

To the Graduate Council:

I am submitting herewith a thesis written by Beverly Jane Thurman entitled "Iron Status of Adolescent Girls." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Nutrition.

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IRON STATUS OF ADOLESCENT GIRLS

A Thesis

Presented for the

Master of Science

Degree

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Beverly Jane Thurman

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ABSTRACT

This nutrition status study was conducted at The University of Tennessee, Knoxville, in conjunction with the Southern Regional Nutrition Project in existence since 1974 in ten sites throughout the Southeast. The primary purposes of the restudy were to evaluate the iron status of adolescent girls, noting influences of race and income upon their iron status, and to investigate relationships between dietary iron, as well as other dietary nutrients, and iron status.

The study involved 94 girls 14 ± 0.5 years of age from Knoxville and Knox County, representing two races (black and white), and two income categories (\$1,200 or less/person/year and \$2,000 or more/person/year). Two 24-hour dietary recalls were obtained from each girl, allowing correlation with values obtained from biochemical analyses. Fasting blood was collected and analyzed to determine hematocrit, hemoglobin, serum iron, unsaturated iron binding capacity and transferrin saturation.

Fifty-six and four-tenths percent of the 14-year-old girls were consuming less than two-thirds of the RDA for iron. The 14-year-old girls were consuming between 5 and 6 mg of iron per 1000 kilocalories per day.

White girls had significantly higher ($p < 0.05$) hemoglobin values than black girls. There were no significant differences in mean hematocrit, serum iron, unsaturated iron binding capacity, transferrin saturation or iron intake values between race/income groups. Hemoglobin

values of less than 11.4 g/dl were seen in 8% of all the 14-year-old girls studied, 3.0% among whites and 9.8% among blacks. Only 1% of all subjects had hemoglobin values below 10 g/dl, 0% among whites and 2.0% among blacks.

When the normal hemoglobin standard was lowered 1.0 g/dl for the black race, the percentage of marginal hemoglobin values in the black population decreased from 9.8% to 2.0% and the deficient hemoglobin values decreased from 2.0% of the black population to 0%.

Fourteen percent of all girls had serum iron values below 40 μ g/dl. Serum iron values below 40 μ g/dl were found among 21.2% of the whites and 9.8% of the blacks. Deficient transferrin saturation values were observed for 25% of the entire group, with 33.3% among whites and 19.6% among blacks. High percentages of deficient serum iron (36.4%) and transferrin saturation values (45.5%) seen in upper-income white girls represent depleted iron stores and indicate that this group is vulnerable to iron-deficiency anemia. Lower-income white girls appear to also be at risk with 27.3% having deficient transferrin saturation levels.

There was a significant positive correlation ($p < 0.05$) between hemoglobin and hematocrit values in lower-income white girls. Hemoglobin values and both serum iron and transferrin saturation values were positively correlated ($p < 0.05$) in black girls. Correlations between iron status measures and ascorbic acid, vitamin A, iron and protein among the race/income groups suggest that high values of the iron status measurements were seen in conjunction with high values of these variables in the diet.

Mean hematocrit, serum iron and transferrin saturation levels were higher in menstruating females, but not significantly higher.

A greater number of upper-income white girls consumed vitamin/mineral supplements than other race/income groups. Only 20% of those consuming vitamin/mineral supplements were consuming supplements with iron. This study illustrates the need for stressing adequate iron intakes for adolescent girls in the future planning of nutrition education and intervention programs, especially those developed for girls in the South.

TABLE OF CONTENTS

CHAPTER	PAGE
I. INTRODUCTION	1
II. REVIEW OF LITERATURE	3
Adolescent Iron Nutriture	3
Rate of growth	3
Rate of iron loss	4
Availability of iron	5
Recommended Dietary Allowance for Iron	7
Food Sources	8
Iron Deficiency	8
Dietary	8
Diagnosis	9
Complications	12
Prevalence	13
Influence of race	14
Influence of income	14
III. EXPERIMENTAL PROCEDURE	16
General Plan	16
Collection Methods	16
24-Hour dietary recalls	16
Venous blood samples	17
Equipment	17
Analyses of Blood	18
Hematocrit	18
Hemoglobin	19
Serum iron	20
Total and unsaturated iron binding capacities and transferrin saturation	21
Statistical Analyses	24
IV. RESULTS	25
Dietary Iron Intake	25
Biochemical Measurements	28
Relationships Among Dietary and Biochemical Data	40
Vitamin/Mineral Supplementation	46
V. DISCUSSION	48
Dietary Iron Intake	48
Biochemical Measurements	49

CHAPTER	PAGE
Relationships Among Dietary and Biochemical Data	57
Vitamin/Mineral Supplementation	61
Conclusions	61
Implications	62
VI. SUMMARY	64
LITERATURE CITED	67
VITA	75

LIST OF TABLES

TABLE	PAGE
I. Dietary Intakes of Iron by Race, Income Level and Age . . .	26
II. Dietary Intakes of Iron per 1000 Kilocalories	27
III. Comparisons of Iron Intake with the 1980 RDA by Race, Income Level and Age	29
IV. Effect of Race and Two Income Levels on Biochemical and Dietary Measurements of Iron Status of 14 ± 0.5-Year-Old Girls	30
V. Hematocrit Values by Race, Income Level and Age	32
VI. Hemoglobin Values by Race, Income Level and Age	33
VII. Effect of Nine Income Levels on Biochemical and Dietary Measurements of Iron Status of 14 ± 0.5-Year-Old Girls	35
VIII. Effect of Race and Nine Income Levels on Biochemical and Dietary Measurements of Iron Status of 14 ± 0.5-Year-Old Girls	36
IX. Biochemical and Dietary Measurements of Iron Status for Menstruating and Nonmenstruating 14 ± 0.5-Year-Old-Girls	38
X. Percentage of Marginal and Deficient Biochemical Measurements of Iron Status by Race and Income Level for 14 ± 0.5-Year-Old Girls	39
XI. Pearson Correlation Coefficients among Dietary and Biochemical Variables for Lower-Income White Girls Aged 14 ± 0.5 Years	42
XII. Pearson Correlation Coefficients among Dietary and Biochemical Variables for Upper-Income White Girls Aged 14 ± 0.5 Years	43
XIII. Pearson Correlation Coefficients among Dietary and Biochemical Variables for Lower-Income Black Girls Aged 14 ± 0.5 Years	44

TABLE

PAGE

XIV.	Pearson Correlation Coefficients among Dietary and Biochemical Variables for Upper-Income Black Girls Aged 14 ± 0.5 Years	45
XV.	Percentage of Girls Aged 9 ± 0.5 to 14 ± 0.5 Years Consuming Vitamin/Mineral Supplements	47

CHAPTER I

INTRODUCTION

During adolescence, the second growth spurt of life occurs, placing increased nutritional demands on the individual, and consequently makes him/her more susceptible to deficiencies. Occurring simultaneously is the increased feeling of independence, which classically manifests itself in a rejection of parental norms.

The adolescent typically places a premium on establishing an identity away from the family, and a great emphasis on establishing oneself within his/her peer group. Ironically, one of the primary familial norms often rejected is a nutritionally adequate diet, a rejection that is reinforced by peer group pressure. Suddenly, a good diet and sound eating habits become unfashionable. Also, since the adolescent is spending more time away from home, he/she is eating away from home and selecting his/her own food. Immaturity regarding the selection of a balanced diet is apt to result in poor food choices. The foods normally selected are those easily accessible, with low nutritional value and a low purchase price, and with high acceptability among peers.

Therefore, with increased nutrient needs and decreased nutrient intake, the adolescent becomes susceptible to deficiencies. Iron deficiency is one of the most common deficiencies encountered, especially in adolescent girls.

In this study, a follow-up to a two-year longitudinal study, the iron status of adolescent girls was evaluated. The objectives of the study were:

1. To evaluate the iron status by hematocrit, hemoglobin, serum iron, unsaturated iron binding capacity, and transferrin saturation determinations.
2. To study the relationship of iron status of the adolescent girls, to factors which may affect iron status—race, income, and dietary iron intake as well as other dietary components determined by analysis of two twenty-four hour dietary recalls.
3. To investigate the effects of menstruation on iron status.
4. To study the incidence of vitamin/mineral supplement consumption among adolescents.

CHAPTER II

REVIEW OF LITERATURE

A. ADOLESCENT IRON NUTRITURE

Adolescence has been described as one of the most critical periods of life with regard to increased iron needs, particularly in teenage girls (1-4). The factors influencing adolescent iron status include the rate of body growth, iron loss and the amount and availability of iron ingested (2).

Rate of Growth

An accelerated growth rate occurs two times throughout life, infancy and adolescence. These periods render the individual especially susceptible to iron deficiency, since blood volume and muscle mass are increased, causing an increased iron need for hemoglobin and myoglobin synthesis. The adolescent growth spurt begins between eight and ten years of age and normally ends between fourteen and sixteen years. The blood volume and muscle mass increase is greater in males than females (5, 6), due to the greater weight gain and larger gain in lean body mass in boys. There are also individual variations in the rate at which lean body mass is added, resulting in differences in the amount of iron required. Other variables that must be considered include the onset of puberty, velocity of growth, and the length of time necessary to complete the maturation process (2). Daniel et al. (7) suggested that the sexual maturity rating accounts for these variables. It is based on

secondary sex characteristics rather than chronological age, and is a better indicator of changing iron needs. Trends cited in the growth and genital development of the United States population include a greater age-adjusted height and weight of children compared to earlier generations and a younger age at which menstruation begins, the average age being 12.5 years (6, 8).

Rate of Iron Loss

Studies using ferric⁵⁵ chloride (9-11) indicate iron losses in adult males and nonmenstruating females range from 0.5 to 1.0 mg of iron per day. Primarily, the iron is lost from the gastrointestinal tract, about 0.4 mg as extravasated red cells, 0.2 mg from bile, and 0.1 mg by exfoliation of the gastrointestinal mucosa. Daily loss from exfoliated skin amounts to 0.2 mg per day and losses in sweat and urine are minimal (12). Conrad et al. (13) suggest a 0.7 ml daily fecal blood loss translating to a 3 mg iron loss. Losses vary according to iron balance changes, decreasing to 0.5 mg in iron deficiency and increasing to 2 to 3 mg in iron overload (12). In addition to these basal iron losses, females must consider menstrual blood losses. Losses incurred by menstrual flow range from 0.5 to 1.5 mg of iron per day, representing the extreme variability among individuals (10-12, 14). Since 0.4 to 0.5 mg of iron are present per ml of blood, depending upon the hemoglobin content of the blood, excessive menstrual losses greatly enhance iron loss (11).

Adolescent girls have an additional iron requirement for growth, amounting to 0.5 to 1.0 mg per day, giving a total requirement of 1.5 to

3.5 mg per day. In pregnancy, the iron requirement is increased to 3 to 4 mg per day during the second and third trimesters because of increasing red cell mass and fetal iron needs (11).

Availability of Iron

The amount of ingested iron and its availability must be considered when estimating iron requirements. Iron is absorbed primarily in the duodenum and upper small intestine. The three factors that determine the degree of iron absorption are intraluminal factors, mucosal factors and corporeal factors (14). Studies concerning the intraluminal factors influencing the absorption of iron showed that larger amounts of iron were absorbed from greater test doses, however the percentage absorbed decreased (15). The form in which iron exists also affects the absorption. Hemoglobin iron is absorbed to a greater degree than inorganic iron and the absorption of hemoglobin iron is not reduced and may even be increased by food or phytates, but is unaffected by ascorbic acid (16-18). Ferrous iron is better absorbed than ferric iron in an acid or alkaline medium, and ferric iron can only be chelated in acid solutions. Hydrochloric acid, from gastric secretions, which creates an acid pH (pH less than 5), solubilizes ferric iron, and then dietary constituents such as sugars (mannitol and sorbitol), polyols, amino acids and ascorbic acid form ferric chelates which are soluble at an alkaline pH and serve to enhance iron absorption. These compounds, by chelation, decrease precipitation and polymerization of iron (14, 19, 20). Other chelators, such as carbonates, oxalates, phosphates, and phytates combine with metal ions to form insoluble complexes which

cannot be absorbed easily (14, 21). Gastric juice contains ascorbic acid which acts as a stabilizer and serves to enhance the absorption of inorganic iron (17, 22). Ethylenediamine tetraacetate, used as an additive and therefore not in significant quantities in the diet, and desferroxamine decrease iron absorption (17). Intrinsic factor increases the absorption of hemoglobin iron but has no effect on inorganic iron, and this is explained by the structure similarity in heme and vitamin B₁₂. Gastroferrin, a component of gastric juice, was proposed by some investigators (23) to decrease iron absorption, but this theory was contested by later research, which showed normal gastric juice did not decrease iron absorption in normal or gastrectomized rats (22). Bile increases iron absorption due to its ascorbate content along with other reducing compounds (23). Secretions from the exocrine pancreas decrease iron absorption (25, 26). Increased intestinal motility decreases iron absorption (27).

