Nutritional Requirements of Adolescence

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Basis for Nutrient Requirements

It is surprising to realize how scanty the data upon which recommendations for adolescent nutrient needs are based. Table 1 shows that substantial information is available only for energy and water. Fragmentary data are available for sugars, dietary fiber, protein, calcium, magnesium, iron, zinc, flouride, iodide, vitamin D, thiamin, riboflavin, and ascorbic acid. All of the other estimates of requirements and recommendations are based on little or no actual data for adolescents, and must be regarded as educated guesses. Thus, interpolation from studies of adults or younger children, evidence from clinical and biochemical measurements, intakes which are associated with good health and growth, body composition studies, and work on experimental animals. (Alfin- Slater and Mirenda 1980, Heald 1979.) It should be kept in mind in interpreting dietary data that for over 30 of the some 50 or more nutrients known to be required by human beings, we simply do not have any data on what the minimum average requirements actually are (Iacono 1976). Table 2 presents estimates of requirements as best as they can be determined today. Recent studies have classified associations between intakes of the various nutrients, other environmental factors, body composition, growth and health status. From the practical standpoint they have increased our ability to predict which individuals are most at risk of nutritional deficiency diseases during pubescence and adolescence. In some cases nutrition support during illness and preventive measures have also improved as a result. However, a great deal remains to be done in elucidating these relationships for many others of the some 50 essential nutrients required by human beings.

Associations between Nutrient Needs and Physiological Age

Forbes (1980) has neatly illustrated the biological rationale for recommended increases during adolescence for several nutrients and how they vary by physiologic age by calculating average daily increments in body content of each nutrient over the second decade of life and daily increments at the peak of the growth spurt. These are provided in Table 3. Note that daily increments at the peak of the growth spurt are almost double the daily average values for the decade. However, body composition data and the results of experimental studies in humans indicate that in fact, increments in bodily content of these nutrients and increased nutrient needs do not rise at a constant rate throughout adolescence, nor are they limited solely to the pubertal growth spurt. Increments are more highly associated with physiological than chronological age.

The nutrient needs of adolescence are best understood in the context of changes in body composition which occur during the period, since many nutrient needs parallel these changes. From the practical standpoint of understanding nutrient needs, it is useful to consider the decade from 10—20 years as consisting of two periods: pubescence and adolescence (McKigney and Munro, 1975).

Pubescence is defined as the period of sexual development which ends with the emergence of the capacity for sexual reproduction. It usually encompasses the years up to age 13 in females and age 15 in males. Pubescence is characterized by an extremely rapid rate of growth in body size, especially in weight, which is similar to that of early infancy. The increase in body size is earlier and less extensive in females than in males. The sexual dimorphism in nutrient needs as well as in anthropometric indices emerges at

Table 1
Current knowledge of human nutritional requirements for adolescents, 1976
(After Iacono, J., Sci Am, pg. 263)

	little or no data	fragmentary data	substantial progress made
Total Energy			●
Carbohydrates	—		
Starch	—		
Sugars		0	
Fibers		0	
Total Fat	—		
Essential Fatty Acids	—		
Protein		0	
Amino Acids	—		
Arginine	—		
Histidine	—		
Isoleucine	—		
Leucine	—		
Lysine	—		
Methionine	—		
Phenylalanine	—		
Threonine	—		
Tryptophan	—		
Valine	—		
Minerals			
Calcium		0	
Magnesium		0	
Iron		0	
Phosphorus	—		
Sulfur	—		
Sodium	—		
Potassium	—		
Copper	—		
Molybdenum	—		
Manganese	—		
Zinc		0	
Chromium	—		
Selenium	—		
Nickel	—		
Vanadium	—		
Chlorine	—		
Fluoride		0	
Iodine		0	
Vitamins			
Vitamin A	—		
Vitamin D		0	
Vitamin E	—		
Vitamin K	—		
Thiamin		0	
Riboflavin		0	
Niacin	—		
Pyridoxine	—		
Pantothenate	—		
Cobalamin	—		
Folic Acid	—		
Biotin	—		
Choline	—		
Ascorbic acid		0	
Water			●

this time. Males experience a very rapid gain in lean tissue and in the mineral skeleton, with resulting increases in needs for protein, iron, calcium and zinc which reside in the lean body mass or the skeleton. Girls also experience a smaller increase in lean body mass but even greater increases in adipose tissue, and thus their needs for these same nutrients are somewhat less. Energy needs for growth are high in comparison to childhood, adolescence and adulthood, although they rarely exceed 10 % of energy requirements even at this time of rapid growth. Both sexes are sensitive to undernutrition with respect to energy. If energy needs are not met the pubescent growth spurt may be delayed or damped. The discrepanies between physiological and chronologic age are greater

