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ANTHROPOMETRY IN THE NUTRITIONAL ASSESSMENT OF PRESCHOOL CHILDREN

by

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INTRODUCTION

Nutrition has a double faceted challenge--that of preventing states of malnourishment and of reducing illnesses that are related to excessive nutritional intake (1). Normal healthy children have a genetically determined physical growth pattern that is affected by environmental factors, including nutrition (2,3). Progress along this pattern is one criterion used to assess the nutritional status of children (4,5) and is a reflection of the nutritional status of the population as a whole (6).

Relatively simple anthropometry has been used in surveys throughout the world to assess protein-energy malnutrition (PEM) in children (7-13). Recently attention has shifted from surveys to continuing surveillance of growth of children (14-16) because children have long been recognized as being "at risk" nutritionally (17). Interest in the use of anthropometric measurements to monitor growth of children is increasing because of the possibility of moderate malnutrition among marginated groups (16,18-22), the incidence of obesity among children (23), and the indication that many hospitalized patients need special nutritional support (24,25).

The purpose of this report was to review the literature regarding the use of anthropometric measurements to assess the nutritional status of preschool children.

NUTRITIONAL ASSESSMENT

Accurate assessment of nutritional status is crucial to the cycle of planning, implementing, and evaluating intervention programs. The issue of hunger looms over the world. In 1974 the United Nations reported that more than 460 million people were permanently hungry. In a step to end hunger, the United States has established a number of federal programs to assure an adequate diet to every citizen. Food aid programs may represent the unsung yet most effective antipoverty efforts of the last 15 years, but they still are far from adequate in their use as a tool of public policy (21). Malnutrition has become a subtle problem, characterized by a lack of various essential nutrients. Nutrition must be raised to a positive concept and the stigma of welfarism associated with nutrition programs must be removed (26). The Presidential Commission on World Hunger (20) recommended that resources of domestic hunger programs be increased and that the continuing nutritional status of Americans be assessed in a systemic way.

NUTRITIONAL RISK OF THE CHILD

National surveys (11,18,19) have identified preschool children and pregnant and lactating women as groups most at nutritional risk. This risk is compounded by marginal environments. A position paper by the American Dietetic Association on a National Nutrition Policy (14) stressed that surveillance on a continuing basis would involve reliable procedures to diagnose individuals who may be at nutritional risk.

The physical status of children of preschool age has been of considerable concern throughout the world. Mortality among 1-5 year old children in developing countries is highest among the 1-2 year old group (6).

If children survive the first 2 years, they often adapt to the health risks of their environment through stunted growth, and in this sense are less endangered by malnutrition than 1 and 2 year old children (12). The susceptibility of the child to nutritional deprivation will be greater during periods of more rapid growth (1).

The second year of life is fraught with risk. Jelliffe (27) suggested the word "secotrant" to signify the risk involved in the transition through the second year. The second year in particular is a period of rapid growth with high nutritional needs for swiftly increasing muscle mass (6). Increases in physical size are achieved by increase in both number and size of cells, and organs are vulnerable to compromised nutrition during stages of hyperplasia (3).

EVALUATION OF GROWTH OF CHILDREN

Tissues of the body grow at different rates. Increments in body weight represent the growth of many tissues (28). The interaction of genetic and environmental factors, including nutrition, effect differences among populations of children in body size, shape, and rate of growth. Larkin et al. (29) and Fitzhardinge and Steven (30) concluded that a multiplicity of factors existed as the cause of growth failure. Specifically, while birth weight seems strongly related to subsequent growth achievement, it cannot be used to explain all cases of inadequate growth in children.

Growth is marked by changes in body shape as well as increase in body size. Longitudinal studies reflect important information about changes in body composition. The ratio of subcutaneous fat and muscle changes early in life. After a rapid rise in fat from birth to 1 year of age, a gradual decline in fat follows to 6 or 7 years of age (31).

Superimposed on changes in fat content of the body are changes in muscle tissue. The muscle width grows at about twice the rate of bone width. The child is at nutritional risk in this critical age period if a deficit of amino acids leave the child incapable of following this growth progression (32).

Rate of growth is considered a sensitive indicator of nutritional status of the child. One time measurements or cross-sectional surveys with each child seen only once, show size achieved at a particular age. Serial observations or longitudinal studies over a defined period permit an extremely useful calculation of growth (1,6,33). Two measurements which permit calculation of growth of children provide a more fruitful interpretation than a single measurement of size. The larger the time span over which multiple observations are made, the surer will be the judgment whether the measurements of a given child are normal (5). Growth charts are constructed with the assumption that children maintain their relative sizes during growth and stay in the same percentiles (3,5).

NUTRITIONAL STATUS

Nutritional assessment measures the prevalence of disease by one or more indicators of nutritional status. The prevalence may be only an inexact approximation of the "true" prevalence of malnutrition (34). Nutritional monitoring and surveillance measure changes in the prevalence of "true" disease or in the risk of disease and require serial observations. Surveillance identifies potential problems. In nutritional screening a cut-off point is selected to identify an exact number of malnourished persons who can be treated. Criteria for screening depend not just on information but on the resources at hand. The cost of missing a case of malnutrition (false negative) and the cost of treating a well nourished child as malnourished (false positive) will limit numbers of persons to be treated where resources are scarce (34).

A source of confusion about indicators of nutritional status is the expectation placed on these indicators (13). It is unreasonable to expect the same indicator, such as arm circumference, to reflect equal usefulness in acute and chronic malnutrition (35), in vitamin deficiency and in protein-energy malnutrition (7), and as a predictor of morbidity. Anthropometry on presumably well children has an unmeasurable reassurance value (5).

Ideally nutritional assessment in the health program begins with an examination of the community to determine how the quality of life relates to the nutritional status of the community. After assessment of the community, four basic methods are employed. Dietary studies give presumptive evidence of nutrient intake which can help explain possible reasons for further findings. Laboratory investigations provide objective but limited biochemical measurements of nutrients within the body. Clinical studies evaluate physical signs of nutritional health or deficiency. Anthropometric methods employ standardized equipment and procedures to obtain physical measurements.

ANTHROPOMETRY OF PRESCHOOL CHILDREN

Among the basic methods of nutritional assessment, anthropometry has the distinction of having the highest accuracy and medium cost and requiring little skill and a minimum of time (15). A proliferation of nutritional status indices has occurred in the search for the most accurate, feasible, and economic anthropometric measurements (12). The relationship between various measurements and their relative advantages was described by the World Health Organization in a review of anthropometry in nutrition surveillance (17).

A comprehensive nutritional assessment procedure includes a profile of serial anthropometric measurements. Anthropometric measurements are frequently the first step in nutritional assessment. Because a child grows with time, no single set of measurements can characterize nutritional status. They have been used to measure growth, body mass, and body composition in the assessment of protein-energy malnutrition (PEM) in children. There is limited evidence that growth inhibition and body disproportion in human beings occurs, except in relation to protein and energy intake (17).

The Committee on Nutritional Anthropometry of the Food and Nutrition Board of the National Research Council was established in 1951 (36). The committee acknowledged that no well defined methods and standards were in existence for the application of anthropometry to nutritional evaluation. The monograph on Assessment of Nutritional Status in the Community by Jelliffe (6) included standardized methods which continue to be used to identify and classify grades of PEM in children whose status may lie occult beneath the tip of the PEM iceberg (fig. 1) (37).

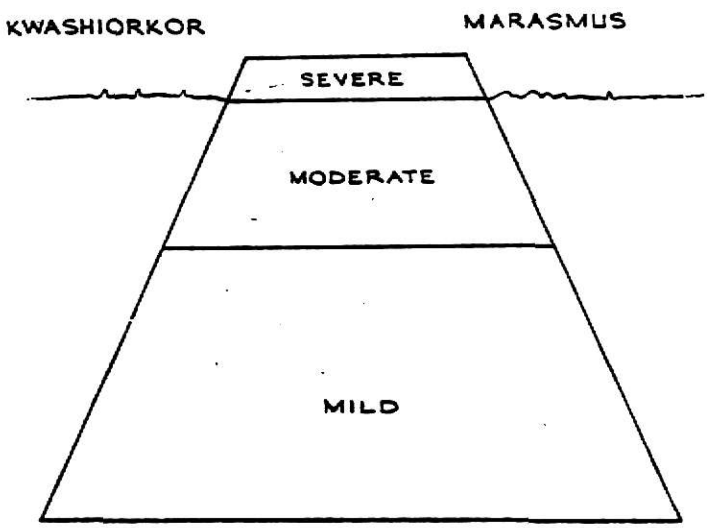

Fig. 1 The protein-energy malnutrition iceberg (37).

The difficulties of making anthropometric measurements on children begin with reliability of measurements and recordings and with decisions of which measurements to take, on which age group, and how to interpret data (17). Measurements should be made as much as possible the way the measurements were made for reference standards.

PROFILE OF MEASUREMENTS

Not all measurements are equally informative at all ages through maturity. The Committee on Nutritional Anthropometry (36) suggested measurements for the 1-6 year old group as follows:

-minimum list for emergency conditions--length (crown-heel maximum), stem length (crown-rump maximum), standing length, weight

-additional for surveys--chest circumference, arm and calf circumferences, and head circumference which could be eliminated at 3 years of age

-desirable for surveys--bicristal and biacromial diameters and skin folds over triceps, below scapula and midaxillary

-desirable for surveys, but impractical--postero-anterior X-ray film of hand and wrist

Jelliffe (6) recommended weight, length or height, arm circumference, and triceps skin fold where ages were known precisely and the following ratios if ages were not verifiable: weight-for-head circumference, weight-for-height, chest circumference-for-head circumference, and arm circumference-for-height. Despite this recommendation, recent textbooks of pediatrics (38-40) continued to omit discussions of arm circumference and skin folds.

Authors of current pediatric journal articles usually referred to weight, height, and head circumference (41-44) and less frequently to skin folds and arm circumference (45,46). Hospital nutrition support services are beginning to clarify their methods of assessment, but only a few authors (24,25) specified special parameters for assessment of children's needs for nutritional support. Growth curves of the National Center for Health Statistics (NCHS) (47) based on length or stature, weight, and head circumferences for children 0-36 months and for 2-18 years of age have been distributed to state and local health departments and have been adapted for use in hospitals, clinics, and physicians' offices (4,48).