Mucosal factors are the primary controllers of the absorption of iron from the duodenum and also play somewhat of a role in iron excretion. Any decrease in the surface area of the duodenum or jejunum will decrease absorption. A decreased iron content of the mucosa causes a resulting increase in iron absorption, until the mucosal receptors are satiated. At this time the mucosa blocks iron absorption (28).

Corporeal factors influential in iron absorption include, first of all, the total body iron content. If the body is iron overloaded, decreased absorption results, and if the body is iron depleted, absorption is increased (29). Accelerated erythropoiesis causes an

increase in iron absorption, whereas a decreased production of red blood cells causes decreased absorption (28).

Another factor defining the availability of food iron is the food source. Iron absorption from plant sources has a range of 1% from rice to 4-6% from lettuce, wheat, and soybeans. Iron absorption from meat is normally 10-15%, and can act to enhance the iron absorption from vegetable sources if ingested together (30).

B. RECOMMENDED DIETARY ALLOWANCE FOR IRON

The Recommended Dietary Allowance (RDA) for 14-year-old females is 18 mg, an amount in excess of the amount needed by the body for obligatory losses, menstrual losses and growth. A 10% absorption of dietary iron is assumed. Daily supplementation with 30 to 60 mg of iron is recommended during pregnancy (31).

Consumption of a balanced diet will afford the female approximately 9 to 12 mg of iron per day. Obviously, the RDA for females of child-bearing age cannot be met through the typical American diet. However, since individuals vary substantially in their needs and ability to utilize dietary iron, their requirements vary. Therefore an intake below the RDA cannot be used solely as a criteria in diagnosing iron deficiency, and the RDA's were not established to do so (32). It has been shown, however, that prolonged intakes of iron appreciably below the RDA will increase the risk of developing iron deficiency (33).

C. FOOD SOURCES

The richest sources of iron are organ meats such as liver, kidney and heart. Pork liver contains 29.1 mg of iron per 3 ounce serving. Other types of animal meat, poultry and fish are also good sources of iron. Shellfish is a good source of iron, 4 ounces of raw oysters containing approximately 7.0 mg of iron. Dried beans and spinach are good vegetable iron sources, each containing approximately 2.0 mg of iron per 1/2 cup of cooked vegetable. Raisins are commonly referred to as a good source of iron, and are percentagewise, but are not normally consumed in large enough quantities to be considered a good source. Five-eighths cup or 3 ounces of raisins contain 3.0 mg of iron. Other fruits, such as apricots and prunes, are also good sources. Enriched breads and cereals contribute considerable amounts of iron to the diet. Enriched white and wheat bread contain approximately 0.8 mg of iron per slice. Ready-to-eat cereals contain from 0.3 mg to 8.8 mg of iron per 1/2 cup. The iron content of cooked cereals ranges from 0.7 mg to 8.4 mg of iron per 1/2 cup. Poor iron sources are milk and milk products, white sugar, unenriched white flour and bread, polished rice, potatoes and most fresh fruits (34-36).

D. IRON DEFICIENCY

Dietary

Monsen et al. (37) established that the daily intake of iron has decreased due to several factors, including a decrease in total kilocalorie consumption, an increased cleanliness in food handling and

decreased use of iron cookware. Studies by Greger et al. (38, 39) showed that one of the nutrients commonly found deficient in the diets of adolescent girls was iron. It has been observed that adolescent girls, in their attempts to maintain slim figures, ignore nutritious meals and resort to nibbling and undereating, which is a suggested explanation for repeated observations of vitamin and iron deficiencies in adolescent girls (6, 10, 40). Greger et al. (38) found that the majority of teens studied consumed much less than the recommended 18 mg of iron. Less than the recommended intakes were also reported in the 1968 Ten-State Nutrition Survey (41). In other studies (11, 40), adolescent girls reportedly had intakes of 10 mg or less of iron each day. Despite these low intakes of dietary iron, several studies found no correlation between dietary iron intake and the occurrence of iron deficiency (33, 38, 42, 43). Monsen et al. (37) also reported low correlations of iron intake with iron absorption and transferrin saturation, which they theorized was due to a combination of small ranges in dietary iron values and large variability in transferrin saturation and iron absorption values. The large range in transferrin saturation and iron absorption values was thought to be due to variable menstrual losses.

Diagnosis

Hematocrit and hemoglobin determinations are two of the most widely used measures for diagnosing iron-deficiency anemia in the survey population. These indicators are not specific to the cause of anemia, but rather are indicative of red blood cell abnormalities (44). A

recent report published by the U.S. Department of Health, Education and Welfare states that hematocrit and hemoglobin values cannot be used interchangeably as a test for iron-deficiency anemia. They found hematocrit values underestimated the prevalence of anemia and recommended that hemoglobin determinations be the method used to screen for anemia (45).

Bainton and Finch (46) suggested serum iron and percent transferrin saturation determinations be used in assessing iron status. These parameters are representative of iron stores and are early indicators of iron storage depletion. They stressed that recognition of hypochromic and microcytic circulating red blood cells was not an early sign of iron deficiency. Erythropoiesis may be altered weeks or months prior to the appearance of hypochromia and microcytosis. They noted that reduced cell size was not diagnostic of iron deficiency, as it presents itself in other conditions such as thalassemia, lead poisoning, and pyridoxine-responsive anemia, in which cases hemoglobin synthesis is also impaired. In addition to the serum iron and transferrin saturation determinations, they also recommended both analyzing reticuloendothelial cells for hemosiderin content and the quantity of iron granules within developing red cells. The normal ranges for these parameters are a serum iron of 90 to 105 $\mu\text{g/dl}$, total iron binding capacity of 280 to 315 $\mu\text{g/dl}$, transferrin saturation of 30 to 35%, marrow hemosiderin of a +2 grading described by Rath and Finch (47), and a sideroblast (iron granule present in red cells) count of 35 to 40% of the developing red cells. The method for this count was discussed by Douglas and Dacie (48). In subjects with chronic iron-deficiency anemia, hypochromic and microcytic

anemia, serum iron was 60 $\mu\text{g/dl}$ or less, the percent transferrin saturation was 16 or less, iron stores were 0 to + 0.5, and the sideroblast count was below 10%. Dallman (49) stated that due to the poor reproducibility of the serum iron and total iron binding capacity, the ratio of serum iron to total iron binding capacity should be emphasized rather than evaluating each value separately. He also made reference to the diurnal variation in the serum iron value, eliciting elevated values in the morning and depressed values in the afternoon and evening.

Jacobs et al. (50) described the merits of determining the concentration of serum ferritin by sensitive immunoradiometric assay in assessing the body stores of iron. It was previously thought that ferritin was not present in normal plasma or extracellular fluid. This assay presents a valuable direct method of assessing subnormal or excessive storage levels.

Finch (51) also advocated the use of the serum ferritin determination in the assessment of iron deficiency in addition to transferrin saturation and red cell protoporphyrin determinations. A serum ferritin of less than 12 $\mu\text{g/l}$, a transferrin saturation of less than 16% and a red cell protoporphyrin of more than 100 $\mu\text{g/dl}$ of red cells were indicative of an inadequate iron supply for erythropoiesis or for the synthesis of essential iron compounds. Cook et al. (52) state that two abnormal levels of these three indices represents iron deficiency.

Dallman (49) included the serum ferritin assay following the prior determination of mean corpuscular volume by electronic counter and the analysis of free erythrocyte protoporphyrin by a simple fluorescence method. A low mean corpuscular volume is indicative of impaired

hemoglobin synthesis, evident in iron-deficiency anemia or thalassemia minor. The free erythrocyte protoporphyrin, used to identify iron deficiency and lead poisoning, becomes elevated because the last step in the synthesis of heme, namely the combination of iron and protoporphyrin, is inhibited.

Complications

Iron-deficiency anemia reduces the oxygen available to the tissues, which affects cardiac output and could eventually lead to death (53). It has been postulated that too much emphasis has been placed on the oxygen transport role of iron, however, and not enough on its other effects (51). Studies have reported that iron-deficiency anemia decreased work performance (54). Muscle function seems to be affected, possibly from a deficiency of glycerolphosphate dehydrogenase activity in skeletal muscle (55). Increased susceptibility to infection due to iron-deficiency anemia has also been reported (56). There is a decrease in the iron-containing enzymes, such as cytochrome C and cytochrome oxidase, and reduced activity of other enzymes, such as aconitase, that require iron as a cofactor (57).

Severe anemia in pregnancy has been correlated with increased risk of premature delivery and also maternal and fetal morbidity (58). Premature delivery has been correlated with mildly anemic states in the mother and hemoglobin values of the mother relate well with fetal birth weight (59).

In rat studies, iron deficiency was shown to interfere with growth, but it is not known if it is due to iron deficiency or decreased food intake (60).

Prevalence

As early as 1928, the prevalence of iron-deficiency anemia in children was evident. Guest and Brown (61) studied children from the Cincinnati, Ohio, area in the 1930's and found high incidences of iron deficiency (30%), especially in adolescent girls. Upon repeating this study in 1957, they found the high incidence had not subsided. A study by Katzman et al. (62) showed a decreased incidence of anemia in later childhood that became apparent again in adolescent females, whose limited iron intake did not meet the demands of puberty and menstruation.

In 1967 Scott and Pritchard (63) found iron stores in healthy young women markedly below the normal range of 1.0 g to 1.5 g. Pearson et al. (1) reported the mean hematocrit readings of a group of post-pubertal females considerably below the normal reading of 42%. There was an 8% frequency of anemia, with a hematocrit of less than 34% considered the criteria for anemia. DeWijn and Pikaar (3) also noted this increase in prevalence of anemia in adolescence, based on lower than normal transferrin saturation levels. In 1972, WHO (64) reported that world wide, deficiency in menstruating females occurred in 10 to 50% of those studied. A survey conducted by Brown et al. (65) demonstrated an incidence of anemia among black females ranging from 11.4 to 27.3%. Anemia, as defined by the National Nutrition Survey, is a hemoglobin value less than 11.5 g/dl. Moore (40) estimated the incidence of

iron-deficiency anemia in the United States to be 5 to 10% of women between the ages of 15 and 45. The criteria for anemia used in this case was the appearance of small, pale erythrocytes, depleted iron stores, plasma iron of less than 40 $\mu\text{g/dl}$, an elevated iron binding capacity and less than 15% transferrin saturation. Hodges and Krehl (66) were able to show positive correlations between hemoglobin and hematocrit values and iron intakes, however they were not significant.

Influence of Race

A question has arisen concerning racial differences in hemoglobin and hematocrit concentrations, and is yet unresolved. Several studies have illustrated the consistently lower hemoglobin concentrations in blacks (41, 43, 44, 49, 62, 67-71). Hemoglobin values of blacks are approximately 1.0 g/dl lower than whites and hematocrit readings are 3% volumes lower than whites, even after socioeconomic factors have been considered. It has not proven to be a genetic difference and may possibly be dietary related. Erythropoietin, a hormone released by the kidneys that influences hemoglobin production, is possibly responsible for the racial difference in hemoglobin concentrations, but no evidence exists to show a difference in production or release of erythropoietin between races (69).

