-containing cells are called sideroblasts and generally account for 30 to 60 percent of the erythrocyte precursors. In a state of iron deficiency without anemia, this number drops to less than 8 percent. Unfortunately, bone marrow determination of iron stores is not feasible for routine screening assessment of iron nutriture.

The percent saturation of transferrin is a reasonably sensitive indicator of iron deficiency. However, it may be normal at a time that marrow iron stores are depleted. When the state of deficiency progresses to a point just short of anemia, the transferrin saturation becomes less than 16 percent. The decrease in saturation occurs both because of a decrease in serum iron concentration and an increase in the level of unbound iron transport protein. With development of iron deficiency anemia, the percent saturation decreases further, usually to values less than 10 percent. At this time the serum iron concentration is usually 50 micrograms per 100 ml of plasma or less (AMA

Committee on Iron Deficiency, 1968). Serum iron-binding capacity can be determined on venous blood. A micromethod using capillary blood obtained by fingerstick has also been described (Yeh and Zee, 1974).

Another method of assessing iron nutriture uses peripheral blood samples. Ferritin is present in serum in small quantities, averaging about 40 nanograms (ng) per ml for children aged 11 to 15 years (Siimes et al., 1974). The data available so far indicate that ferritin content of serum may be a sensitive indicator of iron status. However, this new determination is not generally available at present.

With progression of the degree of iron deficiency, anemia develops. The hemoglobin level accepted for the lower limits of normal for persons living at sea level is 11.0 g per 100 ml blood. This value is applicable to both boys and girls until the sexual changes of puberty occur. At that time, testosterone production by the male is associated with a rising hemoglobin concentration. Therefore, after puberty, the lower limit of normal generally accepted for a male is 12.0 g per 100 ml.

With the onset of anemia, red cell morphology remains normal but as the anemia progresses in severity, the red cells become small and depleted of hemoglobin. The anemia is, therefore, microcytic and hypochromic. The changes in cell characteristics can be determined by microscopic examination of a blood smear or by measuring the red cell indices from a determination of red blood cell count, hemoglobin concentration, and hematocrit. The range of normal values for red cells is shown in table 1 and is applicable for all ages after the newborn period and for both sexes.

TABLE 1.—*Ranges of Values for Normal and Deficient Red Cell Indices*

| | RANGES | |
|---|---|---|
| Value | Normal | Iron deficient |
| | *Cubic microns* | |
| Mean corpuscular volume (MCV) | 80–96 | 50–79 |
| | *Micromicrograms* | |
| Mean corpuscular hemoglobin (MCH) | 26–34 | 12–29 |
| | *Percent* | |
| Mean corpuscular hemoglobin concentration (MCHC) | 32–56 | 24–31 |

Source: G. E. Cartwright: "Diagnostic Laboratory Hematology," 4th ed., Grune & Stratton, New York, N.Y. 1968.

## PREVALENCE OF IRON DEFICIENCY IN ADOLESCENCE

Several surveys have indicated that adolescence is a period of increased risk for iron deficiency in both boys and girls. In interpreting studies of prevalence of iron deficiency in adolescent populations, several variables must be taken into account. The criterion in most surveys has been the hematocrit or hemoglobin concentration (White, 1968; Faigel, 1973; Heald et al., 1974; Shank et al., 1974), whereas in others the state of iron stores (Scott and Pritchard, 1967; White, 1968a) or response to administered iron (Shank et al., 1974) has been determined. Some surveys have included only adolescent girls (Scott and Pritchard, 1967; White, 1968; Shank et al., 1974); others have involved both boys and girls (Faigel, 1973; Heald et al., 1974). Both lower income children and children in more favored economic status have been subjects of study (Faigel, 1973; Shank et al., 1974). Thus, it is not unexpected that the various surveys yield differing prevalence rates for iron deficiency in adolescence, and the more sensitive the indicator of iron deficiency, the higher the prevalence rate. (It must be recognized, however, that reported prevalence rates depend upon the standards used.) Since the change in hemoglobin or hematocrit is a late finding in the progression of iron deficiency, surveys based on these data alone will yield the lowest prevalence rates. Differences in prevalence rates for iron deficiency as a function of socioeconomic status or race are not as striking in adolescents as they are in infants (Daniel et al., 1975).

TABLE 2.—*Prevalence of Iron Deficiency in Persons Age 12 to 17 Years*

| | BOYS | | | GIRLS | | |
|---|---|---|---|---|---|---|
| | Criterion for low value | Mean value | Percent with low values | Criterion for low value | Mean value | Percent with low values |
| Hematocrit | <40 | 43.1 | 15.5 | <36 | 40.7 | 2.4 |
| Hemoglobin | <13 | 14.8 | 7.4 | <11.5 | 13.7 | 1.9 |
| Serum iron | <60 | 112.5 | 2.8 | <40 | 102.1 | 1.1 |
| Transferrin saturation | <20 | 33.6 | 7.7 | <15 | 29.1 | 5.3 |

Source: U.S. Department of Health, Education, and Welfare, National Center for Health Statistics: "Preliminary Findings of the First Health and Nutritional Examination Survey, United States, 1971–72; Dietary intake and biochemical findings." S. Abraham, F. W. Lowenstein, C. L. Johnson. DHEW Publication No. (HRA) 74–1219–1. 1974.