Side of the body for measurements. By international convention some eighty years ago, the left side of the body was recommended for measurements (49). Generally the left side was chosen for measurements in surveys (12,13,49-51). Some authors (7,35,52) did not specify which arm was used and Burgert and Anderson (53) used both arms to compare triceps skin fold values between different calipers. Foster et al. (54) and Keet et al. (55) used the right arm for arm measurements. The Health Examination Survey (56) was based on skin folds on the right arm. Percentiles for triceps skin fold and arm muscle circumference in the

Ten-State Nutrition Survey of 1968-1970 (18) were based on right arm measurements. Blackburn et al. (57) described the protocol of nutritional assessment of hospitalized patients. During examination, arm measurements were to be taken on the non-dominant arm. The Handbook of Clinical Dietetics (58) recommended measurements on the dominant arm.

Age at which measurements are taken. Participants of a conference on "The Assessment and Recording of Measurements of Growth of Children" (5) recommended that weight, height or length, and head circumference should be taken at birth, at nursery discharge, and at 1, 2, 4, 6, 12, 18, 24, 30, and 36 months. Height and weight should continue to be taken at yearly intervals. Christakis (1) recommended that evaluation of growth data usually should be done at three month intervals in children under two years of age, but six month or yearly intervals were satisfactory for children over age two. During the course of therapy of malnourished hospitalized persons, body weight should be obtained daily and other anthropometric measurements every three weeks (57).

Some standards are based on age while others are age-independent. Measurements such as age-appropriate weight, length, and various circumferences are based on the principle that there are differences in rates of growth at various ages. Anthropometric techniques are based on measurement of one variable thought to be greatly affected by nutriture (numerator) compared with one less affected (denominator). The most obvious unaffected denominator is age. Since twenty deciduous teeth usually have erupted by 2 1/2 years of age, the dental second year may be used to establish approximate age (38).

If ages are not verifiable, ratios of a labile tissue to a stable tissue are recommended. Age-independent anthropometry is based on the ratio of a nutritionally unstable tissue such as subcutaneous fat or muscle mass compared with tissue upon which short-term malnutrition is likely to have less effect, such as height and head circumference (59-61). Since fat and muscle are most affected by acute malnutrition, weight and limb circumferences and mid arm muscle mass are likely to be reduced. The ratios of weight-for-height, arm circumference-for-height, and arm circumference-for-head circumference are comparisons of protein-energy stores with linear mass. The widely used denominator of height is relatively unaffected by acute nutriture, but is, of course, affected by chronic malnutrition (62).

Unlike age-independent anthropometry which is intended for a broad age range of early childhood, precise-age independence requires an approximate age category, especially of infants and secotrants (61). Measurements of this type may be of tissues which show a gradual change in the year considered; i.e., arm circumference shows a gradual change in the 2-4 year span (60) and triceps skin fold thickness changes gradually through the 1-5 year span (55).

SELECTION OF PARAMETERS OF MEASUREMENT

Traditionally the clinical assessment of growth is accompanied by basic measurements of height and weight, because rate of gain in both height and weight is accepted as a sensitive indicator of a child's state of health (29). Aside from height and weight, other indices may be of limited value in estimating nutritional status of U.S. children (1). If other indices prove meaningful for evaluating physical growth, the information should be applied. All measurements complement each other. Weight reflects body mass and height reflects linear growth. Arm circumference reflects muscle development or waste, whereas skin fold indicates calorie reserves.

Weight. Body weight alone is a limited measure of gross body size. The increment in weight gain during the second year is slightly less than the birth weight. A slow but constant yearly increment in weight averaging 2.0 kg during the third, fourth, and fifth years is apparent (38). Pomerance (63) collected data which reflected an average yearly increment of 2.3 kg from the second through the fifth year.

The National Center for Health Statistics (NCHS) reference data (47) for body weight from 2-18 years included standardized examination clothing weighing less than 0.1 kg between 2-5 years of age, and 0.1-0.3 kg from 6-18 years of age. Thus, shoes should not be worn during measurements. Weight was recorded to the nearest 0.1 kg (52,54) or to the nearest 0.25 kg (64). Beam, or lever, balance scales were preferred to spring-type scales because the latter become easily stretched from frequent use with expansion of the spring (6). Spring-type scales were used (12,13,65) and were standardized frequently with known weights.

Height or length. Measurements of height or length reflect total body length. Height increases at a slowly declining rate until the onset of puberty. Infants usually increase their length by 50% in their first year. Their length usually is doubled by 4 years of age and tripled by 13 years of age (3). The average child grows approximately 12.5 cm in the second year of life, 7.6-10 cm in the third year and approximately 5-7.5 cm per year thereafter until the growth spurt of puberty (2,63). Height velocities of less than 5 cm per year indicates need for further evaluation at a health center (66).

Standardized procedures for height or length are important. The NCHS reference data (47) for stature were obtained with children in stocking feet. Various reports (5,6,12,50) state that standing height is measured against a calibrated wall perpendicular with the floor, using a head board for horizontal fit at a right angle to the child's crown (fig. 2). The chin is parallel to the floor, bare heels are together, and heels, buttocks, and shoulders touch the vertical surface. Height usually is measured to the nearest 0.1 cm (54,64). Stadiometers have been used in some studies (33,47,66). Platform scales with moveable measurable rods were not recommended for measuring heights of children (5).

Supine body length (fig. 3) requires two examiners. One person holds the top of the infant's head in contact with a fixed headboard and the other holds the feet with toes pointed upward and brings a moveable foot board into contact against the heels (5). Hansman (67) and Pomerance (63) stretched out one leg leaving the other free so the infant would not feel restrained during their respective 40 year Denver study and 20 year New York study.

Length versus height. Some controversary exists about age to begin standing height instead of recumbent length. Vaughan et al. (38) suggested that recumbent length could be more accurate under 5 years of age at which time standing height becomes more convenient. According to Owen (5), recumbent length should be measured to the third year of life, although it may be impractical beyond 18 or 24 months. Hamill and coworkers (4) acknowledged that 2 year old children may be unwilling or unable to stand for satisfactory measurement of stature, so recumbent length may be used to 3 years. Hansman (67) measured children supine to 2 years and erect, subsequently. Length was used by Cheek et al. (52) and by Anderson (12) on children age 1-5 who were "too young to stand". Children between 3 and 6 years did not always comprehend the direction to stretch. Keys (36) stated that crown-heel length should be determined on patients who cannot readily stand.

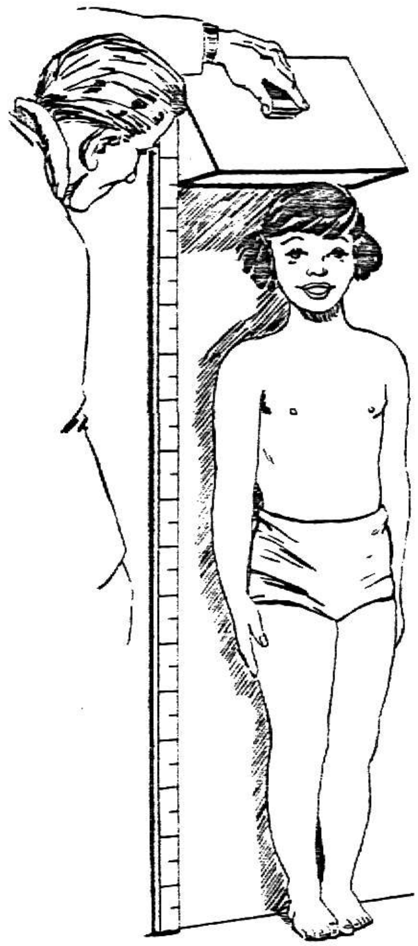

Fig. 2 Measurement of height of the child (6).

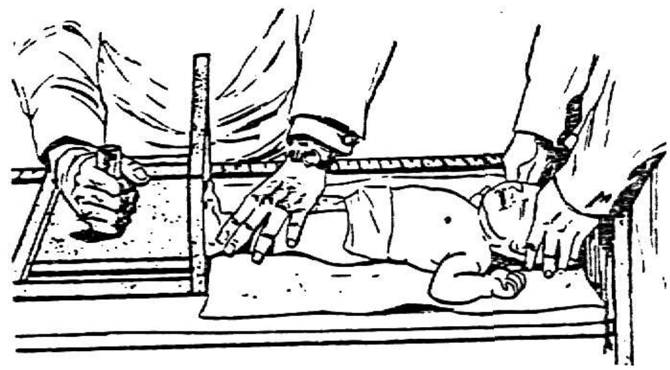

Fig. 3 Measurement of length of the infant (6).

Fig. 4 Measurement of head circumference (6).

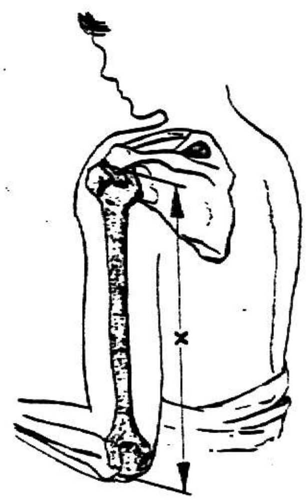

Fig. 5 Determination of midpoint of upper arm (37).

Fig. 6 Measurement of mid-upper arm circumference (37).

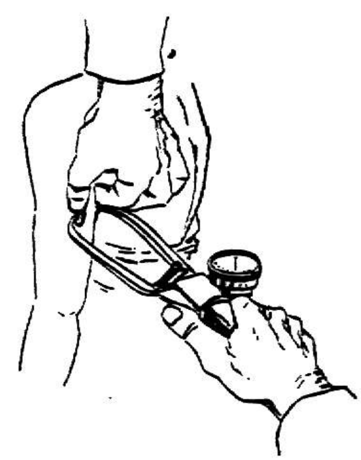

Fig. 7 Measurement of triceps skin fold with calipers (37).

The recumbent length may be as much as 2 cm greater than height (4,36); the difference may be closer to 1 cm after 4 or 5 years of age. If recumbent length is used beyond 5 years, the value obtained may be reduced by 1 cm to correspond to height (38). The difference would suggest growth deceleration. Percentile rankings would shift downward if length were plotted on the birth to 36 month chart of NCHS and stature were plotted at the next visit (4). The 2-18 year charts of NCHS specify height although some reference data taken between 2 and 3 years of age were, in fact, recumbent lengths.