Influence of Income

Iron-deficiency anemia has been a disease state associated with the poorer classes (40, 51, 70, 72). Finch (51) pointed out that most iron consumed by those of lower economic status is in the form of vegetable or non-heme iron which is absorbed only to a small degree by the body.

Karp et al. (70) found that between 1972 and 1975, as food prices escalated, the purchase of meat decreased. With this decrease in meat consumption and the concomitant increase in the consumption of high-energy, low-iron staples, the probability of developing iron deficiency increased. Goel et al. (72) stated that the high incidence of iron-deficiency anemia among the lower classes was possibly a reflection of poor compliance with recommended feeding practices and perhaps lack of nutrition education.

CHAPTER III

EXPERIMENTAL PROCEDURE

A. GENERAL PLAN

Approximately 120 preadolescent girls were studied for 2 years in the S-87 Regional Nutrition Project beginning in 1974 at age 9 ± 0.5 years. Data were again collected on the girls in 1975 and 1976 when they were 10 ± 0.5 and 11 ± 0.5 years of age. The present restudy carried out in 1979 involved 94 of these girls, now adolescents, aged 14 ± 0.5 . Two income categories, those from upper-income families (\$2,000 or more/person/year) and those from lower-income families (\$1,200 or less/person/year) and two racial groups, whites and blacks, were represented. The subjects were selected initially through the city and county school systems of Knox County, Tennessee, and were known to have no metabolic disorders. Informed written consent was obtained from the parents or guardians. Dietary intakes and data from biochemical analyses of fasted blood samples were evaluated to determine iron status.

B. COLLECTION METHODS

24-Hour Dietary Recalls

Dietary information was obtained from each subject twice a year using 24-hour recalls of food intake. The first dietary recall was taken two weeks prior to the day of blood collection and the second one completed the day of the blood collection. The recalls were obtained

by trained interviewers using food models to assist in determining accurate portion sizes. Nutrient composition of the summarized dietaries were calculated using the Extended Table of Nutrient Values.¹

Venous Blood Samples

Following an overnight fast, 13 ml of venous blood were drawn from each subject by a nurse or medical technician from The University of Tennessee Memorial Hospital. All subjects received written instructions prior to the day of collection concerning the fast and blood collection. Three milliliters of blood were drawn into heparinized vacutainer tubes to facilitate the hematocrit and hemoglobin determinations. Ten milliliters of blood were drawn into nonheparinized vacutainer tubes and allowed to coagulate. Following coagulation, the blood was centrifuged at $664 \times g$ for 10 minutes. Each serum sample was extracted from the clotted blood using a Pasteur pipet, placed in a test tube, stoppered, and stored at -12° for future analyses.

C. EQUIPMENT

The Damon/IEC Division Centrifuge Model No. HN-S² was used for centrifugation in all analyses. All absorbances were measured with the Beckman Model 24 Spectrophotometer.³ Unless otherwise specified, all

¹International Dietary Information Foundation, Inc., P. O. Box 38143, Atlanta, GA 30334.

²Damon/IEC Division, Needham Hts., MA 02194.

³Beckman Instruments, Inc., Fullerton, CA 92634.

mixing was done using an automatic mixer.⁴ All glassware used for serum iron and unsaturated iron binding capacity was acid-washed in a nitric acid solution diluted 1 part nitric acid to 4 parts demineralized water. All water used in the serum iron and unsaturated iron binding capacity determinations was demineralized water.

D. ANALYSES OF BLOOD

Hematocrit

Hematocrit determinations were completed on freshly drawn heparinized blood. Capillary tubes 75 mm long were filled to 80 to 90% of their length by capillary attraction. The filled capillary tubes were sealed with Critoseal⁵ (a specially formulated vinyl plastic putty for sealing capillary tubes), and placed into the centrifuge head with the sealed ends of the tubes secured against the outer rubber gasket of the centrifuge head. Four capillary tubes were prepared per subject and centrifuged for 10 minutes at $664 \times g$.

Following centrifugation, hematocrit values were determined by direct measurement of the column of red blood cells and whole blood and calculated as follows.

Calculations.

$$\% \text{ Hematocrit (Hct.)} = \frac{\text{Length of column of erythrocytes (mm)}}{\text{Length of column of total blood (mm)}} \times 100$$

⁴Vortex-Genie, Scientific Industries, Springfield, MA 01103.

⁵Critoseal Fisher Scientific Company, 711 Forbes Avenue, Pittsburgh, PA 15219.

Hemoglobin

Hemoglobin concentration in blood was measured by the cyanmethemoglobin method which utilizes the cyanmethemoglobin reagent and Hycel standards.⁶

Reagents.

1. Cyanmethemoglobin reagent: a preweighed vial of reagent was transferred to a 1 liter volumetric flask, diluted to volume and mixed thoroughly by inversion.

2. Cyanmethemoglobin standard: vials, as purchased, contained the standard solution used in dilutions of 0 to 20 g/dl in the preparation of the standard curve.

Method. Two-hundredths milliliter micropipettes were used to deliver duplicate samples of heparinized blood to tubes containing 5 ml cyanmethemoglobin reagent, and the tubes were mixed well. The absorbance of samples and standards were determined with the spectrophotometer set at 540 nm. The spectrophotometer was adjusted to zero absorbance with the Hycel cyanmethemoglobin reagent blank. Absorbances of standards were determined with each set of samples. The hemoglobin values were determined using the following equation.

Calculations.

$$\text{Grams of hemoglobin/dl of blood} = \frac{A_u}{A_s} \times C_s$$

⁶Hycel, Inc., P. O. Box 36329, Houston, TX 77036.

Au = Absorbance of unknown.

As = Absorbance of standard.

Cs = Concentration of standard.

Serum Iron

Serum iron concentration was measured by the Hycel procedure⁷ which initially involves the destruction of the iron-protein complex, followed by the formation of an iron-ferrozine complex, thus allowing an absorbance measurement with a spectrophotometer.

Other metals that form complexes with ferrozine are monovalent copper and divalent cobalt, copper being the only one common in serum. Thiourea has been added to the iron buffer to prevent copper from forming a complex with ferrozine.

Precautions were taken to avoid hemolysis of the blood samples, because hemolyzed samples resulted in unreliable serum iron and unsaturated iron binding capacity values (73).

Reagents.

1. Iron buffer: a commercial vial containing 1.0% hydroxylamine hydrochloride and 0.2% mercaptoacetic acid as reactive ingredients that act to reduce the pH of the serum and thus release the iron from transferrin.

2. Iron color reagent: a commercial vial of 1.0% ferrozine, used to combine with iron to form a chromogen.

⁷Hycel, Inc., P. O. Box 36329, Houston, TX 77036.

Method. Five-tenths milliliter of each sample was pipetted into marked test tubes and 0.5 ml of demineralized water, to serve as the blank, was pipetted into a test tube. Then 2.0 ml of iron buffer were added to each tube and mixed well. The tubes were placed in a 37° water bath for 10 minutes. After removal from the water bath, absorbances of the samples were measured with a spectrophotometer set at 560 nm. One-tenth milliliter of iron color reagent was added to each tube and mixed well. For 10 minutes the tubes were again placed in a 37° water bath, after which their absorbance was again measured with the spectrophotometer against a reagent blank at 560 nm.

Calculations.

$$A = \frac{B_2 - B_1}{C_2 - C_1} \times D$$

A = Concentration of sample in µg/dl.

B₁ = Absorbance of sample before addition of color reagent.

B₂ = Absorbance of sample after addition of color reagent.

C₁ = Absorbance of standard before addition of color reagent.

C₂ = Absorbance of standard after addition of color reagent.

D = Concentration of standard in µg/dl.

Total and Unsaturated Iron Binding Capacities and Transferrin Saturation

Since transferrin is normally only 25 to 30% saturated with iron, the additional amount of iron capable of binding to transferrin is called the unsaturated iron binding capacity (UIBC). The sum of the

serum iron and the UIBC is known as the total iron binding capacity (TIBC). The percent transferrin saturation is a ratio of the serum iron to the total iron binding capacity. The UIBC was determined directly by saturating the transferrin at an alkaline pH with a known but excess amount of iron. The excess iron was then measured by the serum iron determination method, except at a pH above 7.5, so that the iron-protein complex remained intact. The UIBC was then calculated by subtracting the excess from the known amount of iron added.

Reagents.

1. Iron binding buffer: a commercial vial containing nonreactive ingredients such as buffer, nonionic surfactant, thiourea and preservative.
2. Iron binding reductant: a commercial vial containing 100% hydroxylamine hydrochloride, in powder form.
3. Iron binding working reagent: prepared by the addition of 15 ml of iron binding buffer to the vial containing a premeasured amount of iron binding reductant and mixing by inversion until completely dissolved.
4. Iron standard: a commercial vial containing 0.0035% ferrous ammonium sulfate, with a concentration of 500 µg/dl, which serves as the known but excess amount of iron added to the serum in an alkaline buffer, to saturate the available transferrin binding sites.
5. Iron color reagent: a commercial vial containing 1.0% ferrozine as its reactive ingredient. Ferrozine forms a complex with iron, allowing absorbance to be measured.

Method. Before beginning the assay, the iron binding working reagent was prepared by adding 15 ml of iron binding buffer to the iron

binding reductant, mixing by inversion, and allowing to stand to fully dissolve. The standard was made up of 0.5 ml of iron standard diluted with 0.5 ml of demineralized water. Five-tenths milliliter of iron standard was added to 0.5 ml of each sample. One and five-tenths milliliters of iron binding working reagent were added to each tube, including the reagent blank, comprised of 1.0 ml of demineralized water, and mixed well. All tubes were placed in a 37° water bath for 10 minutes. Their absorbance was measured against the demineralized water blank with the spectrophotometer set at 560 nm. This was followed by the addition of 0.1 ml of iron color reagent to each tube and thoroughly mixing each. All tubes were then returned to the 37° water bath for 10 minutes. Their absorbance was again measured against the demineralized water blank at 560 nm.

Calculations.

$$E = F - \left(\frac{G_2 - G_1}{H_2 - H_1} \times I \right)$$

E = Unsaturated iron binding capacity in µg/dl.

F = Concentration of added iron standard in µg/dl.

G₁ = Absorbance of sample before addition of color reagent.

G₂ = Absorbance of sample after addition of color reagent.

H₁ = Absorbance of standard before addition of color reagent.

H₂ = Absorbance of standard after addition of color reagent.

I = Concentration of standard in µg/dl.

The total iron binding capacity in $\mu\text{g/dl}$ was calculated according to the following equation:

$$J = A + E.$$

J = Total iron binding capacity in $\mu\text{g/dl}$.

A = Serum iron concentration in $\mu\text{g/dl}$.

E = Unsaturated iron binding capacity in $\mu\text{g/dl}$.

The transferrin saturation percentage was calculated as follows:

$$K = \frac{A}{J} \times 100$$

K = Transferrin saturation in %.

A = Serum iron concentration in $\mu\text{g/dl}$.

J = Total iron binding capacity in $\mu\text{g/dl}$.

E. STATISTICAL ANALYSES

Data collected were analyzed at The University of Tennessee Computing Center using the Statistical Analysis System (SAS) developed by Barr et al. (74). Means, standard errors of the means, least squares means and standard errors of the least squares means were determined for dietary intakes and biochemical measurements by race, income and race/income categories. The unequal Duncan's test, run on the Olivetti Underwood Programma 101⁸ and the computer, was used for testing for significant differences between group means. Pearson correlation coefficients among dietary and biochemical data were calculated using the computer.

⁸Olivetti Underwood Corporation, 415 St. Mary St., Burlington, NJ 08016.

CHAPTER IV

RESULTS

A. DIETARY IRON INTAKE

Mean dietary intakes of iron were calculated for lower-income white, upper-income white, lower-income black and upper-income black girls at 14 years of age and compared with data collected when the girls were 9, 10, and 11.¹ Supplements were not included. Of the 14-year olds, the upper-income white girls had the greatest mean dietary iron intakes, with upper-income black girls recording the lowest, shown in Table I. These differences between groups were not statistically significant. The trend established in earlier years had white girls steadily increasing their mean dietary iron intake, whereas black girls decreased their mean dietary iron intake from the first to the second year, but then responded with a progressive increase from 10 to 14 years of age. There was approximately a 1.0 mg increase in the mean dietary iron intake in each 14-year-old race/income group, compared to those of the girls at 11 years of age.