Table 2
Estimates of adolescent nutrient requirements for which there are recommended allowances and substantial data is available

Nutrient	Estimate of requirements ages 10—20 years, means
Energy	2200—2900 calories (Committee on Nutrition, 1980)
Protein	54—78 mg per Kg N per day by factorial method of (WHO 1973)
Calcium	600—1200 mg (Committee on Nutrition 1978; Forbes 1975, 1980 FAO/WHO 1962)
Magnesium	Estimate 300—400 mg interpolated from adult values and a few new studies (Greger et al. 1976, 1977, 1978, 1979)
Iron	5.1—12.9 mg estimated (Hepner 1975)
Zinc	Estimate 15 mg interpolated from adults and new balance studies (Greger et al. 1976, 1977, 1978, 1979)
Fluoride	1.5—2.5 mg found to provide protective effects against caries in adolescents (Committee on Biologic Effects of Atmospheric Pollutants 1971)
Iodine	Estimate interpolated from requirement of 50—70 μg in adults (Food and Nutrition Board 1970)
Vitamin D	2.5 μg (FAO/WHO 1970)
Thiamin	0.4 mg per 1000 Calories (Hart and Reynolds 1957; Dick et al. 1958)
Riboflavin	Estimate of 0.5 mg per 1000 Calories interpolated from studies of children and adults (Heald, 1979).
Ascorbic acid	Estimated at 30 mg in adults for body pool measurements (Hodges et al. 1971) but if tissue saturation is the criteria intakes must be much higher (Irwin and Hutchins 1976)

between as well as within each sex during pubescence. Differences in nutrient needs between the sexes and within individuals of the same sex are also greatest at this time.

Adolescence is the period of growth after the emergence of the capacity for sexual reproduction which extends from approximately 13—17 years in females and 15—21 years in males. Growth is slower and the sex differences in body composition, such as the greater fat to lean in females bodies, are conserved. Needs remain elevated for some nutrients but begin to resemble adult values.

Nutrient requirements in the second decade of life are thus more closely associated with physiological than chronological age since they are affected by growth and the resulting alterations in body composition and physiology which occur as a result of maturation. The wide variation in the timing of pubertal growth means that if recommendations are made by chronologic age, another source of error in nutrient estimates is added to what, for many nutrients, are already fairly tenuous estimates. These errors are the largest for adolescents who mature very early or very late in relation to the reference population. Thus recommendations stated by chronological age can only be regarded as rough approximations for adolescents. Errors in estimates of need and recommendations could be reduced the most by devising tables of recommended nutrient allowances which utilized physiologic age, but physiologic age estimates are rarely available either for groups or individuals in the adolescent population while information on chronological age is easily obtained. Also, the estimates for many nutrients are so imprecise to begin with that errors even after such adjustments would be large for most nutrients. Therefore, precision is sacrificed to practicality and recommendations are made on

Table 3
Average daily increments in body content due to growth for selected substances from 10—20 years

	Body content with increment averaged over period 10—20 Years	Daily increment at peak of growth spurt
Calcium, mg		
males	210	400
females	110	240
Iron, mg		
males	0.57	1.10
females	0.23	0.90
Nitrogen, mg		
males	320 (1.98 gm protein)	610 (3.8 gm protein)
females	160 (0.97 gm protein)	360 (2.2 gm protein)
Magnesium, mg		
males	4.4	8.4
females	2.3	5.0
Zinc, mg		
males	0.27	0.50
females	0.18	0.31
Lean body mass, gm		
males	9.7	18.6
females	5.0	11.1
Body fat, gm		
males	0.20	5.5
females	0.33	13.8
Energy, calories		
males	13	66
females	7	123

Source: Forbes, 1977, with addition of values for lean body mass and fat calculated from Baumeister and Bingert, 1967.

a chronological age basis. Some cognizance is also taken of the heterogeneity of growth during the second decade of life by the use of sex-specific recommendations. These cover three-year age intervals in the American tables. However, it must be recognized that the coefficients of variation in estimates of nutrient requirements are very large for the nutrients for which requirements have actually been determined. For most of the nutrients, no experimentally determined requirements are available at all. Thus subdivisions by age and sex groups are not always meaningful from a statistical standpoint (Hegsted 1975). The secular trend toward earlier physical maturation has also been recognized and taken into account by altering the characteristics of the "reference" individuals who are used as the basis for calculations in the tables; the reference individuals of both sexes in 1942 were about 2 kilograms lighter and shorter than those employed in 1980. These adjustments are in order in view of our knowledge of growth in adolescence in industrialized countries (Eveleth and Tanner 1976; Hauspie 1979).