Head circumference. The rapid increase in brain mass is accompanied by a rapid increase in the head circumference prenatally and during the first year. Head circumference achieves two-thirds of its potential growth by 24 months of age (68). Even though head circumference may not be useful for identifying malnourished children, it is an important screening measurement for micro- and macrocephaly due to nonnutritional medical abnormalities (4). A normal head size reflected the acute nature of a severe PEM of recently weaned Jamaican children (35). These children had a mean head growth of 1.9 cm after seven weeks of rehabilitation compared with an estimated gain of 0.75 cm.

The head circumference is taken to the nearest 0.1 cm with a non-stretchable tape which is applied firmly around the head just above the supra-orbital ridges or most prominent part of the frontal bulge, anteriorly, around the head at the same level on each side, and over that part of the occiput which gives maximum frontal-occipital circumference (fig. 4) (3,5,6,68). Head measurement may be discontinued at 3 years of age (36,38).

Chest circumference. The value of the chest circumference is in relation to the head circumference. After the first six months of life, the chest circumference should overtake that of the head, and the ratio of chest to head circumference should be greater than 1 (6). The chest of a child with PEM does not develop well; thus the chest circumference reflects nutriture. The chest circumference is taken mid-respiration at the level of the xiphoid cartilage to the nearest 0.1 cm (36,38). Coodin et al. (69) measured children at the level of nipples during quiet breathing but not necessarily at mid-respiration. The measurement is taken recumbent up to 5 years; the child stands thereafter (38).

Arm circumference. Various arm circumference indicators have been proposed (60). They have the advantage of being potentially easier, more rapid, and less expensive to obtain than weight and height. Arm circumference can be used to detect PEM in the vulnerable age group when mild forms of PEM may be missed by height and weight parameters (33). Arm circumference also can be used in relation to height or age. The mid-upper arm circumference allows a simple, but accurate, method of assessing the skeletal muscle compartment (70) which reflects the status of PEM. Growth retardation as shown by muscle depletion and by low weight-for-age are characteristic findings of PEM in children (6).

To measure arm circumference the midpoint of the upper arm must be determined (fig. 5). With the arm bent at the elbow at a 90^{o} angle and palm up, the midpoint is measured along the dorsal side of the upper arm between the acromial process of the scapula (bony protrusion on posterior of upper shoulder) and the olecranal process of the ulna (bony point of elbow). Measuring of mid-upper arm circumference follows location of midpoint with the arm hanging flaccid. A nonstretchable tape, 7-12 mm wide, is tightened snugly but not enough to cause skin contour indentation or pinching (fig. 6) (6). The measurement is taken to the 0.1 cm.

Skin fold thickness. Since subcutaneous adipose tissues constitute approximately 50% of adipose tissue stores, skin fold measurements can be used to judge total body fat (59). Skin folds can be measured accurately only at sites where a clean fold can be picked up from underlying tissues. The triceps and subscapular skin folds are considered to be the most satisfactory sites for measurement; they represent limb and trunk fat (56). The triceps skin fold thickness (TSF) was considered preferable by Jelliffe and Jelliffe (37) since standards are available.

Measurements of TSF are taken at a previously located midpoint on the upper arm on the posterior side directly in line with and mipoint to the acromion and olecranon of the child with the arm hanging free (fig. 7). (6). Foster et al. (54) placed partly closed right hand, palm up, into palm of left hand to measure skin fold for right arm. On crying babies, Keet et al. (55) had an assistant flex the elbow 45°.

The subscapular skin fold is measured 1" below the inferior angle of the scapula with the fold picked up at an angle of 45° to the spine (51,55,56). Biceps skin fold is measured over the midpoint of the muscle belly with the arm resting supinated on the subject's thigh (71). Frontal thigh skin fold is measured at the point of maximum circumference (72).

The examiner grasps a vertical pinch of skin and subcutaneous fat between thumb and forefinger 1 cm superior to site of measurement. The skin fold is gently pulled away from the underlying muscle tissue. This may be accomplished better by tightening the muscle, then relaxing it. While maintaining a grasp of skin fold, the jaws of the caliper are placed over the skinfold and allowed to close on its full pressure. Calipers should exert a constant pressure of 10 gm/mm^2 at all openings. Measurements generally were recorded to the nearest 1 mm or 0.5 mm.

STANDARDS OF REFERENCE

Identification of potential health and nutrition problems is based on "standards" which may have been derived from study samples. Appropriate standards must be selected based on the population being examined, availability of data on that segment of population presumed to have achieved optimal growth, and recommendations of agencies who have endeavored to standardize data from different parts of the world (1). Actual measurements can be compared to standards by:

$$\% \text{ standard} = \text{actual measurement} / \text{standard} \times 100$$

The Boston-Iowa standards, also called the Stuart-Meredith standards, were based on two sources of data. Standards of height and weight of children 1-4 years of age were based on measurements of children in Boston in the 1930's (73). Standards for children age 5-18 years of age were based on measurements of children and adolescents of Iowa City in the early 1940's (74). These norms have been used as reference standards in the United States and abroad. Although they are not based on the U.S. preschool population in the 1970's (10,29), the American Academy of Pediatrics recommended their use be continued for evaluation of height and weight until data collected in the Health Examination Survey (HES) can be used for new standards (5).

The head circumference standards developed by Nellhaus (68) also were recommended until data collected by the Fels Research Institute from 1929-1975 were grouped into percentiles by the National Center for Health Statistics (75). Tanner and Whitehouse (49) recently revised standards for triceps and subscapular skin folds on British children. Based on data derived from the United States Ten-State Nutrition Survey of 1968-1970 (18), Frisancho (9) reported percentiles for triceps skin fold, upper arm circumference, and muscle mass. Zeitlin (72) published percentile curves to serve as a reference standard for maximum thigh circumference. The current standards of reference are collated in appendix A-F.

Need for local standards. Jelliffe (6) stated that local standards in developing countries were based on measurements of children from low socioeconomic groups, who were, in fact, undernourished. Development of local standards were encouraged for different ethnic groups with potentially different patterns of growth (5,6,8).

The NCHS percentiles were recommended by the National Academy of Science Committee on Nutrition Advisory to the Center for Disease Control (76) and were recognized by participants in a workshop on "Physical Growth of Ethnic Groups Comprising the United States Populations" as the most appropriate available reference data (77). Data reported on preschool Indian children in Manitoba indicated that the NCHS growth standards for height, weight, and head circumference were valid and appeared to be applicable to children of most races (69). Habicht et al. (78) also considered that standards developed in western countries were relevant to children of most ethnic groups. They reported very small differences in growth among well-to-do ethnic groups--3% for height and 6% for weight. In contrast the growth differences in poor areas approached 12% for height and 30% for weight.

Gallo and Mestriner (79) reported on data collected on 2,115 children from birth to 18 years in Somalia. They found wide differences in the Somali means for height, weight, weight-for-height, and circumferences and the NCHS means. They proposed the construction of local growth charts. The Somali mean for height fell between the 10th and 25th percentiles of NCHS while the mean for weight fell between the 5th and 25th percentiles causing the Somali subjects to be analyzed below average for their age.

Deviation from these NCHS standards was more likely to be due to environmental factors, particularly nutrition, than to racial or ethnic differences. Although differences exist among ethnic groups living in similar conditions in other parts of the world, the use of NCHS percentiles for all persons in the United States for weight and height was considered unlikely to cause serious error (77). The large sample data of the NCHS generated the extreme 5th and 95th percentiles and makes the national reference data more reliable than data from previous smaller samples.

Fryer and coworkers (80) compared weights and heights of preschool children in the twelve North Central states of the United States with the Iowa (74), Boston (73), Denver (67), and Ohio norms. They reported that the growth pattern of the North Central children was similar to those norms established 30 years before.

Graystone (28) and Cheek et al. (52) used the Boston growth curves as reference standards since their data came from North American children. They justified the use of U.S. growth charts in both Guatemala and Peru by the observation that well fed urban middle class children of the same genetic background exhibited a growth pattern identical with the U.S. percentile distribution. Keet et al. (55) used the 50th percentile values of the Boston standards for height and weight. Height and weight of children in a Mississippi pilot study were plotted on the Iowa and Boston charts (22). Data of healthy Negro preschool children plotted on Iowa charts were within the normal range (81). Owen et al. (19) found that 16% of low income black and white children of the 1968-1970 Preschool Nutrition Survey were below the 3rd percentile of the Iowa and Boston height and weight standards. Shakir (33) expressed heights of Baghdad children, 3-72 months of age as a percent of the Boston standards. Underwood et al. (32) used the Iowa standards on 1-18 year olds in West Pakistan since the 50th percentiles of those standards were found to be applicable to healthy populations of high socioeconomic levels of diverse racial backgrounds.

Percentiles. Use of growth charts provide program personnel with standard forms for assessment of physical growth (4,48) and for identification of individuals with unexpected growth patterns. They can be utilized by all levels of workers in nutrition related fields and can be education tools for parents, policy makers, and others (1). The commonly used growth charts have a series of percentile areas that represent average and acceptable ranges of body size according to age and sex (4). Twice the standard deviation (mean $\pm$ 2 S.D.) covers 95% of the distribution; and 68% of a normal distribution is included in one standard deviation of the mean.

Tanner and Whitehouse (49) emphasized that percentiles are observed values of children, not what ought to be. They stated that the actual centiles observed imply nothing as to desirability of people to have a particular distribution, although the population at the 3rd and 97th centiles certainly should be regarded as "at risk". Percentile lines of growth charts are smoothed averages. Individual patterns tend to be less smooth or regular because of error in measurement and because of true variation in growth due to growth spurts. The extent to which deviation from an established pattern identifies abnormality is not sharply defined (5). Besides true individual variation, a variability in physical growth is caused by racial, socioeconomic and geographic conditions (18,28,29).

Interpretation of data. A difficult aspect of interpretation of data concerns the significance of a given measure. Measurements of physical growth are interpreted in relation to some expected value considered to be normal or usual for the child of the age, sex, and genetic potential being measured. No hard data are available for the probabilistic assumption that the atypical child is more likely than the typical child to have disease (5).

Normal growth is likely to be represented by measurements between the 25th and 75th percentiles (4). Measurements between the 10th and 25th percentiles and between the 75th and 90th percentiles may or may not be normal. Normalcy depends on the pattern of previous or later measurements and on environmental factors affecting the nutriture of the child.