Mean intakes of iron per 1000 kilocalories are reported in Table II. When supplements were excluded, lower-income white girls had the greatest iron intake per 1000 kilocalories, and lower-income blacks had the

¹T. Wakefield (1979), The Relationship of Biochemical and Dietary Parameters to Growth in Preadolescent Black and White Girls. Unpublished Doctoral dissertation, The University of Tennessee, Knoxville, TN.

TABLE I
DIETARY INTAKES OF IRON BY RACE, INCOME LEVEL AND AGE^{a,b}

Group ^c	Age (Years)			
	9 ± 0.5	10 ± 0.5	11 ± 0.5	14 ± 0.5
	mg/day	mg/day	mg/day	mg/day
LIW	8.0 ± 0.6 ^{d,e,*} n = 34	9.4 ± 0.6* n = 30	10.0 ± 0.8* n = 30	11.9 ± 1.0* n = 23
UIW	9.5 ± 0.8* n = 31	10.4 ± 0.8* n = 26	11.0 ± 0.9* n = 26	12.3 ± 0.8* n = 15
LIB	11.4 ± 0.9* n = 29	9.7 ± 0.5* n = 28	10.4 ± 0.6* n = 28	11.2 ± 0.9* n = 28
UIB	9.5 ± 0.5* n = 30	9.3 ± 0.5* n = 30	10.2 ± 0.6* n = 29	11.0 ± 0.7* n = 28

^a9 ± 0.5, 10 ± 0.5 and 11 ± 0.5 data taken from T. Wakefield (1979), The Relationship of Biochemical and Dietary Parameters to Growth in Preadolescent Black and White Girls. Unpublished Doctoral dissertation, The University of Tennessee, Knoxville, TN.

^bData are without supplements.

^cLIW = Lower-Income White, UIW = Upper-Income White, LIB = Lower-Income Black, UIB = Upper-Income Black.

^dMean ± SEM.

^eMeans within a column not sharing a common superscript symbol are significantly different (p < 0.05).

TABLE II
DIETARY INTAKES OF IRON PER 1000 KILOCALORIES^a

Group ^b	Number Subjects	Iron
		mg/1000 Kcal/day
LIW	23	5.9 ± 0.3 ^{c,d,*}
UIU	15	5.7 ± 0.2*
LIB	28	5.4 ± 0.2*
UIB	28	5.6 ± 0.2*

^aData are without supplements.

^bLIW = Lower-Income White, UIW = Upper-Income White, LIB = Lower-Income Black, UIB = Upper-Income Black.

^cMeans ± SEM.

^dMeans within a column not sharing a common superscript symbol are significantly different ($p < 0.05$).

lowest intake. The differences between groups were not significant. Mean iron intakes per 1000 kilocalories without supplements are in the 5 to 6 mg range.

Comparisons were made of the dietary iron intake, expressed as a percent of the 1980 RDA, and categorized under the headings, < 33% RDA, 33 to 66% RDA, 67 to 100% RDA, and > 100% RDA, as shown in Table III. Supplements were not included. The number of subjects falling into each section is expressed as a percent of the total number of girls for a designated year. Prior to age 14, increasing percentages of girls were observed in the < 33% and in the 33 to 66% RDA categories with decreasing percentages in the 67 to 100% and > 100% RDA groups. A comparison of 11-year olds with 14-year olds showed a shift of subjects from a high concentration in the 33 to 66% RDA group (70.3% total) to a more even distribution between the 33 to 66% RDA (46.8% total) and the 67 to 100% RDA group (38.2% total). This increase in the total percentage of girls consuming 67 to 100% RDA was mainly due to large increases in the iron intake of girls from both economic factions of the black population and to a lesser degree to small increases in the iron intake of girls from the white population. A slight increase in the total percentage of girls consuming above 100% of the RDA for iron was also noted.

B. BIOCHEMICAL MEASUREMENTS

Least squares means of hematocrit, hemoglobin, serum iron, transferrin saturation determinations and iron intakes for the four race/income groups of 14-year-old girls are presented in Table IV. Iron intakes include supplements. Least squares means were used because they

TABLE III
COMPARISONS OF IRON INTAKE WITH THE 1980 RDA BY RACE, INCOME LEVEL AND AGE ^{a,b}

Group ^c	Percent of Subjects															
	Below 33% RDA				33-66% RDA				67-100% RDA				Above 100% RDA			
	9±0.5	10±0.5	11±0.5	14±0.5	9±0.5	10±0.5	11±0.5	14±0.5	9±0.5	10±0.5	11±0.5	14±0.5	9±0.5	10±0.	11±0.5	14±0.5
LIW	0 ^d	0.8	2.5	2.1	11.6	5.0	16.9	12.8	7.7	10.1	3.4	7.4	7.0	9.2	2.5	2.1
UIW	0	0	3.4	0	3.9	4.2	11.9	7.4	10.9	9.7	6.8	7.4	10.1	9.7	0.8	1.1
LIB	0	0	0.8	4.3	1.5	2.5	18.6	13.8	13.2	14.3	5.1	10.6	9.3	8.4	0.8	1.1
UIB	0	0	0	3.2	3.9	4.2	22.9	12.8	10.9	14.3	2.5	12.8	10.1	7.6	0.8	1.1
Total	0	0.8	6.7	9.6	20.9	15.9	70.3	46.8	42.7	48.4	17.8	38.2	36.5	34.9	4.9	5.4

^aUnpublished data from the S-87 Southern Regional Project, Department of Food Science, Nutrition and Food Systems Administration, College of Home Economics, The University of Tennessee and the Tennessee Agricultural Experiment Station, Knoxville, TN.

^bData are without supplements.

^cLIW = Lower-Income White, UIW = Upper-Income White, LIB = Lower-Income Black, UIB = Upper-Income Black.

^dValues are percent of total subjects per year.

TABLE IV
EFFECT OF RACE AND TWO INCOME LEVELS ON BIOCHEMICAL AND DIETARY MEASUREMENTS
OF IRON STATUS OF 14 ± 0.5-YEAR-OLD GIRLS

Group ^a	Hematocrit	Hemoglobin	Serum Iron	Unsaturated Iron Binding Capacity	Total Iron Binding Capacity	Transferrin Saturation	Iron Intake ^b
	%	g/dl	µg/dl	µg/dl	µg/dl	%	mg/day
LIW	43.5 ± 1.1 ^{c,d,*}	13.3 ± 0.2*	80.2 ± 9.3*	252.2 ± 13.9*	333.3 ± 13.3*	25.2 ± 2.9*	11.9 ± 1.4*
	n = 22	n = 22	n = 22	n = 22	n = 22	n = 22	n = 23
UIW	46.4 ± 1.3*	13.8 ± 0.2*	81.4 ± 13.2*	256.1 ± 19.6*	337.6 ± 18.8*	24.2 ± 4.2*	12.3 ± 1.8*
	n = 15	n = 15	n = 11	n = 11	n = 11	n = 11	n = 15
LIB	44.1 ± 1.0*	12.5 ± 0.2**	81.3 ± 8.9*	265.3 ± 13.3*	347.0 ± 12.7*	23.4 ± 2.8*	11.2 ± 1.3*
	n = 26	n = 26	n = 24	n = 24	n = 24	n = 24	n = 28
UIB	44.1 ± 0.9*	12.7 ± 0.2**	92.1 ± 8.4*	276.4 ± 12.5*	370.4 ± 12.0*	25.8 ± 2.7*	13.0 ± 1.3*
	n = 28	n = 28	n = 27	n = 27	n = 27	n = 27	n = 28

^aLIW = Lower-Income White, UIW = Upper-Income White, LIB = Lower-Income Black, UIB = Upper-Income Black.

^bData are with supplements.

^cLeast Squares Means ± Standard Error of Least Squares Means.

^dMeans within a column not sharing a common superscript symbol are significantly different (p < 0.05).

are more representative of the true mean when comparing groups of unequal sizes. Upper-income white girls had the highest mean hematocrit and hemoglobin values, differences being significant between groups for hemoglobin, but not hematocrit values. Upper-income black girls had the highest mean serum iron, UIBC, TIBC, transferrin saturation and iron intake. These values were not significantly greater than the mean values for the other race/income groups. Lower-income white girls had the lowest mean values for hematocrit, serum iron, UIBC and TIBC, whereas lower-income black girls had the lowest mean hemoglobin, transferrin saturation level, and iron intake. White girls had a significantly greater ($p < 0.05$) mean hemoglobin value than black girls.

Two 14-year-old lower-income black girls were in the first trimester of pregnancy during this study. Blood iron data were collected for one of the girls. Her blood values were: hematocrit, 36.8%; hemoglobin, 12.0 g/dl; serum iron, 120.2 μ g/dl; transferrin saturation, 27.8%. All values were within the acceptable range. Her dietary intake was 13.2 mg/day of iron. The remaining pregnant girl was consuming 17.6 mg/day and took an iron supplement of 25 mg one day. Thus the respective iron intakes of the two girls were 27% and 63% of the RDA for pregnant adolescent girls, which is 48 mg/day (RDA + 30 mg).

Mean hematocrit values for the four race/income groups are presented in Table V. The trend established over the years is toward increasing mean hematocrit values in each race/income group, with either component of the white population having the highest mean hematocrit value. Table VI shows the mean hemoglobin levels at 9, 10, 11 and 14 years of age. Again the pattern of higher mean hemoglobin values in the

TABLE V
HEMATOCRIT VALUES BY RACE, INCOME LEVEL AND AGE^a

Group ^b	Age (Years)			
	9 ± 0.5	10 ± 0.5	11 ± 0.5	14 ± 0.5
	%	%	%	%
LIW	39.8 ± 0.4 ^{c,d,*,**} n = 30	43.0 ± 0.7* n = 29	46.6 ± 0.8* n = 30	43.5 ± 0.9* n = 22
UIW	41.1 ± 0.5* n = 27	43.4 ± 0.5* n = 27	44.5 ± 0.5** n = 26	46.4 ± 1.5* n = 15
LIB	38.9 ± 0.5** n = 28	42.2 ± 0.5* n = 28	43.1 ± 0.7** n = 28	44.1 ± 1.1* n = 26
UIB	41.0 ± 0.4* n = 28	42.5 ± 0.4* n = 28	43.7 ± 0.5** n = 29	44.1 ± 0.9* n = 28

^a9 ± 0.5, 10 ± 0.5 and 11 ± 0.5 data taken from T. Wakefield (1979), The Relationship of Biochemical and Dietary Parameters to Growth in Preadolescent Black and White Girls, Unpublished Doctoral dissertation, The University of Tennessee, Knoxville, TN.

^bLIW = Lower-Income White, UIW = Upper-Income White, LIB = Lower-Income Black, UIB = Upper-Income Black.

^cMean ± SEM.

^dMeans within a column not sharing a common superscript symbol are significantly different (p < 0.05).

TABLE VI
HEMOGLOBIN VALUES BY RACE, INCOME LEVEL AND AGE^a

Group ^b	Age (Years)			
	9 ± 0.5	10 ± 0.5	11 ± 0.5	14 ± 0.5
	g/dl	g/dl	g/dl	g/dl
LIW	13.4 ± 0.2 ^{c,d,*} n = 30	12.7 ± 0.3 ^{*,**} n = 29	13.1 ± 0.3 [*] n = 30	13.3 ± 0.2 [*] n = 22
UIW	13.3 ± 0.1 [*] n = 27	13.1 ± 0.3 [*] n = 27	12.9 ± 0.3 [*] n = 26	13.8 ± 0.2 [*] n = 15
LIB	12.4 ± 0.2 ^{**} n = 28	12.1 ± 0.2 ^{**} n = 28	12.1 ± 0.4 [*] n = 28	12.5 ± 0.2 ^{**} n = 26
UIB	12.6 ± 0.2 ^{**} n = 28	12.1 ± 0.2 ^{**} n = 28	12.8 ± 0.4 [*] n = 29	12.7 ± 0.2 ^{**} n = 28

^a9 ± 0.5, 10 ± 0.5 and 11 ± 0.5 data taken from T. Wakefield (1979), The Relationship of Biochemical and Dietary Parameters to Growth in Preadolescent Black and White Girls. Unpublished Doctoral dissertation, The University of Tennessee, Knoxville, TN.