The extensive physiological changes and adjustments which occur at different times during the second decade of life are often reflected in altered laboratory tests results when standards are stated on the basis of chronological age. Normative data based on biological maturity is now being collected which may ultimately provide better biochemical indices of health during this time of life, just as has been done recently for laboratory indices during pregnancy (Committee on Nutrition of the Mother and Preschool Child 1978). Once these indices have been established, recommendations for intakes during adolescence can be made on a firmer basis.

In this presentation the energy, iron and calcium requirements will be used to show how understanding of the biology of the second decade of life is helpful in developing recommendations for nutrients.

Nutrient Recommendations for Adolescence

The fragmentary data and estimates of adolescent nutrient requirements have been used as the basis for planning recommended levels of intakes by various countries and international organizations (Committee on Dietary Allowances 1980, Food and Agricultural Organization-World Health Organization 1979, Department of Health and Social Security 1979, Isaksson 1977). The current Recommended Allowances for the United States provide specific recommendations for the intakes of 17 nutrients, and estimated safe and adequate ranges of intakes for 11 additional nutrients of the 45 nutrients presently known to be required by human beings (Committee on Dietary Allowances 1980). These recommendations vary somewhat from country to country depending upon the assumptions which are employed, the philosophical basis of providing such standards, and to a lesser extent because of environmental factors, but all are based on the same scientific observations. Tables 3 and 4 illustrate the recommendations for energy from two different scientific bodies.

Recommended nutrient intakes are usually given by chronological age for a refrerence group which is representative of that segment of the population's characteristics. Recommendations generally rise during the second decade of life; like infancy, adolescence is a period during which needs for nutrients increase sharply.

Current nutrient recommendations for adolescents given in the American tables are presented in Table 4. Recommendations are higher than for adults for energy, protein, vitamins D, thiamin, riboflavin, niacin and the minerals calcium, phosphorus, magnesium, and (for males) iron in one or more of the age-sex groups given for adolescents. In comparison to younger children, in addition to elevations in several of the above nutrients, those for vitamins A, B-6, C and E are higher among adolescents. The recommendations remain higher if recommendations are adjusted for differences in energy needs for all of these nutrients except thiamin, riboflavin and niacin.

Energy

Energy recommendations are stated in most tables as minimum average requirements. In contrast, recommendations for other nutrients include a fairly wide margin of safety over and above the requirement.

The major components of the energy requirement are that for maintenance of the body at rest (which includes that fraction of resting needs accounted for by growth in experimental determinations) and the highly variable component contributed by physical activity.

Resting Metabolism

The metabolic rate at rest reflects the energy consumption of actively metabolizing tissue of the lean body mass, especially brain, liver and muscle as well as smaller components for growth and the specific dynamic action of meals. Lean body mass increases dramatically during the pubertal growth spurt and resting metabolic rates increase accordingly. Most of the age and sex differences (such as the declines with age on a weight or surface area basis and the higher rates of males than females on these same bases) in resting metabolism can be accounted for by changes in lean body mass in comparison to total body weight (Holliday 1978). Resting metabolism expressed as calories per square meter per hour or as calories per kilo-