Preschool children are not expected to cross percentile lanes. Data which fall above the 90th and below the 10th percentiles may indicate the need for referral for medical evaluation, with the measurements above the 95th and below the 5th percentiles given priority. Acute illness or nutritional deficiency may be suspected when stature-for-age is above the 10th percentile of NCHS, but weight-for-stature is below the 5th percentile (82). Obesity may be suspected when weight-for-stature is greater than the 95th percentile. Accurate skin fold measurements can differentiate between obesity and unusually good muscle development, both of which can place the child above the 95th percentile for weight-for-height. The NCHS weight-for-height charts were constructed using data on girls 90-137 cm tall and less than 10 year old, and on boys 90-145 cm tall and less than 11.5 years old. The charts are not appropriate for plotting weight-for-stature values for any child showing physical signs of pubescence (4).

Evaluation and diagnostic procedures at the Kansas University Medical Center consider values for height less than the 5th percentile to be abnormal (66). Roche and McKigney (77) reported that a child at age 3 who was below the 3rd percentile for weight was at greater risk than one who was below the 3rd percentile at 6 years of age. Larkin et al. (29) classified children as having growth failure if height or weight or both was below the 3rd percentile.

The basis for an individual child's 3rd percentile rank for height or weight below 97% of her or his peers may be due to many factors including: intra-uterine growth, prematurity, maternal deprivation, inadequate diet, illness during infancy, and small parents (29). Growth achievement does not necessarily reflect present eating patterns. However, protein-energy deficiency and low income were generally associated with poor growth achievement (6,22). Data from the Ten-State Nutrition Survey were used to evaluate the influence of income level on growth (18). Mean height and weight for white children were almost always greater for the high income groups. The mean skin fold thickness and head circumference measurements reflected this same tendency.

Fitzhardinge and Steven (30) reported that small infants maintained their disadvantage through 4-5 years. Only 22% of the underweight children studied by Larkin and coworkers (29) had low birth weights of less than 2.5 kg. Some of these low birth weight children had overcome an initial growth handicap when they entered the study at 14 months of age. But a majority of the low birth weight children had inadequate growth patterns in both height and weight.

RELATION BETWEEN NUTRITIONAL STATUS AND ANTHROPOMETRY OF CHILDREN

Anthropometry alone cannot define nutritional status. It may aid in identification of malnutrition. It may distinguish chronic and acute stages of undernutrition, but the diagnosis of type and severity of protein-energy malnutrition (PEM) depend on the integration of clinical and biochemical data with dietary background and anthropometric measurements. Body weight and length usually are part of the initial evaluation of nutriture and other parameters provide indepth assessment.

BODY WEIGHT AND LENGTH (HEIGHT)

Height and weight are the anthropometric measurements most in use. The measurement of weight has enjoyed the prestige of being the best index of nutrition and growth of children (7). Changes in height are slower to respond to factors that are detrimental to growth than are changes in weight. Growth responses are noted in changes in weight before changes are noted in other aspects of growth.

Variations of weight. Satisfactory growth of children must include adequate increases in body fat, lean body mass, bone, muscle, and body organs. Weight varies with all body tissues. As an index of growth, weight is subjected to greater variation than height and may be conspicuously unreliable as a measure of body fatness (45). Weight alone or even weight related to height was recognized as an inadequate measure of fatness in the Ten-State Nutrition Survey (18) so skin fold measurements also were included.

Overweight. Since fat changes markedly with variations of dietary intake and has a large influence on weight, weight gain may not be a wise index of satisfactory growth (28). Growth should be achieved without excessive fat deposit (83). Increased fat deposition must be considered when weight is used to evaluate growth of children. A child who is growing well by the index of weight may be adding excessive fat tissue (84). Interrelationships of obesity and cardiovascular disease and hypertension (85) and the question of progression of obesity into adult life have raised concern about the wisdom of using weight gain as an index of satisfactory growth, if indeed, the child may be adding excessive adipose tissue (23,86).

Hueneman (23) observed children at 6 months of age who were above the 90th percentile for weight. Their high skin fold measurements substantiated the gain of large amounts of fat. When about one half (n=270) of these fat children were studied as 3 years of age (83), less than one fourth were still over the 90th percentile for weight. A trend to leanness was detected with increasing age.

Dine et al. (87) questioned the relationship between accretion of height and weight during the first several years of life and height, weight, and degree of ponderosity at age 5. They examined 582 children in private clinic practice and concluded that a generalization could not be made of the concept that obese infants become obese children. Thirty percent of the variation in weight and ponderosity indexes at age 5 could be accounted for by the measurement of weight in the first years of life. No account could be made for the other 70% of the variation. The percentage of children whose measurements for height, weight, and various weight-height ratios fell into the highest decile (90-100) at age 5 are shown by the single bars for each index in figures 8,9. The location of those children within all deciles at ages 4, 3, 2, 1 year, 6 months, and birth are shown in successive panels below the panels for the heaviest

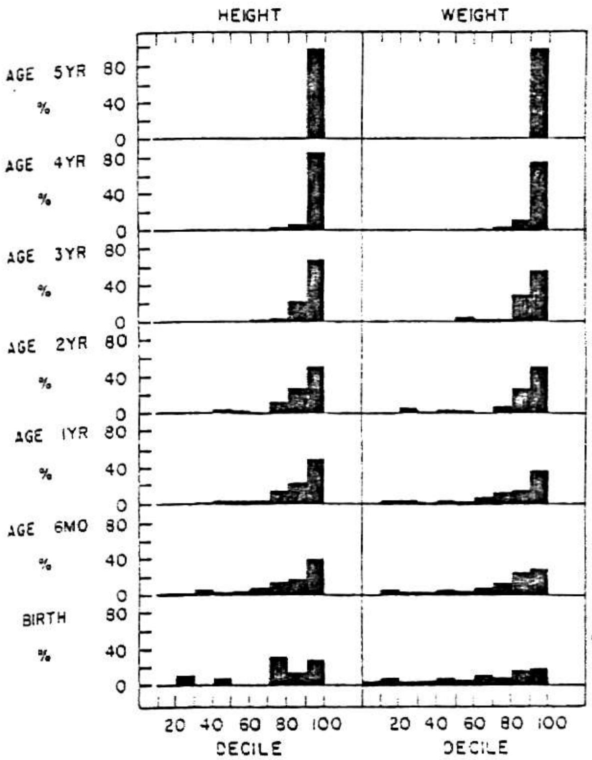

Fig. 8 Percentage of children at or above 90th percentile for height and weight at age 5, and location of children at other ages (87).

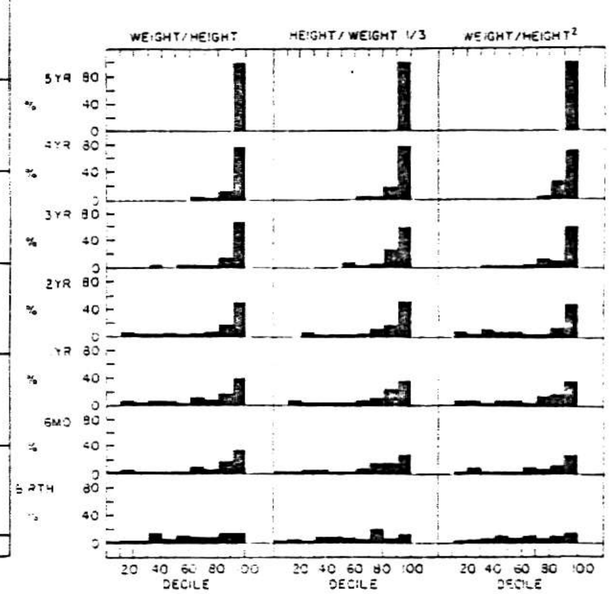

Fig. 9 Percentage of children at or above 90th percentile for weight/height, ponderal index, and Quetelet index ratios at age 5, and location of children at other ages (87).

children at age 5. Thus for weight (fig. 8), 38% of the children in the top height group at age 5 also were in the top decile at age 1. For the weight/height ratio (fig. 9), 40% were in the top decile at age 1. For the height/weight$^{1/3}$ (ponderal index), 38% were in the top decile at age 1. And for the weight/height^2 ratio (Quetelet index), 36% were in the top ratio at age 1. Factors influencing weight at age 5 were only partially related to ponderosity during the first years of life. About 36-40% of the children who were in the top deciles could be "tracked" toward a trend in ponderosity by age 5.

Large birth weights of infants born to diabetic mothers did not correlate with weights of children who were traced at ages ranging from

4-13.5 years (mean 7.8 years) (46). Similar numbers of nondiabetic children had heights and weights greater or less than the 50th percentiles. Twenty percent of the children had weights and combined skin folds which exceeded the 90th percentile. Their obesity correlated well with maternal obesity rather than with birth weight.

Jerusalem children (88) whose mean calorie intake was below 100% of the United States Recommended Dietary Allowance (RDA) were slightly heavier than the U.S. reference population. The percentage of children with decreased calorie intakes increased with age, but this decrease in intake did not reflect the distribution of the weight percentile. Nor was an association found between calorie intake and height percentile, although the mean protein intake was 200% of the RDA. At age 30 months, 43% of the children were below the 50th percentile for weight and height. By 48 months of age, 44% were below the 50th percentile for weight and 55% of the children were below the 50th percentile for height.

One of the problems of the study of ponderosity in early childhood is the lack of a precise cutoff point for identification between obesity and overweight. Both are part of a continuum. Brasel (86) indicated that most clinicians agree that an infant who is above the 85th percentile of weight-for-height on a growth chart should be considered obese. The obesity risk of the infant is increased for the child who continues to cross weight-for-age percentile lanes. The infant who crosses from the 50th to the 60th to the 70th percentile lane is at greater obesity risk than the infant with a birth weight at the 80th percentile and who remains there during childhood (86).

Underweight. Low income was associated with a high percentage of children falling below the 15th percentile for weight. The Ten-State

Nutrition Survey (18) showed that this association was greater in the under 5 age group (29%) than among older children.

A criterion for weight deficiency for admission to a Women, Infant, and Children (WIC) program is less than the 10th percentile of weight according to NCHS or Boston-Harvard standards (89). Severe weight-for-age deficit (<60% expected) failed to distinguish severely clinically malnourished children from those whose underweight was due to short stature (90), nor did weight-for-age discriminate between acute and chronic forms of malnutrition. Waterlow's criteria (91) for the point at which malnutrition begins was a weight-for-age less than 80% of the 50th percentile of standard.