^bLIW = Lower-Income White, UIW = Upper-Income White, LIB = Lower-Income Black, UIB = Upper-Income Black.

^cMean ± SEM.

^dMeans within a column not sharing a common superscript symbol are significantly different (p < 0.05).

whites than in the blacks exists, whether it be the upper- or lower-income, with a general increase with age in mean hemoglobin values across all race/income groups.

Mean values of various iron status measures for nine income categories are listed in Table VII. Supplements were included. The higher mean hematocrit and hemoglobin values were clustered primarily in the upper-income brackets, although some high mean values were seen in a few lower-income categories. The highest mean serum iron value and a high transferrin saturation level were evident in the \$4,000 to \$5,499 income group. The \$14,000 to \$17,999 group had the highest mean transferrin saturation level. The greatest mean iron intake value was observed in the \$10,000 to \$13,000 income group, due to the iron supplements being taken by the upper-income black girls, with the \$3,000 to \$3,999 and \$4,000 to \$5,499 groups having the next highest mean values. The mean iron intake was significantly greater ($p < 0.05$) in the \$10,000 to \$13,999 income category than in the less than \$3,000 and \$5,500 to \$6,999 income brackets.

In Table VIII, the mean biochemical and dietary measurements of iron status are presented for each race/income level. There were no significant differences in mean iron intake values, however black girls of the \$10,000 to \$13,999 income bracket had the greatest mean intake, due again to the vitamin/mineral supplements the black girls were taking. Significant differences existed in all other iron status parameters. The mean hematocrit values for white girls in the \$14,000 to \$17,999 income range and black girls in the \$5,500 to \$6,999 income group were significantly greater ($p < 0.05$) than black girls of the \$8,500 to

TABLE VII
EFFECT OF NINE INCOME LEVELS ON BIOCHEMICAL AND DIETARY MEASUREMENTS
OF IRON STATUS OF 14 ± 0.5-YEAR-OLD GIRLS

Income	Hematocrit	Hemoglobin	Serum Iron	Transferrin Saturation	Iron Intake ^a
	%	g/dl	µg/dl	%	mg/day
<\$3,000	43.4 ± 2.1 ^{b,c,*} n = 6	12.8 ± 0.4* n = 6	91.2 ± 18.3* n = 6	24.0 ± 5.6* n = 6	8.8 ± 2.7** n = 6
\$3,000-\$3,999	42.5 ± 2.3* n = 5	12.7 ± 0.5* n = 5	56.9 ± 20.0* n = 5	18.4 ± 6.1* n = 10	12.9 ± 3.0*,** n = 5
\$4,000-\$5,499	43.7 ± 1.6* n = 10	13.0 ± 0.3* n = 10	108.7 ± 14.1* n = 10	29.2 ± 4.3* n = 10	12.9 ± 1.9*,** n = 12
\$5,500-\$6,999	46.7 ± 1.7* n = 9	12.5 ± 0.3* n = 9	68.6 ± 14.9* n = 9	27.7 ± 4.6* n = 9	9.1 ± 2.2** n = 9
\$7,000-\$8,499	43.7 ± 1.6* n = 10	13.0 ± 0.3* n = 10	70.5 ± 14.1* n = 10	21.1 ± 4.3* n = 10	10.9 ± 2.0*,** n = 11
\$8,500-\$9,999	42.4 ± 1.8* n = 8	12.7 ± 0.3* n = 8	90.5 ± 15.8* n = 8	27.9 ± 5.2* n = 7	10.5 ± 2.4*,** n = 8
\$10,000-\$13,999	45.1 ± 1.3* n = 15	12.5 ± 0.3* n = 15	84.0 ± 11.5* n = 15	22.1 ± 3.7* n = 14	16.0 ± 1.7* n = 15
\$14,000-\$17,999	44.8 ± 1.8* n = 8	13.4 ± 0.3* n = 8	102.2 ± 16.9* n = 7	29.3 ± 5.2* n = 7	12.4 ± 2.6*,** n = 8
\$18,000+	44.7 ± 1.1* n = 20	13.4 ± 0.2* n = 20	89.8 ± 10.0* n = 20	20.0 ± 3.4* n = 16	12.0 ± 1.5*,** n = 20

^aData are with supplements.

^bLeast Squares Means ± Standard Error of Least Squares Means.

^cMeans within a column not sharing a common superscript symbol are significantly different (p < 0.05).

TABLE VIII
EFFECT OF RACE AND NINE INCOME LEVELS ON BIOCHEMICAL AND DIETARY MEASUREMENTS
OF IRON STATUS OF 14 ± 0.5-YEAR-OLD GIRLS

Income	Hematocrit %	Hemoglobin g/dl	Serum Iron µg/dl	Transferrin Saturation %	Iron Intake ^a mg/day
<u>White</u>					
<\$3,000	38.9 ± 3.4 ^{b,c,**} (2) ^d	12.7 ± 0.7** (2)	109.8 ± 32.0*,** (2)	26.0 ± 9.0** (2)	4.5 ± 4.9* (2)
\$3,000-\$3,999	43.3 ± 2.8*,** (3)	12.9 ± 0.5*,** (3)	59.0 ± 26.1*,** (3)	20.1 ± 7.3** (3)	12.3 ± 4.0* (3)
\$4,000-\$5,499	43.4 ± 2.4*,** (4)	13.5 ± 0.5*,** (4)	115.9 ± 22.6*,** (4)	30.7 ± 6.3*,** (4)	14.6 ± 3.1* (5)
\$5,500-\$6,999	41.0 ± 3.4*,** (2)	13.3 ± 0.7*,** (2)	66.3 ± 32.0*,** (2)	53.3 ± 9.0* (2)	10.6 ± 4.9* (2)
\$7,000-\$8,499	43.4 ± 1.8*,** (7)	13.1 ± 0.4*,** (7)	57.9 ± 17.1** (7)	17.8 ± 4.8** (7)	12.1 ± 2.6* (7)
\$8,500-\$9,999	46.7 ± 2.8*,** (3)	13.4 ± 0.5*,** (3)	83.7 ± 26.1*,** (3)	22.0 ± 7.3** (3)	10.7 ± 4.0* (3)
\$10,000-\$13,999	46.7 ± 4.8*,** (1)	13.1 ± 0.9*,** (1)	176.5 ± 45.2* (1)	39.2 ± 12.7*,** (1)	11.8 ± 7.0* (1)
\$14,000-\$17,999	50.2 ± 2.4* (4)	13.7 ± 0.5*,** (4)	103.1 ± 26.1*,** (3)	29.5 ± 7.3*,** (3)	13.1 ± 3.5* (4)
\$18,000+	45.4 ± 1.5*,** (11)	14.0 ± 0.3* (11)	86.2 ± 13.6*,** (11)	12.5 ± 4.5** (8)	12.6 ± 2.1* (11)
<u>Black</u>					
<\$3,000	45.7 ± 2.4*,** (4)	12.9 ± 0.5*,** (4)	81.9 ± 22.6*,** (4)	23.1 ± 6.3** (4)	10.9 ± 3.5* (4)
\$3,000-\$3,999	41.2 ± 3.4*,** (2)	12.3 ± 0.7** (2)	53.7 ± 32.0** (2)	15.8 ± 9.0** (2)	13.7 ± 4.9* (2)
\$4,000-\$5,499	43.8 ± 2.0*,** (6)	12.6 ± 0.4** (6)	104.0 ± 18.5*,** (6)	28.3 ± 5.2** (6)	11.6 ± 2.6* (7)
\$5,500-\$6,999	48.3 ± 1.8* (7)	12.3 ± 0.4** (7)	69.3 ± 17.1*,** (7)	20.4 ± 4.8** (7)	8.7 ± 2.6* (7)
\$7,000-\$8,499	44.5 ± 2.8*,** (3)	12.7 ± 0.5** (3)	99.9 ± 26.1*,** (3)	28.8 ± 7.3*,** (3)	8.9 ± 3.5* (3)
\$8,500-\$9,999	39.9 ± 2.1** (5)	12.3 ± 0.4** (5)	94.6 ± 20.2*,** (5)	32.2 ± 6.3*,** (4)	10.3 ± 3.1* (6)
\$10,000-\$13,999	45.1 ± 1.3*,** (14)	12.5 ± 0.3** (14)	77.4 ± 12.1*,** (14)	20.7 ± 3.5** (13)	16.3 ± 1.9* (14)
\$14,000-\$17,999	39.3 ± 2.4** (4)	13.2 ± 0.5*,** (4)	101.6 ± 22.6*,** (4)	29.1 ± 6.3*,** (4)	11.7 ± 3.5* (4)
\$18,000+	43.8 ± 1.6*,** (9)	12.7 ± 0.3** (9)	94.2 ± 15.1*,** (9)	27.5 ± 4.5** (8)	11.2 ± 2.3* (9)

^aData are with supplements.

^bLeast Squares Means ± Standard Error of Least Squares Means.

^cMeans within a column not sharing a common superscript symbol are significantly different (p < 0.05).

^dNumber of subjects.

\$9,999 and \$14,000 to \$17,999 income groups and whites of the <\$3,000 group. Mean hemoglobin values for whites of the \$18,000+ income group were significantly greater ($p < 0.05$) than whites in the <\$3,000 income group and all black girls except those in the <\$3,000 and \$14,000 to \$17,999 income groups. White girls in the \$10,000 to \$13,999 income range had a significantly greater ($p < 0.05$) mean serum iron level than white girls of the \$7,000 to \$8,999 income group and black girls of the \$3,000 to \$3,999 income category. White girls in the \$5,500 to \$6,999 income group had a significantly greater ($p < 0.05$) mean transferrin saturation value than most other income groups of both black and white girls excepting white girls of income ranges \$4,000 to \$5,499, \$10,000 to \$13,999 and \$14,000 to \$17,999 and black girls of income ranges \$7,000 to \$8,499, \$8,500 to \$9,999 and \$14,000 to \$17,999.

Means for various biochemical and dietary iron status measures observed in the menstruating and nonmenstruating 14-year-old girls are presented in Table IX. There were no statistically significant differences between the two groups; however, mean hematocrit, serum iron, and transferrin saturation values were higher in menstruating girls than nonmenstruating. Mean hemoglobin and iron intake values were slightly higher in nonmenstruating girls. Supplements were included in calculating the mean iron intake.

An evaluation of the biochemical data from the 14-year-old girls appears in Table X. A greater percentage of white girls had marginal hematocrit values and both deficient serum iron and transferrin saturation levels than black girls. Black girls had a greater percentage of marginal and deficient hemoglobin levels than did white girls. Lower-income girls

TABLE IX
BIOCHEMICAL AND DIETARY MEASUREMENTS OF IRON STATUS FOR MENSTRUATING
AND NONMENSTRUATING 14 ± 0.5-YEAR-OLD GIRLS

Group	Hematocrit	Hemoglobin	Serum Iron	Transferrin Saturation	Iron Intake ^a
	%	g/dl	µg/dl	%	mg/day
Menstruating	44.4 ± 0.5 ^{b,c,*}	12.9 ± 0.1*	87.3 ± 4.9*	24.3 ± 1.5*	12.0 ± 0.7*
	n = 84	n = 84	n = 83	n = 77	n = 85
Nonmenstruating	43.8 ± 1.9*	13.2 ± 0.4*	70.1 ± 17.0*	20.7 ± 5.1*	13.6 ± 2.6*
	n = 7	n = 7	n = 7	n = 7	n = 7

^aData are with supplements.

^bLeast Squares Means ± Standard Error of Least Squares Means.

^cMeans within a column not sharing a common superscript symbol are significantly different (p < 0.05).