Table 4
Dietary Recommendations for adolescents

Nutrient and Source	Males 11—14	Males 15—18	Males 19—22	Females 11—14	Females 15—18	Females 19—22	Pregnant	Lactating
Recommended Dietary Allowances, 1980:								
Protein, gm	45	56	56	46	46	44	+ 30	+ 20
Vitamin A, μg, R.E.	1000	1000	1000	800	800	800	+ 200	+ 400
Vitamin D, μg	10	10	7.5	10	10	7.5	+ 5	+ 5
Vitamin E, mgα, T.E.	8	10	10	8	8	8	+ 2	+ 3
Vitamin C, mg	50	60	60	50	60	60	+ 20	+ 40
Thiamine, mg	1.4	1.4	1.5	1.1	1.1	1.1	+ 0.4	+ 0.5
Riboflavin, mg	1.6	1.7	1.7	1.3	1.3	1.3	+ 0.3	+ 0.5
Niacin, mg, N.E.	18	18	19	15	14	14	+ 2	+ 5
Vitamin B_6, mg	1.8	2.0	2.2	1.8	2.0	2.0	+ 0.6	+ 0.5
Folacin, μg	400	400	400	400	400	400	+ 400	+ 100
Vitamin B_{12}	3.0	3.0	3.0	3.0	3.0	3.0	+ 1.0	+ 1.0
Calcium, mg	1200	1200	800	1200	1200	800	+ 400	+ 400
Phosphorus, mg	1200	1200	800	1200	1200	800	+ 400	+ 400
Magnesium, mg	350	400	350	300	300	300	+ 150	+ 150
Iron, μg	18	18	10	18	18	18	30—60mg	30—60mg
Zinc, mg	15	15	15	15	15	15	+ 5	+ 10
Iodine, μg	150	150	150	150	150	150	+ 25	+ 25
Estimated Safe and Adequate Daily Dietary Intakes, Food and Nutrition Board:								
Vitamin K, μg	50—100							
Biotin, μg	100—100							
Pantothenic acid, mg	4—7							
Copper, mg	2.0—3.0							
Manganese, mg	2.5—5.0							
Fluoride, mg	1.5—2.5							
Chromium, mg	0.05—0.2							
Selenium, mg	0.05—0.2							
Molybdenum, mg	0.15—0.5							
Sodium, mg	900—2700							
Potassium, mg	1525—4575							
Chloride, mg	1400—4200							

gram total weight is highest during pubescence, reaches it peak for the decade when the pubertal growth spurt is at its maximum, and declines thereafter (Topper and Mulier 1932; Johnston 1953; Eichorn 1955; Wang, Kaucher and Wong 1936; and Daniel 1977). However, since the lean body mass increases over the same interval on the basis of energy needs per day requirements for resting metabolism rise on a population basis from ages 10—20 and then stabilize until age 20. On an individual basis, the timing of the growth spurt will determine when increases in resting metabolism appear. Thus early maturers exhibit increases in energy needs for resting metabolism at an earlier age than do late maturers. This is one of the reasons why peaks for energy intakes occur at different chronologic ages for early and late maturers even within the same sex (Mitchell, Reed, Valadian, et al, 1966).

Growth

The energy requirement for growth cannot be ascertained directly, but it can be calculated from experimentally determined values for resting metabolism and body composition data. The costs vary, depending chiefly upon the composition of the tissue of gain. Even during the pubertal spurt the energy needs for growth are small in comparison to that required for maintenance. Picou (1978) has calculated the energy costs of growth in children recovering from protein-calorie malnutrition and suggests that when the new tissue is solely lean tissue, an energy cost of 1.2 cal per gram is appropriate, whereas if it is all fat approximately 8 calories per gram of gain would be required. Using Forbes (1980) figures of average daily increments in lean body mass and fat over 10—20 years, the energy costs of growth are trivial, i.e., about 13 calories per day in males and 7 calories per day in females. Even at the peak of the growth spurt males' tissue of gain only requires 66 calories per day and females' 123 calories per day (see Table 3). Thus the energy requirements for adolescent growth constitute only a small percentage of total calorie intakes (Payne and Waterlow, 1977).

How is it if the energy needs for growth are so small that even in Western countries, in times of severe privation such as wartime, the pubertal growth spurt is delayed? (Tanner 1962). The responses to acute undernutrition for energy usually include a decrease in voluntary physical activity followed later by catabolism of adipose tissue and a decrease in resting metabolism, all of which husband what energy is available from food. However, when energy intake deficits exceed those which can be accommodated by these homeostatic mechanisms, growth is slowed or stopped. Among young adolescents who must engage in heavy physical labor while subsisting on low energy intakes, the first of these compensations cannot be made. Apparently during times of privation in Western countries and presently among poor adolescents in developing countries, intakes were restricted either by rationing or by poverty, expenditures for necessary physical activity remained high, adipose stores which were small to begin with were not sufficient to meet the needs of growth, and as a result the growth spurt was delayed. In Western countries today these conditions are uncommon in adolescent populations, although they may be present in certain subgroups which will be discussed later.