Underweight was defined by Bollag (44) as a weight that was greater than one standard deviation below the expected weight-for-height when he studied children hospitalized with diarrhea. Although 38% of the children had heights greater than the 50th percentile, 47% of the children were underweight. Since weight-for-height reflects current nutritional status, the underweight status was considered to be current. However, weight deficiency did not merely reflect the acute stage of dehydration. The children probably were underweight before the onset of diarrhea.

Scrimshaw (92) reported that preschool children of developing countries may have calorie intakes that are close to the estimated minimal energy intake of basal metabolism rate x 1.5. The child adjusts to decreased energy intake by reduced activity. Acute infections increase protein requirements. The infected child needs a margin above the normal protein requirement to allow rapid repletion before the next acute infection. The depleted body adjusts by retaining nitrogen more efficiently than one which is replete. As repletion occurs, retention of nitrogen becomes less efficient, following saturation kinetics. Even with calorie intake 10% above normal needs, lean body mass is lost unless the diet is 500 calories more than the normal requirements (92). Edema contributes to body weight and often masks the loss of weight of both lean body mass and fat in undernutrition.

A relationship between nutritional status and body weight was observed by Rao and Singh (7). The observed differences in anthropometric measurements were compared with averages of children with signs of PEM and vitamin deficiencies. In all groups of children, weight was found to have the closest relationship with other measurements. The median weights of normal, PEM, and vitamin deficient females were 81.4 cm, 78.0 cm, and 80.3 cm, respectively. For males the weights were 82.4 cm, 78.6 cm, and 83.0 cm, respectively. Comparison of the correlation coefficients gave evidence that weight, weight-for-height, and calf circumference, in that order, showed maximal variations and were the most sensitive anthropometric measurements in the assessment of PEM.

Owen and coworkers (22) reported that 16% of the Mississippi preschool children they studied had weights and heights that fell below the 3rd percentile of Boston charts. Urine amino acid tests remained normal, but 10% of the Negro children (85% of the sample) were excreting small quantities of beta-aminoisobutyric acid which is normally detected in trace amounts. The height and weight deficit was not correlated with the incidence of anemia which had a trend of decreasing incidence with increasing age. Fifteen percent of 1-6 year old children had hemoglobin values below 10gm/100 ml. The incidence fell to 3.8% for 3-6 year old children.

The 50th weight percentiles of preschool children of the Ten-State Nutrition Survey (18) are shown in table 1. Values are variable, but the

TABLE 1

Weight 50th percentiles (kg) of Ten-State Nutrition Survey 1968-1970 (18)

Age midpoint, years	Boston Standard	White	Black	Puerto Rican	Mexican-American
		Males			
1	10.1	10.01	9.77	8.60	9.60
2	12.6	12.34	12.25	12.83	12.90
3	14.0	14.17	14.53	15.70	13.70
4	16.5	16.22	16.43	16.15	16.37
5	19.5	18.54	18.54	17.40	18.10
6	21.9	20.54	20.48	20.40	20.04
		Females			
1	9.8	9.31	8.72	9.00	9.35
2	12.3	11.82	12.05	11.90	11.73
3	14.4	13.38	13.77	13.60	14.00
4	16.4	15.47	15.30	15.97	14.90
5	18.8	17.65	17.61	16.70	16.67
6	21.1	19.57	19.75	20.23	19.92

data appear to reflect that Mexican-American and Puerto Rican children lagged slightly below the Boston standards and behind the white and black children of comparable age in median weight.

Height and skeletal length relationships. Linear growth reflects primarily the increase in length of the skeleton, with small contributions from the tissues between vertebrate and long bones (84). Height-for-age can be looked upon as an indication of long-term dietary history. By contrast, weight-for-height reflects the current dietary intake of the child (93). Linear growth is more stable than weight as an indicator of development. At any age, taller children have greater amounts of lean body mass than smaller children (3). Most children are lean relative to their earlier body configuration (38).

The 15th percentile was used as a cutoff for relative short for age children in the Ten-State Nutrition Survey (18) and it reflected a high prevalence of undersized children. In a "normal" standard, one would expect to find 15% of the children with height below the 15th percentile. However, 41% of the white children and 36% of the black children under 6 years of age were under this level which indicated an excess of undersized children in the ten states surveyed. This excess also was associated with poverty levels.

By using growth data from the Fels Research Institute, Garn (94) introduced the heights of parents into the evaluation of height of children. The heights of both parents were averaged to give a midparent stature. The mean heights of children of each sex at yearly age levels were calculated according to parental size. The height of a child being measured could then be evaluated according to potential genetic size.

Hawk and Brook (45) concluded there was a significant genetic contribution to the variation of both height and weight, although body fatness appeared largely determined by environmental factors. The correlation of 256 midparent and growing offspring measurements were highest for height (0.67 males, 0.63 females), less for weight (0.47 males, 0.42 females), and insignificant for combined skin folds (0.23 males, 0.24 females). The correlations for body weight were between those for height and skin fold because weight is affected by the other measurements.

Small-for-date infants were followed through 4 years of age by Fitzhardinge (30). In general, accelerated velocity of growth in the first 6 months made it possible for them to attain their individual growth curve by 2-3 years. Their average weight and height at 4 years remained between the 10th and 25th percentile. A large 35% of the heights and weights fell below the 3rd and only 8% were above the 50th percentile.

About 37% of the children referred to the Kansas University Medical Center (KUMC) from January 1972 to May 1977 (66) for evaluation of short stature were classified as having familial, primordial or genetic short stature, all involving a chromosomal abnormality or a family history of parental short stature (table 2). The diagnosis of the category of short stature did not vary with age, except in the diagnosis of skeletal disorders, which were identified at 2 years of age. Males comprised most of the largest diagnostic category of constitutional short stature, which indicated that growth rate was normal ($\geq$5 cm per year) but that skeletal age was retarded. Growth rates were improved after treatment of endocrine and chronic nutritional disorders.

TABLE 2

Referrals for evaluation of short stature at KUMC, January 1972 to May 1977 (66)

Category (n)	Total	Males	Average age diagnosis	Average Growth rate	Growth rate post-treatment
	%	%	year	cm/year	cm/year
Non-endocrine (109)	75	51			
constitutional (52)	36	92	10.1	5.2[a]	
familial (16)	11	63	8.4	4.4	
primordial (18)	12	61	8.9	4.9	
genetic (21)	14	10	9.3	4.6	
skeletal (2)	2	100	2.0	4.5	
Endocrine (32)	22	50	9.4-14	2.5-4.0	5.2-7.3[b]
Chronic nutrition (3)	3	65	9.3	4.0	8.5 ± 5.0[c]

[a]all growth rates of non-endocrine groups differed significantly from those of endocrine groups at $P < 0.05$.
[b]all post-treatment growth rates differed significantly from pre-treatment rates at $P < 0.05$.
[c]mean$\pm$S.D.

Criteria used by the KUMC to assess growth rate were: a) any child with a growth rate less than 5 cm per year was likely to have endocrine or chronic nutritional disease as cause of short stature; b) any child with a growth rate less than 5 cm per year that "fell off" from a normal growth curve may have had an endocrinological cause of short stature; c) the growth rate for non-endocrine-caused short stature paralleled the normal growth curve with a growth rate of at least 5 cm per year. Children with constitutional short stature had retarded bone age with significant growth potential. Undernutrition will retard bone growth and delay calcification of the skeletal centers of ossification (3). The incidence of stature retardation due to chronic nutritional disease was 3%.

Acute changes in nutriture were not reflected in stature. Short stature did not appear to be associated with clinical malnutrition except that a significantly lower amino acid ratio was reported than in control subjects ($P \angle 0.001$) (90). Stunted children were more frequently anemic (89,90).

Growth curves and grids. Height and weight are dynamically related to each other through an increase of both in the growing child (95). Physical growth along predicable patterns has become a standard on which to evaluate how a child is growing and to assess nutriture. On the growth curves, each percentile line is a constant percent of the normal weight for age, taking the 50th percentile as normal or 100 percent weight for age.

A grid for plotting weight against height without regard for age is based on the principle that in healthy growth, development proceeds along a channel of a given body type on an age schedule specific for the subject, and that each child should be his or her own standard of comparison (84). The grid is divided into two connected graphs. By plotting actual measurements on a chart, one can determine how a child is developing. Height and weight when plotted for one age give information relative to other children of the same age. Several measurements at different ages enable one to visualize the child's progress in growth. Most children stay in approximately the same percentile lane. Those children who fall below the 5th percentile (meaning that only 5% of the population are lighter or shorter) should be screened further for genetic, nutritional, or other environmental causes of retarded growth.

The growth standards constructed by NCHS (47) are presented in smooth curves, but data of individuals are characterized by peaks and valleys. Growth spurts may not correspond to smoothed curves and monthly plateaus and spurts are normal. The data of the tallest children (above the 95th percentile by 8 years of age for girls and by 9 1/2 years for boys) were eliminated from calculations of grids of NCHS assuming the tallest children may have entered puberty. In a normal population of children of the same height, the heavier child also will be older. Body weight can be distributed by stature groups because the age-independence is close enough to the weight-for-height.

Jaworski (48) consolidated the eight growth charts of NCHS and designed one single height and weight growth chart applicable for boys and girls from birth to 11 years (appendix G). The smoothed percentiles of NCHS all were within 1/2 inch and 1/2 pound from the combined averages. This chart was presented with 5th and 95th percentiles only to simplify routine pediatric office use.

Growth rates. The increment in growth is the change in a parameter between observations (84). Growth rates or increment curves are more informative than size attained. Increments of growth in children, that is, height-for-age, weight-for-age, weight-for-height, are informative if repeated measurements are taken. Serial measurements aid in monitoring the consistency of children in maintaining a percentile lane of growth.

Interpretation of weight is complex. Adipose tissue and lean body mass are both components of weight. The failure to distinguish between gain or loss of either component is a source of dissatisfaction with ratios of weight.

The increment (I) in weight will be the difference in value of weight (W) at one time (t) and another value at a later time (t+1) (63):

$$I = W_{t+1} - W_t \quad \text{or} \quad I = 44\# - 40\# = 4\#$$

The use of increments has a disadvantage because a child who adds 5 pounds at age 3 is not growing at the same rate as a child who adds 5 pounds at age 4. Pomerance (63) obtained increments in height and weight of pediatric patients across a broad economic base in New York City over a 20 year period beginning in 1949. Increments in height and weight are shown in table 3.