TABLE X
PERCENTAGE OF MARGINAL AND DEFICIENT BIOCHEMICAL MEASUREMENTS OF IRON
STATUS BY RACE AND INCOME LEVEL FOR 14 ± 0.5-YEAR-OLD GIRLS

Measure	Criteria	% Whites (n = 33)	% Blacks (n = 51)	% Lower Income (n = 46)	% Upper Income (n = 38)	% LIW ^a (n = 22)	% UIW (n = 11)	% LIB (n = 24)	% UIB (n = 27)
Hematocrit	Marginal 31-35	3.0	2.0	2.2	2.6	4.5	0.0	0.0	3.7
%	Deficient <31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Hemoglobin	Marginal 10-11.4	3.0	9.8	10.9	2.6	4.5	0.0	16.7	3.7
g/dl	Deficient <10	0.0	2.0	0.0	2.6	0.0	0.0	0.0	3.7
Serum Iron	Deficient <40	21.2	9.8	10.9	18.4	13.6	36.4	8.3	11.1
µg/dl									
Transferrin	Deficient <15	33.3	19.6	23.9	26.3	27.3	45.5	20.8	18.5
Saturation									
%									

^aLIW = Lower-Income White, UIW = Upper-Income White, LIB = Lower-Income Black, UIB = Upper-income Black.

had a much greater percentage of marginal hemoglobin levels than upper-income girls, however upper-income girls had a greater percentage of marginal hematocrit values and deficient hemoglobin, serum iron and transferrin saturation levels than lower-income girls.

Lower-income white girls had a greater percentage of marginal hematocrit values than all other race/income groups. Lower-income white girls also had a high percentage of girls with marginal hemoglobin values, but not as high as the percentage of marginal values in the lower-income black girls. Upper-income black girls had the greatest percentage of deficient hemoglobin values. Serum iron and transferrin saturation values were deficient in the greatest percentage of upper-income white girls, with the other race/income groups having comparable percentages of deficient serum iron and transferrin saturation values.

Of all the 14-year-old girls studied, 8% had marginal or deficient hemoglobin levels, or values less than 11.4 g/dl. One upper-income black girl had a deficient hemoglobin value. Blacks had 86% of the marginal or deficient hemoglobin levels. Of the blacks, the lower-income group had 67% of the hemoglobin values below 11.4 g/dl. Fourteen percent of all girls had deficient serum iron values. Whites made up the greatest percentage of this group, with 58%. Twenty-five percent of the 14-year olds had deficient transferrin saturation values, and of this percentage, white girls made up 52%.

C. RELATIONSHIPS AMONG DIETARY AND BIOCHEMICAL DATA

Another aspect of the study was to investigate relationships among dietary iron values and the biochemical determinations. Pearson

correlation coefficients were calculated and are presented in Tables XI through XIV for each race/income group of 14-year-old girls. Supplements were included in the iron intake data. Significant positive correlations ($p < 0.05$ or $p < 0.01$) existed between iron intake and kilocalories, total, animal, vegetable and mixed protein, total fat, ascorbic acid and vitamin A in the lower-income white girls (Table XI) and lower-income black girls (Table XIII), excepting the nonsignificant positive correlation between iron intake and ascorbic acid in lower-income blacks. Upper-income white girls (Table XII) lacked significant positive correlation ($p < 0.05$) between iron intake and animal and mixed protein, ascorbic acid and vitamin A. Upper-income black girls (Table XIV) had only significant correlations between iron intake and total fat, as well as vitamin A.

There was a significant positive correlation ($P < 0.05$) between iron intake and hemoglobin values in lower-income white girls (Table XI), but no significant correlation of iron intake with any other biochemical determination in this or any other race/income group. Hematocrit determinations of lower-income white girls showed a significant positive correlation ($p < 0.05$) with hemoglobin values, kilocalories and total fat. Upper-income white girls (Table XII) showed a significant positive correlation ($p < 0.05$) between hematocrit values and both animal protein and total fat. Hemoglobin values of the lower-income white girls (Table XI) showed positive significant correlation ($p < 0.05$) with mixed protein, ascorbic acid, vitamin A, hematocrit values and iron, as mentioned above. There was a positive significant correlation ($p < 0.05$) between hemoglobin values and ascorbic acid in upper-income black girls

TABLE XI
PEARSON CORRELATION COEFFICIENTS AMONG DIETARY AND BIOCHEMICAL VARIABLES
FOR LOWER-INCOME WHITE GIRLS AGED 14 ± 0.5 YEARS^a

Variable	Kilocalories	Total Protein	Animal Protein	Vegetable Protein	Mixed Protein	Total Fat	Ascorbic Acid	Vitamin A	Iron ^b	Hematocrit	Hemoglobin
Total Protein	0.85**										
Animal Protein	0.68**	0.94**									
Vegetable Protein	0.84**	0.67**	0.42								
Mixed Protein	0.22	0.13	-0.10	0.16							
Total Fat	0.85**	0.80**	0.77**	0.63**	-0.15						
Ascorbic Acid	0.70**	0.58**	0.36	0.69**	0.46*	0.45*					
Vitamin A	0.22	0.15	-0.05	0.50*	0.28	0.01	0.33				
Iron	0.80**	0.74**	0.50*	0.82**	0.49*	0.50*	0.82**	0.49*			
Hematocrit	0.45*	0.41	0.35	0.29	0.15	0.44*	0.39	0.26	0.31		
Hemoglobin	0.37	0.37	0.23	0.33	0.49*	0.24	0.50*	0.45*	0.46*	0.51*	
Serum Iron	-0.22	0.01	0.05	-0.15	0.07	-0.26	-0.17	0.05	0.00	-0.09	-0.08
Transferrin Saturation	-0.19	0.03	0.04	0.06	-0.12	-0.12	-0.21	0.53*	-0.02	0.13	0.05

^an = 23; *(p < 0.05); **(p < 0.01).

^bData are with supplements.

TABLE XII
PEARSON CORRELATION COEFFICIENTS AMONG DIETARY AND BIOCHEMICAL VARIABLES
FOR UPPER-INCOME WHITE GIRLS AGED 14 ± 0.5 YEARS^a

Variable	Kilocalories	Total Protein	Animal Protein	Vegetable Protein	Mixed Protein	Total Fat	Ascorbic Acid	Vitamin A	Iron ^b	Hematocrit	Hemoglobin
Total Protein	0.81**										
Animal Protein	0.58*	0.91**									
Vegetable Protein	0.74**	0.48	0.12								
Mixed Protein	0.39	0.33	0.11	0.15							
Total Fat	0.90**	0.75**	0.56*	0.62*	0.36						
Ascorbic Acid	-0.17	-0.32	-0.34	0.02	-0.19	-0.31					
Vitamin A	-0.12	-0.01	-0.02	0.10	-0.09	-0.19	0.32				
Iron	0.88**	0.75**	0.45	0.80**	0.48	0.77**	0.03	0.02			
Hematocrit	0.43	0.46	0.54*	0.09	-0.16	0.51*	0.10	-0.35	0.30		
Hemoglobin	0.06	-0.12	-0.11	0.17	-0.46	-0.06	0.33	0.24	-0.08	0.29	
Serum Iron	0.04	-0.15	-0.20	0.17	-0.12	0.09	0.32	0.57*	0.06	-0.22	0.02
Transferrin Saturation	0.31	0.25	0.19	0.33	-0.11	0.48	0.22	0.26	0.42	0.46	-0.01

^an = 15; *(p < 0.05); **(p < 0.01).

^bData are with supplements.

TABLE XIII

PEARSON CORRELATION COEFFICIENTS AMONG DIETARY AND BIOCHEMICAL VARIABLES
FOR LOWER-INCOME BLACK GIRLS AGED 14 ± 0.5 YEARS^a

Variable	Kilocalories	Total Protein	Animal Protein	Vegetable Protein	Mixed Protein	Total Fat	Ascorbic Acid	Vitamin A	Iron ^b	Hematocrit	Hemoglobin
Total Protein	0.94**										
Animal Protein	0.86**	0.97**									
Vegetable Protein	0.65**	0.50**	0.29								
Mixed Protein	0.59**	0.54**	0.41*	0.35							
Total Fat	0.96**	0.95**	0.91**	0.52**	0.53**						
Ascorbic Acid	0.28	0.31	0.21	0.52**	0.18	0.24					
Vitamin A	0.31	0.44*	0.46*	0.11	0.19	0.37	0.26				
Iron	0.91**	0.90**	0.80**	0.69**	0.53**	0.89**	0.37	0.40*			
Hematocrit	-0.16	-0.11	-0.12	-0.04	-0.05	-0.24	-0.20	-0.08	-0.24		
Hemoglobin	0.12	0.18	0.13	0.11	0.33	0.06	0.17	0.18	0.14	0.36	
Serum Iron	-0.04	0.00	0.03	-0.06	-0.12	-0.01	-0.13	0.41*	0.02	0.01	0.42*
Transferrin Saturation	-0.12	-0.04	0.01	-0.16	-0.17	-0.09	-0.04	0.39	-0.06	-0.09	0.51*

^an = 28; *(p < 0.05); **(p < 0.01).

^bData are with supplements.

TABLE XIV
PEARSON CORRELATION COEFFICIENTS AMONG DIETARY AND BIOCHEMICAL VARIABLES
FOR UPPER-INCOME BLACK GIRLS AGED 14 ± 0.5 YEARS^a

Variable	Kilocalories	Total Protein	Animal Protein	Vegetable Protein	Mixed Protein	Total Fat	Ascorbic Acid	Vitamin A	Iron ^b	Hematocrit	Hemoglobin
Total Protein	0.91**										
Animal Protein	0.78**	0.93**									
Vegetable Protein	0.63**	0.60**	0.31								
Mixed Protein	0.38*	0.27	0.03	0.02							
Total Fat	0.94**	0.88**	0.81**	0.59**	0.22						
Ascorbic Acid	0.12	0.19	0.14	0.30	-0.12	0.13					
Vitamin A	0.46*	0.44*	0.45*	0.30	-0.05	0.46*	0.52**				
Iron	0.34	0.29	0.25	0.30	0.00	0.42*	0.17	0.52**			
Hematocrit	-0.15	-0.20	-0.23	-0.09	0.03	-0.13	0.08	0.00	0.20		
Hemoglobin	0.17	0.28	0.36	-0.05	0.05	0.14	0.39*	0.12	0.21	0.18	
Serum Iron	-0.11	0.01	0.07	-0.10	-0.08	-0.01	0.15	0.05	0.06	0.01	0.45*
Transferrin Saturation	-0.17	-0.04	0.07	-0.21	-0.17	-0.05	0.19	0.04	0.05	-0.05	0.48*

^an = 28; *(p < 0.05); **(p < 0.01).

^bData are with supplements.

(Table XIV) along with significant positive correlation ($p < 0.05$) between hemoglobin and both serum iron and transferrin saturation in all black girls (Tables XIII and XIV). Upper-income white girls (Table XII) and lower-income black girls (Table XIII) showed significant positive correlations ($p < 0.05$) between serum iron and vitamin A values. A significant positive correlation ($p < 0.05$) was seen in lower-income white girls (Table XI) between transferrin saturation and vitamin A.

D. VITAMIN/MINERAL SUPPLEMENTATION

The dietary data were collected with and without supplements. For the purpose of analyzing iron status in the 14-year-old girls, data included iron supplements, whereas in analyzing dietary iron intake, supplements were excluded. Percentages of girls consuming vitamin or mineral supplements at ages 9, 10, 11 and 14 years are recorded in Table XV. Approximately 16% of the subjects were consuming vitamin and/or mineral supplements. Only 20% of those supplements contained iron. Forty-seven percent of upper-income 14-year-old white girls consumed vitamin/mineral supplements; in contrast, the lowest percentage of girls consuming supplements was found among the lower-income white girls (4%). In all race/income groups except the upper-income white group and the lower-income black group, the percentage of girls using vitamin/mineral supplements has declined as the girls have aged.