Physical Activity

The energy costs of physical activity which involve moving mass over distance also vary somewhat by physiological age, since as weight increases so does the cost of moving the body from one place to another. Thus the early maturing boy who has a large body size will require more energy to run a race than his age mate who is a late maturer, who is lighter, and heavier individuals such as males more than lighter individuals. However, these differences are relatively small in comparison to the proportion of time the individual devotes to moderate or heavy activities as opposed to light or sedentary activities. Differences in energy expenditures from reclining to extremely heavy activities range from about 72 to 720 calories per hour.

The physical activity of adolescents has rarely been measured directly; more frequently estimates are calculated by measuring energy intakes and subtracting the proportion of total energy intake which is assumed to be due to resting metabolism. Data obtained from indirect calorimetry, activity diaries and those calculated from energy intakes all suggest that adolescents in Western countries, expecially the United States, are quite sedentary (Durin et al. 1974, Consolazio 1976, Malina 1974, 1979). For example, Huenemann (1974) showed that in 17-year-old Californian adolescents, only about 5 % of the entire day was devoted to moderately heavy activity, and less than 1 % to heavy activity. A sexual dimorphism also is evident, males expending a higher proportion of their energy intakes in physical activity than females. Also, Forbes (1973) has shown that among American adolescents 13 years and older the ratio of total energy intakes to resting metabolism needs are 2:1 for males but only 1.5 to 1.7 to 1 for females. There is some evidence from the work of Stone and Barker (1939) that, at least in the 1930's, postmenarcheal adolescent girls had rather negative attitudes toward vigorous physical activity and interests in more sedentary pasttimes; and apparently such differences persist today.

Even with adolescents of the same sex the propensity toward a physically active life does not appear to be uniformly distributed over the population. For example, in the studies Huenemann et al. (1974) the leanest subjects had much higher energy intakes and the fattest subjects had lower intakes, differences which are not explainable simply on the basis of a difference in their resting metabolic rates. Time and motion studies have confirmed that indeed obese adolescents are less physically active as a group than their leaner peers (Bullen, Reed and Mayer 1974). Since the obese mature earlier as a group than the nonobese, in females both early puberty and their greater fatness may conspire to perpetuate a disinclination toward physical activity among them.

Trends in Recommendations for Energy

Table 5 shows the successive recommended dietary allowances for adolescent energy intakes used in the United States from 1942—1980 (Committee on Dietary Allowances 1974, 1980; National Research Council 1943, 1945, 1948; Food and Nutrition Board 1953, 1958, 1963, 1968.) These allowances reflect experts' best judgments of energy intakes resulting from the sum of all of the components which influence this requirement. The effects of the secular trend toward earlier physical maturation have been taken into account in the successive recommended tables by altering the weights and heights of the reference individuals employed, and these effects are further minimized in Table 5 by expressing intakes per kilogram for the reference individuals employed. Even with these adjustments, recommendations have fallen precipitously over the years for ages 10—20.

Other highly industrialized countries also have adjusted their recommended energy allowances for adolescence in a downward direction in the past few years (Bass 1979).

The major reason for these declines is decreased physical activity among adolescents at all ages. The greater availability of automobiles and convenience devices which minimize obligatory energy expenditures in daily workaday life, the ubiquity of television sets and popularity of sedentary pursuits during leisure time no doubt all have contributed to the increasingly sedentary life styles characteristic of most American adolescents.

Table 5
Successive editions of the Recommended Dietary Allowances for energy during adolescence expressed as Calories per kilogram for the reference individual

Year	Mean Calories per kilogram for persons 10—19 years		Highest recommendation during decade	
	Males	Females	Males	Females
1942	67	58	75	76
1945	67	56	75	76
1948	65	56	73	74
1953	65	53	73	69
1958	63	54	71	73
1963	62	52	74	71
1968	59	51	72	74
1974	59	50	77	73
1979	50	45	81	75
Difference:				
1942—1979	—17	—13	+6	—1

Energy Intakes of American Adolescents

We have observed that American recommendations for energy intakes have declined, but have said little about actual energy intakes for adolescents. Table 6 shows energy intakes which were ascertained in the national Health and Nutrition Examination Survey (HANES) of 1971—73 with estimates of resting metabolism for adolescents at the 50th percentile of height and weight of the National Center for Health Statistics norms, which were based in large measure on the same survey (Hamill et al. 1979).