TABLE 3

Increments in weight and height of boys and girls, age 1-6, 50th percentile (63)

Age intervals	Boys	Girls	Boys	Girls
	Weight(lb.oz)		Height(in)	
12-15 months	1.8	1.9	1.25	1.25
15-18 months	1.4	1.6	1.25	1.25
18-21 months	1.5	1.5	1.0	1.25
21 month - 2 years	1.3	1.5	1.0	1.0
2-2 1/2 years	2.4	2.4	1.5	1.5
2 1/2- 3 years	2.4	2.8	1.25	1.5
3-3 1/2 years	2.4	2.4	1.5	1.5
3 1/2- 4 years	2.0	2.8	1.25	1.25
4- 4 1/2 years	2.8	2.8	1.5	1.5
4 1/2- 5 years	2.8	2.0	1.25	1.25
5 - 6 years	4.8	4.12	2.5	2.5

Velocity (V_t) of growth is the rate of incremental changes over an accepted interval between visits and is expressed as a percent (63):

$$V_t = \frac{W_{t+1} - W_t}{W_t} \times 100\% \quad \text{or} \quad V_t = \frac{44\# - 40\#}{40\#} \times 100\% = 10\%$$

The measurement of the velocity of growth is possible only when the child has been measured at successive ages. Velocity of growth is achieved within a stated period of time, usually 6-12 months (63,84). The velocity curve shows the period of relative fast or slow growth. Since velocity is not affected by the initial size, it should be a valid measurement of growth. A decrement or negative velocity indicating weight loss would be possible. Linear measurements reflect only stability or positive velocity.

Pomerance (63) suggested that since growth was not perfectly related to age by simple linear measurements, the use of logarithmic expressions compensated for lack of true linearity. Smoothed curves of percentiles for weight velocity (appendix H) and height velocity (appendix I) are expressed as percent gain for each age interval. Intervals are calculated for the x-intercept of present observation back to the previous one (63).

The velocity curve has significance to the nutritional requirements of the body. A steady supply of nutrients is needed for cell multiplication and increase in cytoplasm, and for extracellular materials essential to body function during periods of rapid growth. If nutrients are limited during rapid growth, the body becomes more vulnerable to growth than during periods of slow steady increase. The second year of life is considered a time of rapid growth for the preschool child.

Height and weight indexes. Since height and weight have been inadequate as sole indices of growth, a number of indexes of more meaningful measurements have been devised. These indexes relate weight to height in an attempt to assess adiposity. Some may be more suitable for adults than for children.

RELATIVE WEIGHT: ratio between the observed weight and the standard weight for sex and height. While it reflects the current status of the child (93), the identification of obesity by 120% IBW may not be applicable to children (94).

WEIGHT/HEIGHT: this simple ratio appears to underestimate obesity.

WEIGHT/HEIGHT^2: (Quetelet index or body mass index BMI) takes into account that height is a linear measurement and weight reflects body mass or volume; this index minimizes changes in height but is not as good as other indexes for children (87). It may produce errors in classification at the extreme of the height range.

WEIGHT/HEIGHT^3: suggested as more applicable to children because weight is not independent of height during growth (84).

HEIGHT/WEIGHT$^{1/3}$: (ponderal index) tends to overestimate incidence of obesity in short individuals. A higher value indicates thinness and a lower value indicates obesity (87).

WEIGHT INDEX: difference between actual weight-for-height ratio and normal weight-for-height ratio. A perfect pattern would be zero since weight and height increase with age (30,95).

Weight-for-age and weight-for-height were acceptable criteria to identify children who were malnourished in 1966 (6). The weight-for-height index appeared to DuRant and Linder (64) and to Anderson (12) to be a reliable measure of relative body weight and the best single anthropometric indicator of current nutriture in preschool children more than one year old. It also provides an estimate of the risk of current malnutrition.

Weight-for-height is an excellent indicator of recent nutritional status, while height-for-age indicates long-term nutriture (91). Height-for-age also indicates shortness or tallness and weight-for-height indicates thinness or fatness. A 90% of reference weight-for-height limit provided a useful cutoff point for defining malnutrition in 9-66 month old children measured by CARE (12).

At a weight index of 1.0, the child is normal regardless of weight or length. Classification of nutriture by weight-for-height or weight-for-age requires an accurate scale and either knowledge of age or accurate measurement of height. Since changes in weight and height are concurrent during any 6 month period during the early years, an index for assessing weight in relation to height is sometime desirable for programs concerned with weight changes (95). Participants of a 1975 workshop organized by the National Institute of Child Health and Human Development (77) recommended that the weight-for-height ratio was inappropriate for screening purposes because ethnic groups differ in relative leg length.

Weight-for-age measurements have limited application for children (82,96) and may conceal "stunting" and "wasting" conditions. Results of studies lend direct support to the observation that weight-for-height better identifies clinical malnutrition than does weight-for-age or height-for-age. Rural El Salvadoran children (90) who were categorized as severely malnourished by "stunting" ($<$82.5% expected height-for-age) or "wasting" ($<$80% expected weight-for-height) were re-examined for clinical assessment of severe malnutrition. Only 13% of the "stunted" children but 94% of the "wasted" children were malnourished by clinical judgment. The acute nutritional deficiency and lower ratio of nonessential to essential amino acids resulted in catabolism of body muscle and release of endogenous essential amino acids.

Waterlow (91) observed that in two hypothetical children with a similar weight-for-age deficit (table 4), the physical states of the two were not the same. The 70% deficit in weight-for-height of child A represented an acute state of malnutrition. Growth as shown by height had been satisfactory until an acute nutritional or infectious episode halted the

TABLE 4

Comparison of two hypothetical children with the same deficit in weight-for-age (91)

	Normal	A	B
Age (year)	1	1	1
Weight (kg)	10	7	7
Height (cm)	75	75	65
% Weight-for-age	100	70	70
% Height-for-age	100	100	87
% Weight-for-height	100	70	100

growth in weight. The deficit height-for-age of child B reflected retardation in linear growth over a long period of time. Child A may be referred to as "wasted" since underweight refers to children who are below the expected weight-for-age. Child B may be described as "stunted" and "nutritional growth failure". From the public health point of view they are both PEM, but they do have different natural histories and preventive measures will differ.

Chronic undernutrition and severe PEM are related. A history of growth failure increased by eightfold the incidence of clinically severe PEM of children from a rural Mexican community (97). Not all children who were judged to be chronically undernourished by their growth failure developed clinically severe PEM. Children with PEM were not significantly retarded in growth in comparison to children without PEM, although both groups had a similar growth history. A steady fall-off from predicted height and weight levels seemed to result from chronic nutritional deprivation.

Over- and underweight deviations are a subject of concern from the nutritional point of view. However, the height deviation of the small child is of greater concern than of the tall child (70). The skeletal dimensions are much less affected in mild to moderate PEM than the reserves of protein (muscle) and calories (fat) (37).

Fast or slow growth of a child is not necessarily abnormal. Some children grow slowly and always remain small; others grow rapidly and always remain large. The tendency to judgmental terms such as advanced or retarded suggests that children should not deviate from the central trend and that deviation implies abnormality.

Conclusions on use of measurements of weight and stature. Yearly weight gains of 2.3 kg per year are expected of children after their second year. Weight gain may be an unreliable measure of body fatness although changes in body weight are noticed before changes of other physical measurements. Despite concern of professionals about the interrelationship of obesity and risks of health, the generalization that obese infants become obese children was questioned. However, 36-40% of overweight children at age 5 were classified overweight at age 1 by various height and weight indexes. Weight between the 25th to 75th percentiles is considered normal. Children who are above the 85th percentile of weight-for-height should be considered obese and those who are one standard deviation below the expected weight-for-height should be considered underweight.

In the assessment of PEM, weight and weight-for-height ratios showed maximal variation and were sensitive anthropometric measurements. Weight-for-height reflected current nutritional status. Height-for-age was considered an indication of long-term nutritional status. Genetics contributed to variation of both weight and height, but environmental factors were the determinant in body fatness. Annual increments of height decreased each year, but a growth rate less than 5 cm per year was indicative of endocrine disease or chronic nutritional disease which caused short stature in childhood.

Growth spurts of children may not correlate with smoothed curves of growth charts. By plotting measurements, the clinician can determine how the child is developing relative to persons of the same age and how the child is progressing. Velocity rates are not commonly used, but they reflect the need of nutrients for cell multiplication and increase in cytoplasm during periods of rapid growth. The various ratios of height and weight fail to distinguish between changes in adipose tissue and lean body mass of children; they may be more suitable for adults than for children. Weight-for-age has limited application for children.

Children whose measurements fall below the 3rd or 5th percentile should be screened for causes of retarded growth. Healthy growth proceeds along the child's specific channel on the grid or chart. The child is not expected to shift percentile lanes. Judgments of retarded or advanced growth imply that deviation from the central trend is abnormal. The pattern of growth of children is individualized.

SKIN FOLD THICKNESS MEASUREMENTS

Measurements of skin fold thickness have been and are being used with greater frequency to provide a reasonable estimate of subcutaneous fat reserves (1,64,70,98,99), a quantitative index of calorie reserves (6,31,56), a measure of fatness or leanness (51), a basis for differentiating between obesity and overweight (3), and a clarification of the relationship between height and weight (5). They have the potential for identifying children who are obese or severely undernourished 1,4,55).

Assumptions of skin fold thickness. The validity of skin fold measurement rests on the assumptions that fat is the major variable of the body (6,99) and the measurement of subcutaneous fat will reflect total body fat (56). These measurements are based also on assumptions of distribution of fat around muscle and bone and of skin thickness (100). The increase in subcutaneous fat resulting from high calorie intake and low energy expenditure is assumed to reflect increase in calorie reserves (9).

Infrequent use among clinicians. Although skin fold thickness measurements have been used in nutritional status surveys, they have not become popular among clinicians. A reason for their infrequent application in clinical practice may be the question as to what the measurement actually means relative to measurements of other children (5,64). While it is unlikely that a child suffering chronic calorie undernutrition may exhibit a greater than 10th percentile skin fold thickness, this lower percentile may be exhibited by children in intensive athletic training (99).

The triceps skin fold thickness (TSF) measurement is of limited value in the diagnosis of malnutrition (101). When the cause of the malnutrition is primarily semistarvation, there is a reduction in TSF reflecting loss of body fat, a reduction in muscle mass reflecting loss of skeletal muscle, and reduction in body weight reflecting both muscle and fat losses. However, if the stress is trauma or infection, these anthropometric measurements are maintained in the normal range initially and the visceral proteins are reduced.