TABLE XV
PERCENTAGE OF GIRLS AGED 9 ± 0.5 TO 14 ± 0.5 YEARS CONSUMING
VITAMIN/MINERAL SUPPLEMENTS^a

Group ^b	Age (Years)			
	9 ± 0.5	10 ± 0.5	11 ± 0.5	14 ± 0.5
	%	%	%	%
LIW	14 ^c	26	22	4
UIW	21	28	22	47
LIB	29	23	9	11
UIB	21	25	26	14

^a 9 ± 0.5 , 10 ± 0.5 and 11 ± 0.5 data taken from data presented at the Stokely-Van Camp Annual Symposium, Knoxville, TN, 21-23 May, 1979. Disney, G. W., Wakefield, T., Mason, R. L. & Beauchene, R. E. (1979) Nutritional status of preadolescent girls.

^bLIW = Lower-Income White, UIW = Upper-Income White, LIB = Lower-Income Black, UIB = Upper-Income Black.

^cPercent of subjects in respective race/income groups.

CHAPTER V

DISCUSSION

A. DIETARY IRON INTAKE

Mean dietary iron intakes of the 14-year-old girls for each race/income level studied were below the RDA for their age group (Table I, page 26). These results are consistent with those obtained in previous studies (37, 38, 41, 44, 75-78). Fourteen-year-old black girls had lower iron intakes than white girls, a finding supported by studies of Gaines and Daniel (78) and Daniel et al. (7), but contrary to findings by Wharton (76).

The greatest mean dietary iron intakes per 1000 kilocalories (Table II, page 27) without supplements were evident in the white girls. This indicates that the higher iron intake is due to better (however, not significantly better) selection of iron-rich foods rather than a greater kilocalorie intake. The range of dietary iron intakes per 1000 kilocalories was 5 to 6 mg/1000 kilocalories, a range similar to that observed in the Ten-State Nutrition Survey (41) and the HANES study (44).

Dietary iron intake among race/income groups when broken down by percentage of the RDA (Table III, page 29) showed that the percentages of girls of all groups that consumed between 33 to 66% of the RDA decreased, with a comparable increase in the percentage of girls consuming 67 to 100% of the RDA. The greatest decrease (10%) was evident in the upper-income black girls consuming 33 to 66% of the RDA, with an equal

percentage increase (10%) in upper-income black girls consuming 67 to 100% of the RDA, indicating an improvement in their dietary iron consumption since age 11.

The decrease in total percentages of girls in the 33 to 66% RDA range and the increase in total percentages in the 67 to 100% RDA range, resulting in a more even distribution, suggests an improvement in dietary iron intake across all race/income groups. Both the HANES (44) and the Ten-State Nutrition Survey (41) support the finding that mean dietary iron intakes increase with age (7).

Cumulative percentage distribution data showed that approximately 95% of the 14-year-old girls consumed dietary iron in amounts below the RDA (Table III, page 29). Fifty-six and four-tenths percent were consuming less than two-thirds of the RDA for iron.

B. BIOCHEMICAL MEASUREMENTS

Hematocrit, hemoglobin, serum iron and transferrin saturation were the biochemical measurements chosen for use in assessing iron status. Low hemoglobin and hematocrit values represent the last stage of iron depletion, whereas serum iron and transferrin saturation reflect the status of iron stores (44). Mean hematocrit values (Table IV, page 30) for 14-year-old girls were very similar between all groups with upper-income white girls having the greatest mean value. The HANES study (44) reported that whites generally had greater mean hematocrit concentrations than blacks and also that the upper-income groups of both races had greater mean hematocrit concentrations than lower-income groups. These results are not in complete agreement with those found in this study.

Results on the 14-year-old girls of this study did show that whites had a greater mean hematocrit concentration than blacks and upper-income white girls had a mean hematocrit concentration greater than lower-income white girls, but upper-income and lower-income blacks had identical mean hematocrit concentrations.

Hemoglobin values (Table IV, page 30) were significantly greater for whites of both income groups as compared to blacks of both income groups. This finding is supported by several studies (43, 49, 62, 67-70, 79), which noted that hemoglobin levels were approximately 1.0 g/dl greater in whites than in blacks. Hemoglobin levels of white girls and black girls were higher in the upper-income groups than in the lower-income groups. Similar findings were noted in the Ten-State Nutrition Survey (80) and the HANES study (44).

The girls in the upper-income brackets of both races had higher mean serum iron values (Table IV, page 30) than girls in the lower-income brackets, a finding not consistent with that found in the HANES study (44), where racial differences were prominent but income level differences were not. Several studies (63, 80, 81) reported that the serum iron concentration was variable within the same subject. Fluctuations in the serum iron were seen from day to day in the Ten-State Nutrition Survey (80) and it was suggested that the serum iron may be increased by recent iron intakes. It was also noted that some blood samples may have been unfasted samples, resulting in high serum iron concentrations.

Unsaturated iron binding capacity results (Table IV, page 30) showed black girls had the highest mean levels, with upper-income blacks having the slightly greater mean value. Upper-income blacks had the

greatest mean total iron binding capacity value with lower-income blacks having the second greatest value. These values are not diagnostic in themselves. Dallman (48) suggested that, because of the extreme variability of these values, the ratio of serum iron to total iron binding capacity (transferrin saturation) be used to assess iron status. Cook et al. (81), however, advocated the use of the total iron binding capacity, because of its high reproducibility within the same subjects compared to the low reproducibility observed in transferrin saturation and serum iron results within the same subjects.

The mean transferrin saturation level (Table IV, page 30) was highest among upper-income black girls, and lowest in lower-income black girls. Daniel et al. (7) saw a slight racial difference in transferrin saturation values, whites having higher transferrin saturation values than blacks, but saw no differences due to income status. The HANES study (44) also found whites to have higher transferrin saturation values than blacks. Results observed in this study do not support these findings. Very high transferrin saturation levels, observed for a few girls in this study, were believed to be a result of unfasted blood samples (80). Transferrin saturation values were observed by Cook et al. (81) to be highly variable within the same subject, comparable to serum iron variations, and these investigators recommended the use of total iron binding capacity, since it was more consistent. Scott and Pritchard (63) noted that in only one-third of those subjects with depleted iron stores was the transferrin saturation less than 15%, suggesting negligible iron stores often existed when transferrin saturation levels were greater than 15%.

Mean values obtained for each iron parameter were comparable to normal values found by Cook et al. (81). The mean hematocrit concentration for this group of 14-year-old girls, 44.3%, was slightly higher than that observed by Cook et al., 41.3%; the mean serum iron, 86.0 $\mu\text{g/dl}$, was lower than the normal mean observed in that same study, 116.0 $\mu\text{g/dl}$; the total iron binding capacity mean for the 14-year olds, 349.7 $\mu\text{g/dl}$, closely resembled the observed normal value, 335.0 $\mu\text{g/dl}$; mean transferrin saturation for the girls, 24.0%, was much lower compared to the normal observed by Cook et al., 35%. These comparisons suggest a subtle depletion of iron stores among the 14-year-old girls studied.

Mean hematocrit and hemoglobin values (Tables V and VI, pages 32 and 33) in the 14-year-old girls increased from those observed at 9 years of age, indicating a trend toward a decreasing number of girls with iron depletion. This could be explained by greater mean iron intakes found in these girls at 14 years compared to 9 years of age, due to increased maturity regarding food selection. Daniel et al. (7) also found that girls increased iron intakes with age, which he explained also by increased maturity. DeWijn and Pikaar (3) noted that hemoglobin levels increased from 13 g/dl in school-age children to 14 g/dl in adolescents, primarily from increased blood volume evident in the adolescent growth spurt.

To further elucidate any trends influenced by income, the two large income levels were subdivided into nine income brackets (Table VII, page 35). There was a general trend toward increasing values for the biochemical analyses with increasing income status, supporting findings of previous studies (44, 75, 80). The nine categories were then

separated by race (Table VIII, page 36). Results indicated a similar trend of increasing values for the iron status measurements with increasing income, within each race, suggesting the lower-income groups were in a more precarious iron balance than upper-income groups. An attempt was made to correlate iron data by race/income groups, but the small number of subjects occupying each group made it difficult to cite any meaningful correlations.

Mean values of parameters indicating iron status of menstruating and nonmenstruating 14-year-old girls (Table IX, page 38) were within the normal ranges and no significant differences were seen between the two groups. These data are similar to those cited in a study by Greger et al. (38), in which he found no significant differences between hematocrit levels of the two groups. Nonmenstruating girls had a higher mean hemoglobin and iron intake level than menstruating girls, but mean hematocrit, serum iron, and transferrin saturation levels were all greater in menstruating girls. Monsen et al. (37) reported that menstruating women have such limited iron intakes that iron depletion frequently results. The mean iron intakes of the 14-year-old girls were below the RDA regardless of menstruating status. One-fifth of the menstruating female population, as reported by Cook et al. (52) is iron deficient and absorbs iron at the maximum absorption rate. The mean transferrin saturation level in both groups of girls was lower than the normal value, 35%, reported by Cook et al. (81), and could be an indication of depressed iron stores and impending iron-deficiency anemia.

Evaluation of the biochemical analyses (Table X, page 39) indicated a high percentage of marginal hemoglobin values in the black population. As studies have indicated, normal values are not the same for blacks and whites (67-69, 79). Blacks have significantly lower hemoglobin levels than whites, approximately 1.0 g/dl lower. This difference was evident in the mean hemoglobin values (Table IV, page 30). When the normal hemoglobin standard was lowered 1.0 g/dl for the black race, the percentage of marginal hemoglobin values in the black population decreased from 9.8% to 2.0% and the deficient hemoglobin values decreased from 2.0% of the black population to 0%. Marginal and deficient hemoglobin values for blacks then become very comparable to those reported for the white population. The percentage of deficient serum iron and transferrin saturation levels in white 14-year-old girls were nearly double those found in black girls. This indicated the greater depletion of iron stores in whites than in blacks, a finding that conflicts with results observed in a study done by Daniel et al. (7), which indicated whites had slightly greater iron stores than blacks.

Garn et al. (68) indicated the mean hemoglobin levels were slightly greater in upper-income people than those of lower incomes. Results from the 14-year-old girls in this study showed a smaller percentage of upper-income girls with marginal hemoglobin levels compared to lower-income girls, in agreement with the Garn et al. study. The greatest percentage of low serum iron and transferrin saturation values were present in the upper-income groups. The percentage of deficient transferrin saturation levels was also high in the lower-income group, indicating both upper- and lower-income groups had a considerable number

of girls with deficient iron stores. Depleted iron stores in one-fourth of healthy college girls were reported by Scott and Pritchard (63), similar to the results found in the 14-year-old girls. Cook et al. (52) reported low transferrin saturation levels in 15.2% of the adolescent girls studied, a percentage somewhat lower than that seen in the present restudy.

Lower-income black girls had the greatest percentage of marginal hemoglobin levels. Lower-income whites and upper-income blacks had similar percentages of marginal hematocrit and hemoglobin values. The percentages of deficient serum iron values were consistent in all race/income groups, except for the large percentage of deficient serum iron values in the upper-income white group, representing the depletion of iron stores. Upper-income white girls showed a high percentage of deficient transferrin saturation levels, again indicative of iron depletion. In other race/income groups, 25% of the girls had deficient percent transferrin saturations. A greater percentage of white girls having deficient iron stores compared to black girls is not consistent with the Daniel et al. study (7), as stated earlier, which found white girls having slightly better iron stores than blacks.