Shown in table 2 is an example of the prevalence rates for iron deficiency anemia observed in a group of children aged 12 to 17 years. These data are derived from the preliminary findings of the first Health and Nutrition Examination Survey (Abraham et al., 1974). It is of interest that in this HANES survey differences in prevalence rates were related to race and income level. However, iron deficiency among adolescents can be found at all levels of economic status, in both sexes, and in all races (Faigel, 1973; Shank et al., 1974; Daniel et al., 1975). A particularly striking finding of the

Health and Nutrition Examination Survey was the greater prevalence of low hemoglobin and hematocrit levels among boys in comparison to girls. It should be noted, however, that in the HANES report hemoglobin levels below 13 g/100 ml blood are considered low for boys. If the more generally accepted figure of 12 g hemoglobin had been used as the lower level of normal, 4.2 percent of males would have fallen below the norm as compared with 8.5 percent reported. In any case, the prevalence of low levels of transferrin saturation is sufficient to suggest that a number of adolescents likely are at risk of iron deficiency. Because of its importance, it is worthwhile considering some of the factors that might contribute to the prevalence of iron deficiency among adolescents in this country.

## FACTORS CONTRIBUTING TO IRON DEFICIENCY AMONG ADOLESCENTS

The recommended daily allowance for iron during adolescence is 18 mg (Food and Nutrition Board, 1974). From many available studies (White, 1968; Beal and Meyers, 1970; Ten-State Nutrition Survey, 1968–70; Daniel et al., 1975) it is clear that both boys and girls during this period rarely achieve the RDA for iron in their diet. Although the intake figures vary, in general, girls during the period from 12 to 16 years of age have an average intake of 9 to 13 mg of iron per day. Boys during this same period consume an average of 10 to 16 mg. There are some differences related to race and economic status, but in all groups diets tend to be less than optimal for iron. About 80 percent of girls and 75 percent of boys consume less than the recommended allowances of 18 mg.

To further explore the reasons for the deficiency of iron in the diet of adolescents, it is important to review adolescent food habits (Hampton et al., 1967; Schorr et al., 1972; Frankle and Heussenstamm, 1974). A detailed analysis of the causative factors influencing adolescent diets is beyond the scope of the presentation. However, it is clear from all studies that consumption of diets low in iron in comparison to need is a common finding. Dairy products relatively low in iron content may contribute up to 50 percent of daily calorie intake (Hampton et al., 1967). Food habits, such as vegetarianism, may eliminate meat products from the diet, thus removing one of the sources of easily absorbed iron (Frankle and Heussenstamm, 1974). Many foods popular among adolescents contain little iron. "Fast foods," which are important components in many adolescent diets, vary widely in iron content from considerably less than one-third of the RDA to one-half or more (Chem and Lachance, 1974). Almost one-fourth of the recommended calorie intake for adolescents is from foods eaten between meals. In general, these foods tend to be lower in iron content than foods eaten at meals (Thomas and Call, 1973). Thus, the choice of between-meal snacks may determine the extent of contribution to the total iron intake for the day.

## RECOMMENDATIONS AND CONCLUSIONS

It is clear that adolescence is a period in which there is an increased need for dietary iron that may be coupled with little or no change in the amount of iron previously present in the diet. Thus, the most important modification to be made during adolescence is to increase the intake of iron-containing foods.

The best dietary source of absorbable iron is from meats of all varieties. Foods containing low amounts of iron should be limited in their contribution to the daily calorie intake.

An important area for nutrition counseling is improvement of the quality of foods eaten between meals with respect to iron content. An increase in the level of iron fortification of flour, bread, and other bakery goods is currently under consideration; if adopted, bakery goods may play a significant role in the future in reducing the prevalence of iron deficiency among adolescents (Swiss and Beaton, 1974). Because of the general lack of compliance with recommendations for prophylactic medication, it seems doubtful that long-term administration of iron tablets is practical, and truly effective dietary supplementation may require iron fortification of a variety of foodstuffs (Elwood et al., 1970).

In conclusion, iron deficiency is a common finding among adolescents of both sexes. It is more prevalent, at least by currently used standards, in boys than in girls, and occurs in all races and at all levels of economic status. It is caused by rapid growth during adolescence resulting in increased need for iron without a concomitant increase in dietary iron intake. Periods of increased demands, such as pregnancy, frequently lead to iron deficiency anemia. The most effective method of reducing the prevalence of iron deficiency among adolescents is to increase dietary iron intake. This increase can be accomplished by increasing the amount of iron-containing foods in the diets of adolescents through dietary counseling or by providing iron fortification of foods commonly eaten by adolescents.

Because of the prevalence of iron deficiency among adolescents, it is important that hematocrit or hemoglobin determinations be done sometime around the completion of the adolescent growth spurt and achievement of sexual maturation. Therapeutic iron should be given to those persons who are found to be anemic. If transferrin saturation can be determined, those persons with levels less than 16 percent also should be treated with therapeutic iron administration. Adolescent girls with a history of menorrhagia particularly should be counseled as to their diet, and their state of iron nutriture should be determined periodically by hemoglobin and/or transferrin saturation measurement. Girls and boys who have an unusually rapid adolescent growth spurt are also candidates for careful observation for iron deficiency.

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U.S. GOVERNMENT PRINTING OFFICE: 1977—O-225-901