The use of calipers by clinicians presents technical difficulties (5,6,99). Persons who have participated in nutritional surveys were trained with standard procedures and usually carried through complete surveys. Malina (98) correlated duplicate readings taken one week apart by one person on randomly selected white male subjects of all ages and recorded reliability coefficients of 0.91, 0.94, and 0.95 for triceps, subscapular, and midaxillary sites, respectively. Repeated measurements by one observer may vary as much as 5% and variability among trained personnel may vary by 10% (86).

Another reason that skin fold thickness measurements are not popular is the question of validity of skin fold as a good index of body fat (50,64,102,103). Skin fold measurements are hard to make on obese persons because of the difficulty in palpating the fat-muscle interface (103). No valid skin fold measurement is possible on the most obese children because a proper skin fold cannot be raised clear of tissues underneath (49). The change in skin fold thicknesses is not proportional to loss of body weight in well children (64). For example, an obese child may lose 20 pounds with little change in skin fold thickness.

Correlation of skin fold thickness with other measurements. The measurement of TSF has been utilized in obesity studies of adults more than other skin folds (71,100). Total body fat and lean body mass are usually not measured in routine screening or medical examinations, but research findings from such studies delineate important age-associated changes in body composition (77). Flynn et al. (50) plotted derived fat values[a] against TSF values for 4-6 year old Negro and white children. In this age group, little relationship (r=0.4) existed. This was in agreement

[a]Derived fat values: Total body fat was derived by subtracting lean body mass from total body weight. Lean body mass was derived from Forbes formula dividing the milliequivalents of K by Forbes factor of 68.1. Total body K was calculated by counting gamma emissions of naturally occurring ^{40}K (50).

with the opinion from the Committee on Nutrition of the American Academy of Pediatrics (99) that the estimation of body density, water, or potassium from skin fold measurements is difficult and especially so, in children. When skin fold thickness was correlated with direct measurement of fat in adults, the caliper measurements were 60% accurate (104).

Correlation of skin fold thickness with nutritional status. For populations characterized by low degrees of fatness, the measurement of subcutaneous fat may not be a sensitive indicator of nutritional status and growth (9). If subcutaneous fat is preserved by adequate caloric intake, even in view of protein deficiency, the reliability of skin fold measurements in PEM may not be applicable (55). Keet and coworkers (55) in Cape Town found that there was a good correlation between weight and height-for-age and skin fold thickness in children between 1-5 years of age. Children suffering from PEM usually were below the 3rd percentile in weight, height, and head circumference. Triceps and subscapular skin folds usually were below the 10th percentile, and mostly far below the 3rd percentile. Underwood and coworkers (32) agreed with these skin fold findings. Well-fed children had height, weight, head circumference, and skin folds above the 3rd percentile, with few exceptions. The correlation coefficient (r=0.52) between weight and skin fold was significant. The correlation between height and skin fold was similar to that between weight and skin fold at r=0.59.

Skin folds ought to be considered in relation to body weight (56). Although the weight-for-height of girls studied by Coodin et al. (69) exceeded the NCHS standards, the girls were not considered obese because their TSF measurements were in the low to normal range of the British standards (49). Consider the measurements of two boys, each 6 years of age and each with the same TSF measurement. Boy I has a weight near the

	Boy I	Boy II	
age	6 yr	6 yr	
weight	18 kg	32 kg	
height	100 cm	136 cm	
weight/height	95 th	50 th	percentile
TSF	9 mm	9 mm	
percentile TSF	95 th	50 th	percentile

95th percentile in weight-for-height and a TSF at the 95th percentile according to NCHS (75). Boy II, apparently larger, ranks at the 50th percentile in weight-for-height and has a TSF at the 50th percentile. Boy I, though not heavy, is fat. The heavy boy is not fat. Thus the estimation of fatness sharpens the evaluation of growth status of children.

Correlation of limb and trunk fat measurements. The quantity of subcutaneous tissue varies in different regions of the body (31,98). The TSF is the most frequently taken measure of adipose fat and is used to estimate limb fat. The subscapular and midaxillary folds are indicative of trunk fat and are well correlated with limb fat in the 6-11 year age range (56). The coefficients of correlation among the triceps, subscapular, and midaxillary skin folds were computed by age, sex, and race for the black and white children of the Health Examination Survey (56). There were no differences in correlations by age and sex. The combined correlations ranged from 0.79 to 0.87, indicating that for children in the 6-11 year age group, the thicknesses were strongly related in a positive direction. Correlation (r=0.87) between the two measurements of trunk fat was the highest and that (r=0.79) between the limb fat and midaxillary skin folds was the lowest. Subscapular and triceps skin folds were highly related in a linear fashion.

The correlations for the children of the Health Examination Survey were very similar in magnitude and direction to those presented by

Malina (105) for a smaller sample of 6-13 year old children. For those children, the trunk measurements had the highest oorrelation (r=0.93), while correlations for triceps and either trunk measurement were r=0.82. The assumption was made that a child who had greater limb fat deposits also had greater fat deposits on her or his trunk. However, both sites change during growth, so both measurements are recommended (56).

Garn and coworkers (106) evaluated subscapular and triceps skin folds of Michigan children. They reported that skin folds were correlated to body weight, that subscapular skin folds showed a greater (r=0.73) correlation to body weight than triceps (r=0.70) in white children, and that the subscapular value was as useful as summing the two values in the evaluation of quantity of body fat.

Variation of skin fold thickness with age, sex, and race. A review of literature revealed that skin fold thickness of various sites varied with race, age, and sex (31,54,56,64) of children. Complete standards for all these groups are not readily available to clinicians.

Age. A yearly decrease of fat content of the body is evident during childhood and is reflected in figure 10 (107) from white participants in the Ten-State Nutrition Survey. The TSF of children decreases from age 3 for both sexes until age 5 for girls and age 7 for boys, when a slight increase is apparent in older children. The preschool fatness loss in the male is one of the aspects of changing levels of fatness in the life cycle. Boys at age 2 years have a median (50th percentile) skin fold of 10 mm which declines gradually and, at approximately the age of 8 years, reaches its lowest value of 8 mm. In contrast girls have a stable TSF of 10 mm between 2-8 years of age, thereafter showing a rapid increase (108). The 5th and 95th percentiles for boys and girls, age 1-6, is 5-6 mm and 14-16 mm (9).

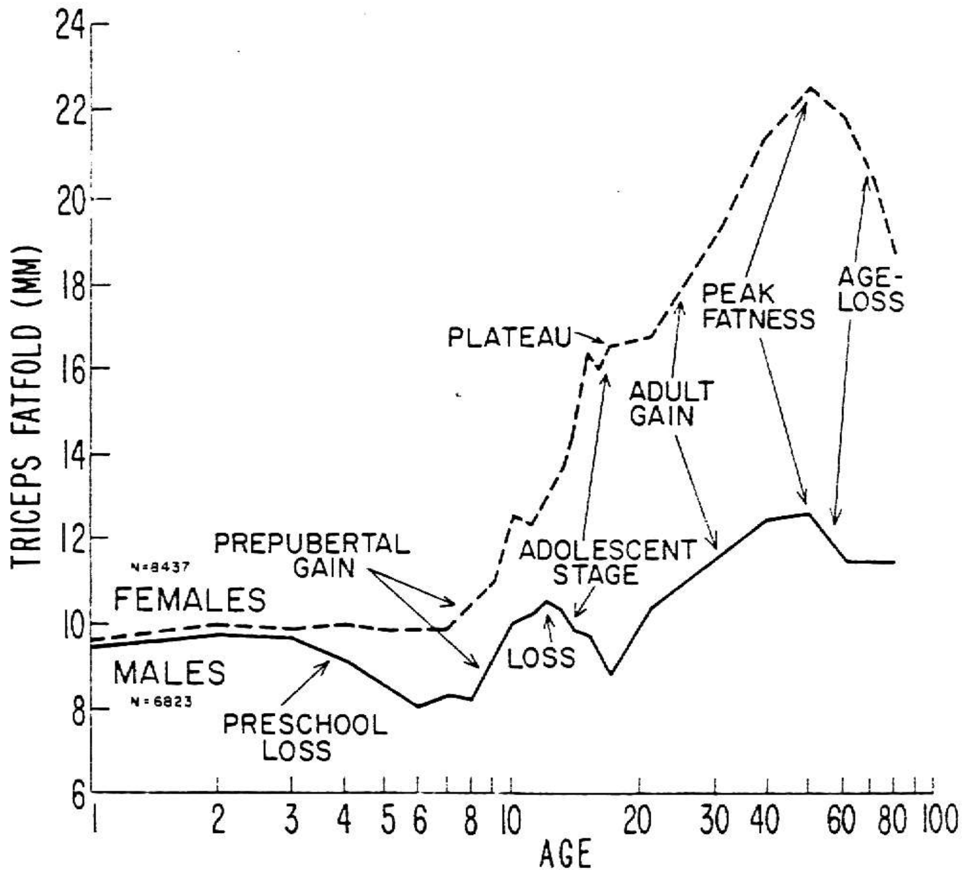

Fig. 10 Life-cycle fatness trends in females and males for white participants in the Ten-State Nutrition Survey, 1968-1970 (107).

Malina et al. (31) reported that skin folds showed a rapid increase in thickness from birth to 3-6 months of age, followed by a decrease in thickness from 6 to 18-21 months of age. At that time, triceps, biceps, subscapular, axillary, and lateral thigh skin fold increased and calf and anterior thigh skin folds stabilized until 36-42 months of age.

An increase in skin fold thickness measurement with age also is greater in children with calorie intake over requirements (18). One assumption about body fat is that an absolute lower limit is necessary for body functions (56). However, the upper limit may be altered by extrinsic factors which affect the energy needs of the body. Skin fold measurements are reliable in assessment of suboptimal nutrition and early PEM, particularly where exact ages are not known. The standard values of the triceps and subscapular skin folds vary with less than 2 mm between the ages of 1-5 years, so that exact ages may be of less importance than when dealing with weight (55).

Race. Various data indicated there were significant ethnic differences in the distribution of subcutaneous fat (11,50,51,54,56,98). Caucasian children had higher median skin folds than Negro children, indicating more fat in most age groups or less lean body mass. However, the Preliminary Findings of the Health and Nutrition Examination Survey (HANES) (11) could not aid in determining if these differences were due to differences in nutrition, since statistically significant differences in median TSF were observed in children in the income groups above poverty level.