Hemoglobin values reflect the amount of iron in red cells, which is decreased in iron deficiency. Iron-deficient erythropoiesis refers to curtailed hemoglobin synthesis in the erythroid, due to a lack of iron supply. Percent transferrin saturation is considered the best index of iron supply (46). To study the iron picture somewhat closer, the percentage of individuals with deficient or sufficient hemoglobin levels was compared to the percentage who also had deficient serum iron

and percent transferrin saturation levels. Forty-four percent of the girls with marginal or deficient hemoglobin levels had acceptable serum iron and transferrin saturation levels, and 44% had deficient serum iron and transferrin saturation levels. The remaining 12% of the girls with marginal or deficient hemoglobin levels had deficient transferrin saturation levels only, but serum iron values for these girls ranged from 41.9 to 52.4 $\mu\text{g/dl}$, and were therefore close to being deficient. Of the girls with acceptable hemoglobin levels, 12% had accompanying deficient levels of transferrin saturation and serum iron. The range of hemoglobin values in these cases was 11.8 to 13.9 g/dl, indicating that some of the girls were close to having deficient hemoglobin values. The percentage of girls with acceptable hemoglobin values having only deficient transferrin saturation levels was 10%. These girls, with acceptable hemoglobin levels, could become iron deficient if any demands were made on the already diminished iron stores. The percentage of girls with acceptable hemoglobin levels, 92%, relates well to the 95% found in the Ten-State Nutrition Survey (80) for white girls in the 13 to 17-year-old age category. Fifteen percent of the 14-year-old girls studied had two of the four measurements of iron status within the marginal or deficient range.

Eight percent of all the girls had hemoglobin values less than 11.4 g/dl and 1% had a value of less than 10 g/dl. The majority, 86%, of the girls with low hemoglobin values were black and more than half of these black girls were of the lower-income bracket. Serum iron values were deficient in 14% of the girls, with 21.2% among white girls and 9.8% among black girls. Since the white population was considerably

smaller than the black population, whites have a much higher percentage of deficient serum iron values. Transferrin saturation values were deficient in 25% of the total population, with 33.3% among white girls and 19.6% among black girls.

Upper-income white girls had the greatest percentage of deficient serum iron values and transferrin saturation values, 36.4% and 45.5%, indicating this group as the most at risk of developing iron-deficiency anemia. Lower-income white girls also have a high percentage of serum iron and transferrin saturation values in addition to a somewhat elevated percentage of marginal hemoglobin values, indicative of depressed stores and also impaired erythropoiesis. Therefore, the white population is in a state of poor iron balance, more so than the black population.

C. RELATIONSHIPS AMONG DIETARY AND BIOCHEMICAL DATA

Positive correlation existed between hemoglobin and hematocrit values in all race/income groups (Tables XI-XIV, pages 42-45), however only positive significant correlation existed in lower-income white girls. Positive correlation between hemoglobin and hematocrit values is consistent with the correlations observed by Greger et al. (38) and also in the Ten-State Nutrition Survey (80). There were positive significant correlations between hemoglobin values and both serum iron and transferrin saturation levels only in the black population, a finding that conflicts with that found in the Ten-State Nutrition Survey (80), where a low positive correlation was observed between hemoglobin values and

serum iron values, but not transferrin saturation values, for both sexes and age groups.

Iron intake was positively correlated with hemoglobin levels in all income groups except upper-income white girls, but significant only in lower-income white girls. Similar positive correlations between hemoglobin values and iron intake have been noted in other nutritional studies involving teen-age girls (66, 80). With the positive correlation between hemoglobin and hematocrit values having previously been cited, it seemed reasonable to assume that hematocrit values would be positively correlated with iron intake values, which was the case in all race/income groups except the lower-income black girls, where a negative correlation was reported. Of the iron intake and hematocrit correlations that were positive, none were significant. Greger et al. (38) also reported a positive correlation between hemoglobin and hematocrit values, but found hematocrit values inversely correlated to iron intakes, a finding consistent with that found in the lower-income black group. An explanation given for this inverse relationship was that hematocrit values were all within the normal range as opposed to the varied iron intakes. Significant positive correlation was seen between serum iron values and vitamin A values in upper-income white and lower-income black girls. Transferrin saturation values were positively correlated to iron intake values, however not significantly, in the upper-income populations, but negative correlations existed in the lower-income groups. Low correlations between iron intake and transferrin saturation values were also shown by Monsen et al. (37). They theorized the low correlation was due to the small variation in iron intakes, although low, compared

to the large variation in transferrin saturation values. No significant correlations between iron intake and transferrin saturation levels were reported by Daniel et al. (7).

Correlation coefficients were obtained for such dietary variables as kilocalories, total protein, vegetable protein, mixed protein, total fat, ascorbic acid and vitamin A. These factors play a role in iron absorption, acting either to enhance or hinder absorption. There was a high positive correlation between iron intake and kilocalories, total protein, animal protein and vegetable protein in all race/income groups except the upper-income black group where there were low positive correlations between all variables just mentioned. Kilocalories were positively correlated to iron intake in all groups and significantly in the white population and lower-income blacks. This illustrates the fact that as kilocalorie consumption increases, iron intake does also. Six milligrams of iron per 1000 kilocalories is commonly used to estimate iron intake (82). Conrad (14) noted that the iron content of the diet is the most important factor affecting iron repletion. The American diet, which is abundant in total protein, primarily from animal sources, contains 10 to 20 mg of iron per day. This is contrasted with the vegetarian diets of Asians, which contain 5 to 10 mg of iron from vegetable sources (82). The fact that as total protein and vegetable protein increase in the diet, so does the total iron content, lends support to the positive correlation between both total protein and vegetable protein, and iron intake, significantly correlated in all groups except upper-income black girls.

There was a significant positive correlation between iron intake and total fat in all groups, suggesting the high fat content of foods supplying the iron in most diets. Upper-income black girls had a significant positive correlation between iron intake and total fat, but much lower than the other race/income groups, possibly due to the iron supplementation in this group. DeWijn and Pikaar (3) stated that high fat diets could hinder iron absorption, which could be a factor in comparing the iron status of the upper-income black girls, who have low correlations of iron intake and total fat to lower-income blacks who have high correlations of iron intake and total fat; however, the mean iron intake of upper-income black girls is also higher than lower-income black girls.

There were positive correlations between iron intake and ascorbic acid in all race/income groups; however, the only significant positive correlation existed in the lower-income white group. Lower-income white girls had low iron intakes and yet their iron status, judging by the mean percent of transferrin saturation, was second only to the upper-income black girls. This may suggest the utilization of ascorbic acid as a means of increasing the availability of ingested iron (24, 84). Vitamin A and iron intake were positively correlated in all groups, the correlation being statistically significant in all groups except the upper-income white girls, where there was a very low positive correlation. The very low correlation among upper-income white girls may be suggestive of a decrease in iron release, purported to be a ramification of vitamin A deficiency (85). This theory is a possible explanation for the low

serum iron and moderately low transferrin saturation levels seen in the upper-income white girls.

D. VITAMIN/MINERAL SUPPLEMENTATION

Data collected on the use of vitamin/mineral supplements (Table XV; page 47) shows upper-income whites consuming the greatest quantity, upper-income blacks next, with lower-income blacks following closely behind. The lowest percentage of girls consuming supplements was the lower-income white girls. Only three girls consumed vitamins containing iron. Two girls were upper-income blacks and one was a lower-income black. The lower-income black girl consuming a 25 mg iron supplement did not contribute a blood sample. The other two, upper-income black girls, consuming 50 mg and 5 mg supplements, had values for each iron parameter well above the normal values reported by Cook et al. (81). Their iron intakes without the supplements were 13.6 and 6.5 mg per day, respectively. Therefore it appears that supplementation is benefiting these 14-year-old girls, and the other race/income groups should be encouraged to take iron supplements to meet the RDA.

E. CONCLUSIONS

Dietary intake of iron is greater in white girls than black girls when supplements are excluded. The mean dietary iron intake without supplements is more representative than the mean iron intake with supplements in the upper-income black group as a whole. This is because only two upper-income black girls were taking iron supplements, one being a 50 mg supplement, resulting in an inflated mean iron intake.

Therefore white girls are consuming more iron, but upper-income white and lower-income black girls have the lowest iron stores, according to mean transferrin saturation levels. This discrepancy between iron intake and iron stores may be a result of poor iron availability, due to factors affecting absorption. Another explanation could be the level of accuracy obtained in procuring the 24-hour dietary recall. In looking at the percentages of deficient transferrin saturation levels among groups, which are more representative than mean values, upper- and lower-income white girls had the lowest iron stores. White girls also had a greater percentage of girls with low hematocrit and hemoglobin levels after lowering the standard by 1.0 g/dl for black girls. Therefore, from this study it can be concluded that white adolescent girls, compared to black girls, are in a poorer state of iron balance and that income may have a minor influence on iron nutriture, upper-income groups having slightly better iron status.

F. IMPLICATIONS

The increased demands on body stores, especially iron stores, accompanying the adolescent growth spurt are leaving the teenager, who enters adolescence insufficiently prepared for such demands, in an iron-deficient state. Steps must be taken early, with the school-age child, to prepare him/her for the demands of adolescence. This should be a time, following the growth spurt of infancy, when iron stores can be rebuilt. A conscious effort must be made to closely monitor food intake at this age, making sure high-iron food sources are available and consumed. Once the child enters adolescence, there must be a

continued effort to see that adequate calories and sufficient nutrients are consumed in order for the adolescent to maintain a good supply of iron throughout adolescence.

Nutrition education plays a major role in making parents aware of the iron needs during infancy and adolescence. It is through nutrition education that means of increasing iron intakes can be dispersed. These include: providing information regarding high iron sources, including foods that enhance and those that inhibit iron absorption and providing information about both iron fortification and supplementation. Through nutrition education, all those involved in providing adequate nutrition for adolescents can be reached and the problem of iron deficiency lessened.

CHAPTER VI

SUMMARY

The primary purposes of this study included evaluating the iron status of adolescent girls (14 ± 0.5 years), noting any effects of race and income upon their iron status and investigating the relationships between dietary iron intake as well as other nutrients, and iron status. In addition to these primary purposes, other facets of adolescent iron nutriture were examined. These included the effects of menstruation on iron status and the percentage of girls consuming vitamin/mineral supplements.

White girls had significantly greater ($p < 0.05$) hemoglobin levels than black girls. There were no significant differences observed in the mean hematocrit, serum iron, transferrin saturation or iron intake between race/income groups.

The percentages of girls with marginal and deficient hematocrit values were similar between races and income groups. There was a much higher percentage of marginal hemoglobin concentrations in the black population (9.8%) than the white (3.0%), and also a greater percentage of marginal hemoglobin levels in the lower-income black population (16.7%) than other race/income groups. Whites had a greater percentage of girls with deficient serum iron values (21.2%) than blacks (9.8%). Upper-income girls had a larger percentage of deficient levels of serum iron (18.4%) than did lower-income girls (10.9%). Upper-income whites had the greatest percentage of girls with deficient serum iron values

(36.4%). There was a higher percentage of deficient transferrin saturation levels among white females (33.3%) than black females (19.6%). Upper- and lower-income groups had similar percentages of girls with deficient transferrin saturation levels, lower-income having 23.9% and upper-income with 26.3%. Upper-income white girls had the largest percentage of deficient percent transferrin saturation levels (45.5%).

Fifty-six and four-tenths percent of the 14-year-old girls were consuming less than two-thirds of the RDA for iron. The 14-year-old girls were consuming between 5 and 6 mg of iron per 1000 kilocalories.

Significant positive correlations ($p < 0.05$) were cited between hemoglobin and hematocrit values in lower-income white girls and between hemoglobin and both serum iron and transferrin saturation values in blacks.

Lower-income white girls had highly significant positive correlations ($p < 0.01$) between iron intake and kilocalories, total protein, vegetable protein and ascorbic acid. There were significant positive correlations ($p < 0.05$) between iron intake and animal protein, mixed protein, total fat, vitamin A and hemoglobin values. Upper-income white girls had highly significant positive correlations ($p < 0.01$) between iron intake and kilocalories, total protein, vegetable protein and total fat. In lower-income black girls, highly significant positive correlations ($p < 0.01$) existed between iron intake and kilocalories, total, animal, vegetable and mixed protein and total fat. Significant positive correlations ($p < 0.05$) existed between iron intake and vitamin A. A highly significant positive correlation ($p < 0.01$) existed between iron intake

and vitamin A in upper-income blacks, and a significant positive correlation ($p < 0.05$) was seen between iron intake and total fat.

The prevalence of vitamin/mineral supplementation was greatest in upper-income white girls, 47% of the girls consuming supplements but only 20% of the supplements consumed by the 14-year-old girls contained iron.

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