Females' intakes are below the recommended allowances for energy throughout the decade, as are males' until about 15 years of age. However, their energy intakes appear to be adequate to sustain good growth and development. The pubertal spurt is early, and obesity, rather than extreme leanness, is the most prevalent energy-associated nutritional problem (Garn, Clark and Guire, 1975). Moreover, Forbes' (1973) analysis of secular trends in height and weight for age over the period from 1880 — 1960 in American adolescents indicate that they have become relatively heavier in comparison to their heights at ages over 13 years in females and over 15 years in males, although younger children have not.

It is also worth noting that recommended allowances are only about a thousand Calories over resting metabolism, and that for females, mean energy intakes range from 300—700 calories over the component due to resting metabolism. Also, the component of energy intakes attributable to physical activity is quite small, especially for females, and particularly for females over 15 years of age. These characteristics inherent in the low energy intakes of adolescents give rise to practical nutritional problem. Even though physical growth does not appear to be compromised (Burman, 1979; Czajka-Narins, Hodges, et al., 1965; Lee, 1978; Hodges and Krehl, 1971), it is more difficult to assure that nutrient recommendations for protective nutrients are met unless dietary planning is careful.

Iron

Two extensive reviews present data on body

Table 6
Estimated Resting Metabolic Rates and Mean Energy Intakes of American Adolescents
HANES 1971—74

Age	U.S. Recommended Allowance 1979 mean	Mean Energy, Intake	Estimated Resting Metabolic[2)3)] Rate (50th percentile)	Estimate of Physical Activity (by difference)	Ratio Total Intake to Resting Metabolism
Males:					
10—11	2 525	2 261	1 299	962	1.7
12—14	2 675	2 519	1 514	1 005	1.7
15—17	2 775	2 981	1 784	1 197	1.7
18—19	2 825	2 949	1 804	1 145	1.6
20—24	2 800	2 888	1 786	1 102	1.6
Females:					
10—11	2 300	2 023	1 249	774	1.6
12—14	2 200	1 932	1 384	548	1.4
15—17	2 125	1 756	1 415	341	1.2
18—19	2 100	1 739	1 364	375	1.3
20—24	2 050	1 691	1 327	364	1.3

Sources
1) Dietary Intake Findings US 1971—74. Data from the National Health Survey Series 11 202. DHEW Publ. No. (HRA) 77—1647, July 1977. USDHEW/PHS/HSA/NCHS, Hyattsville, 1977.
2) Hamill, RVV, Drizd, TA, Johnson, CL, Reed, RB, Roche, AF, and Moore, WM. Physical growth. NCHS percentiles. Am. J. Clin. Nutr. 32: 607—629, 1979.
3) Metabolic rates from Boothby-Dubois table, p. 241 in Albritton, E.C. **Standard Values in Nutrition and Metabolism.** Philadelphia: W. B. Saunders, 1954.

iron content during growth, growth increments and estimates of urinary, cutaneous, and menstrual losses (Hawkins, 1964; Bowering, Sanchez and Irwin, 1976).

A great deal of new information has been amassed over the past decade on iron requirements during the second decade of life and their association with pubertal events.

The bodily requirements for iron is enormously variable during the years from 10—20 because alterations in both size and sex, as well as possibly in race affect it (Greenwood and Richardson, 1979). Sexual maturity ratings are helpful in gauging when requirements are likely to be most elevated. Also, the speed at which individuals move from one period of sexual maturity to the next may also be useful in assessing iron needs for optimal growth.

During pubescence lean body mass increases dramatically and accounts for high proportion of total weight gain, particularly in males. Since each kilogram of fat-free body weight contains a good deal of iron, this increment in body composition alone increases iron needs greatly. Increases in blood volume and hemoglobin which occur in both sexes but which are also greater in males further add to iron requirements (Bowering, Sanchez and Irwin, 1976).

During adolescence, the female experiences further increases in need for iron with the onset of menses. Menstrual losses of adolescents are widely variable (Schlophoff and Johnston 1949; Hallberg el al. 1966; Greger and Buckley 1977), but losses appear to be correlated with apparent absorption of iron (Greger and Buckley 1977). Pregnancy imposes additional burdens.

Because hematologic standards for adolescents are based on chronologic age alterations in hemoglobin, hematocrit and transferrin saturation which are more closely related to physiologic age within sex and race are obscured. Recent work has clarified these associations (Daniel, 1973; Daniel, Gaines and Bennett, 1975). Hemoglobin and hematocrit standards by sexual maturity rating, sex and race are now available (Daniel, 1977). Using the 15th percentile of hematocrits by appropriate sexual maturity rating standards and a transferrin saturation of less than 16 % Daniel found 3.3 % of teenaged males and 2.4 % of teenaged females to be anemic and to respond to iron supplements. An additional 5 % of the males and 15 % of the females in the same population had normal hematocrits but depressed transferrin saturation levels. These adolescents were considered to have an elevated risk of iron deficiency anemia under conditions of stress such as increased menstrual losses, accidents or serious illness. Dietary iron intakes have also been assessed and related to sexual maturity ratings standards for hemoglobin hematocrits. (Gaines and Daniel, 1974). Intakes of iron in both males and females increase as physiological age increases, but there is no correlation between the amount of intake and transferrin saturation. It is not possible to know the status of iron stores simply by knowing iron intakes since absorption of dietary iron varies depending upon the size of the stores and diet. More studies of iron absorption during adolescence on different types of diets are needed.

The current recommended dietary allowances for iron during the second decade of life are 18 mg for females at all ages and for males until 18 years, declining to 10 mg in males over that age. The recommendation for pregnancy and for the first two to three months after parturition are for 30—60 mg supplemental iron salts. The major changes from earlier editions of the recommended dietary allowances are an increase in the allowance for pubescent males and a doubling or tripling of the recommendation for pregnancy. While the prevalence of iron deficiency anemia does not appear to have changed for more than 30 years, it is probably the most common nutritional disease seen among adolescents (Heald 1979). The continuing presence of anemias of this type, the advent of more sensitive measures than hematocrit and hemoglobin determinations, evidence of low iron intakes in subgroups of adolescents and newer data on the physiology of iron metabolism during puberty and pregnancy are probably responsible for the recommended increases.

Calcium

Calcium requirements are also closely associated with the growth of lean body mass and the mineral skeleton (Forbes 1975). They vary by sex and physiological age as well as size (Johnston 1953, Forbes 1978). Estimates of the increments in body calcium content during growth vary depending upon the method which is used. Neutron activation yields the highest values, while metacarpal cortex thickness and estimates derived from calculations based on a calcium content of 22 gm per kilogram on lean body mass (the content seen in adults) are lower (Committee on Nutrition, 1978). The methods also differ in the ages at which they find that increments in calcium are maximal and the age at which skeletal growth ceases. Nevertheless, all show that peak daily increments are greater, last longer, and occur later in males than in females, and that total body calcium content differs by sex and by size, increasing by 20 grams per centimeter of final height in adults when determinations are made by neutron activation methods (Committee on Nutrition, 1978).

Pubescence is a period of rapid increase in lean body mass. The growth of the mineral skeleton is of particular interest. The skeleton contains virtually all of the body stores of calcium; approximately 45 % of the total adult skeletal mass is laid down during adolescence, and most of the skeletal growth takes place during pubescence. Average linear growth is as much as 0.25 mm per day with an increase of as much as 1.2 gm per day in the dry weight of the skeleton during this time. Calcium retentions at times close to the peak of the growth spurt are extremely high, estimates varying from averages of about 200 mg per day for females and 300—400 mg per day for males, with a rather wide variability (Greenwood and Richardson 1979). There is little variation in bone mineral until after the pubertal growth spurt. The increase in bone mineral is highly correlated with age, height, weight and surface area in males, but only after the growth spurt (Krabbe et al. 1980). After the velocity of longitudinal growth begins to decrease, mineralization proceeds at a rapid rate and serum alkaline phosphatase values begin to fall (Bennett, Ward and Daniel 1973; Krabbe et al. 1980).

During adolescence, while linear growth is less rapid, endochondral bone growth and the mineralization of the skeleton still keep needs high.

The absorption of calcium varies by age, amount of intake, and also with the presence of other substances in the diet, chief among them vitamin D, lactose, protein, very low calcium phosphate ratios and the phytate content of the diet (Committee on Nutrition 1978). These factors must be taken into account in studies of requirements.

The recommended allowance for calcium in the United States is currently 1200 mg for both sexes until 18 years and 800 mg thereafter. Since their inception, the recommended allowances have fallen from highs of 1300 mg for females and 1400 mg for males. The earlier allowances were based mainly on calcium balance studies. These studies strongly reflect previous intakes, and on high calcium diets such as those eaten by many American children, maximal calcium retentions are seen at intakes of this magnitude. The perils of setting recommendations at levels which correspond to maximal calcium retentions seen at the peak of the growth spurts of all individuals have been well described by Forbes (1975) and result in very high recommendations. He suggests averaging spurt values of individual children rather than taking the peak values for each child. The former viewpoint apparently still prevails, however. While recommendations remain high in the U.S., the difficulties of calcium balance studies are now better appreciated. Methods for ascertaining body calcium increments during growth, while imperfect, are now better developed and more weight is now being placed on these latter types of studies in evaluating data on calcium needs. Nevertheless, the present recommendation for calcium remains considerably (e.g 500—600 mg) higher than are those of many other countries. The rationale for the high American recommendations rests chiefly upon the emphasis given to peak values for individuals during the growth spurt, the customary high calcium intakes and also on the extremely high protein intakes (which are likely to negatively affect calcium balance) in the country which presumably lead to high maintenance needs.

Failure to meet the recommended allowances cannot be taken as evidence that a calcium deficiency state exists. Fortunately, even on very low intakes homeostatic mechanisms are sufficient to preserve serum calcium concentration. In healthy adolescents the only instance of ill health which is clearly documented is that of adolescent rickets, which is attributable to lack of vitamin D, especially in Northerly climates during seasons of the year when endogenous skin synthesis by the action of solar ultraviolet rays is at a minimum (Stamp and Round 1974), although it may be conditioned by diets which are low in both vitamin D and bioavailable calcium. Asian adolescents residing in the United Kingdom who subsist on such diets sometimes exhibit rickets of this type during the growth spurt (Arneil and Barltrop 1979). Treatment with vitamin D usually cures the condition; preventive measures stress both increased vitamin D intakes and greater as well as more highly bioavailable calcium in the diet. Severe rickets can deform the boney structure of the pelvis which may contribute to later difficulties in childbearing. More immediately apparent problems such as deformities in the long bones of the leg are also of concern since they are stigmata which label the adolescent as "different" and present life-long cosmetic and functional problems.

Other Nutrients

Five recent publications discuss the scientific basis for other nutrients which have not been dealt with in the preceeding sections (McKigney and Munro 1975; Heald 1979, 1975; Greenwood and Richardson 1979; Falkner and Tanner 1979). Included in the discussions are nutrients such as retinol and folic acid which have been frequently found to be low in adolescents' diets in comparison to recommended intakes. One is struck with the paucity of information which exists about the actual requirements for these vitamins during pubescence and adolescence in contrast to the more extensive data base which exists for nutrients such as protein.

Conclusion

The nutrient requirements in adolescence have been determined directly by experimental studies of the age group only for a minority of the nutrients for which there are recommended allowances. Interpolation of nutrient requirements determined on adults or in younger children is the most common approach which is taken to fill these gaps in the case of nutrients for which direct data are lacking. Epidemiological evidence, clinical data, usual intakes, and data from experimental animals are also sometimes employed. A great deal of judgment, which varies from one expert group to another, is involved when these latter approaches are taken, and also when recommendations are made. In general, estimates of requirements vary less than do recommendations based on these requirements issued by various scientific bodies.

It is useful to take physiological rather than chronological age into account when performing studies of nutrient requirements during adolescence. Good data is available on energy and iron requirements by physiologic age. It is apparent even when variability due to physiologic age is taken into account that energy needs have decreased drastically over time owing to environmental influences which have influenced physical activity dramatically. Iron requirements and recommendations have changed less over time, although they have been revised somewhat in light of the finding that pubescent males have much higher requirements than were suspected previously. Our knowledge of the associations between physiological age and the calcium requirement is less complete. Recommendations have changed somewhat to take these recent findings into account. Also, in the cases of both calcium and iron there is a growing recognition of the importance of other dietary constituents upon their absorption and metabolism. Estimates of requirements and recommendations for other nutrients during the years from 10—20 have also changed over the past four decades.

A great deal of work remains to be done to put nutrient recommendations for adolescents on a firmer scientific basis. New investigations of biological and biochemical growth are needed (Karlberg et al. 1978; Morrison et al. 1978; Ibsen and Anderson 1978). Studies of growth and nutritional status as influenced by changing sociocultural conditions or by direct interventions are also required (Larson 1980; Klerman 1979; Lampl, Johnston and Mack 1978). It is to be hoped that the momentum of research which characterized the 1970's on this area of nutrition will be expanded in the 1980's.

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Acknowledgement

The author is appreciative of support furnished by Research Career Development Award KO4 AM 00272-03 from the National Institutes of Health, which permitted preparation of this paper.

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