The nature of the difference for fat distribution was evident in the site at which measurements were taken, that is, limb or trunk.. In the case of limb fat, race was the determinant of skin fold thickness. On the trunk, sex was the determinant of skin fold thickness.

Flynn et al. (50) and Malina (98) reported that white boys had more fat (weight minus lean body mass) than Negro boys, but that all girls had comparable amounts. White children 5-14 years of age, studied by Foster et al. (54) had a mean TSF value that was consistently larger by 2.5 mm than that of black children. Robson et al. (51) compared the mean triceps and subscapular skin fold thicknesses of Negro children of the Island of Dominica in the Caribbean with English children and found a similarity in trends by age in both sexes and of both races for both sites of measurement. The amount of fat in the triceps region was less in Negro than Caucasian races. The subscapular thicknesses of both sexes of both races were not significantly different. The weighted mean differences between their skin fold measurements is shown in table 5.

TABLE 5

Skin fold thickness in Caribbean and English children (51)

		Weighted mean difference, mm
Subscapular		
	male	0.19
	female	0.73
Triceps		
	male	1.67
	female	2.25

The distribution of skin fold thickness shows a considerable skewness to the right at every age beyond 5 years for girls and beyond 7 years for boys. This skewness in fat may be seen, for example, by examining the TSF table (9) of 5 year old white girls (appendix D). The difference between the 50th and 95th percentile is 6 mm (from 10.0 to 16.0 mm) while the difference between the 5th and 50th percentile is only 4 mm (from 6.0 to 10.0 mm). Since the distribution is asymetrical, the mean will be displaced away from the center of distribution and the standard deviation cannot be used to define the middle two-thirds of the distribution (56).

Sex. Differences in the amount of body fat exist between boys and girls. The 5-14 year old girls studied by Foster and coworkers (54) and the 6-11 year old girls of the Health Examiniation Survey (56) displayed a 25% larger TSF than boys, and the sexes showed different patterns of gaining subcutaneous fat at the triceps site after age 5, the girls gaining until age 9 and the boys decreasing in triceps thickness to age 7, followed by a slight increase. From 4-7 years of age, girls had, on the average, thicker skin folds at all sites measured by Malina et al. (31). This sex difference of fat reflects body composition variation and is not just a body size variation. Boys and girls of the same body weight exhibit differences in the amount of body fat.

Application of standards of skin fold thickness. Current standards for triceps and subscapular skin folds of British children were published by Tanner and Whitehouse (49). The triceps skin fold measurements of white subjects from 0-44 years old who were included in the Ten-State Nutrition Survey of 1968-1970 have been published as percentiles by Frisancho (9). The triceps skin fold values of black subjects were published in the Ten-State Nutrition Survey report (18). These standards facilitate the classification of children by percentile norms in the evaluation of nutritional grades. Since North American children have relatively high calorie intakes and skin fold measurements have value in nutrition surveys, the standards published by Frisancho may be taken as adequate standards of nutritional calorie reserves for children with high calorie intakes (56).

High calorie intake is reflected in increases in subcutaneous fat. The levels of fatness that are considered average to U.S. populations are found only in the upper ranges of the fat distribution of other populations, so skin fold measurement may not be a sensitive indicator of nutritional status and growth for other populations (9). Crispin et al. (109) reported that all measurements (height, weight, body circumferences, and muscularity) except skin fold thickness tended to be greater for children from middle to upper middle income families than for the children of families receiving public assistance. When skin fold thickness is greater than the 85th percentile (86) or 90th percentile (82), the child should be under supervision. When the skin fold value exceeds the 95th percentile, referral to a treatment center for counseling usually is desirable (82).

Evaluation of nutritional status must take into account ethnic variations in fat deposit (105). Jelliffe (6) cited a critical need for locally applicable standards. Interpretation of size of some ethnic groups relative to the national reference standard should be made with care (77). The possibility that the amount of fat in the triceps region is less in Negro than in Caucasian races would suggest that a more accurate assessment of nutritional status might be obtained if skin folds and other anthropometric measurements were not used interchangeably for ethnic groups. Data collected from groups other than Negro and white children were not included in the Ten-State Nutrition Survey report (18).

Parsons et al. (24) assessed the nutritional status of hospitalized children on admission and determined that 6% of the children had deficit skin folds ($<$5th percentile of the Ten-State Nutrition Survey). Although 20% of the children had at least one subnormal anthropometric measurement, a significant decrease in skin fold was the only change demonstrated on patients still hospitalized after 2 weeks. The mean TSF decreased from 10.33 mm to a mean of 8.21 mm ($P < 0.01$). These children were identified as surgical patients who apparently had received adequate nitrogen intake but a deficit of calories.

Triceps skin fold thickness showed a dramatic increase (2.0 ± 0.9 mm) on Kenyan children (110) after drug treatment for Ascaris, roundworm, infection compared to a decrease of 1.1 ± 1.2 mm in control groups. Weight gain and arm circumference measurements did not differ between the two groups. This finding suggested that even light Ascaris infection affected nutritional status in young children and that only the triceps skin fold thickness (of the measurements made) was sensitive to the change in nutriture. Parasitic infestation is very common among some populations. Stool examination of Brazilian children revealed that 60% of the children had parasites (111).

Conclusions on skin fold thickness measurements. The use of skin fold thickness as a measure of fatness or leanness or of nutritional status may be a valuable tool, provided standards appropriate to ethnic groups are used. Its use in surveys has been primarily for identifying children who are severely malnourished, because these measurements are assumed to reflect total body fat and therefore, calorie reserves. The application of skin fold measurements in clinical practice could serve as a basis for differentiating between obesity and overweight and could be a valuable tool for detection of early obesity in childhood.

With correct procedures and interpretation, the use of calipers for measuring skin fold thickness is reliable. However, valid measurements of the extremely obese child are not possible. A poor correlation (r=0.4) existed between skin fold thicknesses and other measurements of total body fat in 4-6 year old children. The correlation coefficients between skin fold and either weight (r=0.52) or height (r=0.59) were significant, indicating that for populations with low degrees of fatness, measurement of subcutaneous fat may not be a sensitive indicator of growth. If skin folds are considered in relation to body weight and percentiles are plotted, a good estimate of fatness is obtained. Although triceps and trunk skin fold measurements are strongly related in a positive direction, both measurements are recommended during periods of growth.

Skin fold thickness varies with age, sex, and race. The standard values of the skin folds vary less than 2 mm between the ages of 1-5 years. Skin fold measurements are nonlinear. The triceps skin fold of children decreases at age 3 for both sexes. A slight increase is apparent at age 5 for girls and at age 7 for boys before the prepubertal gain in thickness. Excessive calorie intake can alter skin fold thickness measurement with age and a heavier child also will have a larger skin fold.

Boys and girls of the same body weight exhibit differences in amount of body fat; girls have skin fold measurements 25% thicker than do boys. The nature of significant ethnic differences in distribution of fat is evident in sites of measurement. On the basis of limb fat, Caucasian children have 25% thicker skin folds than Negro peers. Trunk measurements are not noticeably different between these two racial groups. Comparison of skin folds of North American children with children of other countries is difficult because the children from other countries usually come from lower income and lower nutritional backgrounds. Triceps skin fold thickness appears to be sensitive to a deficit of calories following hospitalization and to infection.

ARM CIRCUMFERENCE MEASUREMENTS

The arm circumference (AC) as a public health index of PEM of early childhood was reviewed by Jelliffe and Jelliffe in 1969 (37) and has been used increasingly, particularly to study nutriture of children 1-5 years of age (7,10,12,13,33,35,50,54,112,113). The techniques of AC include accurate measurement with a tape (114) or a plastic bangle which is passed to mid arm (112).

Zerfas (114) claimed that AC measurement had as much predictive value as weight, height, and skin folds in assessment and was considered to be more practical and cheaper to obtain than other soft tissue indices. Not all authors agreed that AC was an adequate predictor of nutritional status (7) nor that it gave a precise diagnosis (102). It is used because of its presumed lesser involvement by subcutaneous edema (37). The presence of nutritional edema labels a child as severely malnourished irrespective of AC measurement (115).

Search of the literature did not reveal that AC was used often as an indicator of obesity in children. Measurement of AC was most frequently used to calculate arm muscle mass (Frisancho (9). Because it correlated well with the calculated mid arm muscle circumference, Jelliffe (6) assumed that AC could be used by itself. The AC may serve well as a single measure of nutritional status. Its critical limit is the application of the correct technique of measurement and the interpretation of the measurement. If the measurement is taken to the nearest 0.1 cm and the error in taking the measurement is in the order of 0.5 cm in both directions, a relatively large error is present in relation to the narrow range of observed AC measurements.

Standards for arm circumference. According to Jelliffe (6), arm circumference measurements have been compared with values derived from a sample of Polish children; those values continued to serve as a reference until data from the Health and Nutrition Examination Survey became available in 1974 (9). Compared to height and weight, AC shows little change during childhood. Arm circumference is believed to be relatively constant between the age of 1-5 years (60), increasing only 1.5 cm in normal 1-6 year old children (33). During this period, growth is occurring but it is accompanied by a change in muscle-fat proportion (60). Arm circumference may indicate differences in fat stores.

Some of the mean arm circumferences reported in literature are summarized in table 6. The data reported by Rao and Singh (7), Keller et al. (17), and Frisancho (9) confirmed that the AC increases 0.8-1.4 cm from 12 or 18-60 months of age. Little difference (<0.6 cm) was noted

TABLE 6

Arm circumference of preschool children
as reported in the literature

Study	Age	Number	Males	Females	Combined	Source
	months		arm circumference (cm)			
Anderson (12)	9-66	1433			15.4	Colombia
		744			16.4	Costa Rica
		2023			15.8	Dominican Republic
		1822			14.1	India
		1258			14.2	Pakistan
Cheek et al. (52)	36-48	7	15.8*			Guatemala
	48-60	4	17.2			
	60-72	6	16.1			
Flynn et al. (50)	48-60	34	17.4*	17.3*		U.S. Negro
	48-60	32	16.1	16.3		U.S. white
Rao and Singh (7)	12-36	1234	12.8**	12.6**		India
	36-60	1058	13.7	13.7		
	12-60	2292	13.2	13.1		
Keller et al. (17)	12-23	≃500	14.0*			Phillip-pines
	24-35	≃500	14.5			
	36-47	≃500	15.0			
	48-60	≃500	15.1			
Frisancho (9)	6-17	313	15.2**	14.6**		U.S. white
	18-29	350	15.7	15.5		
	30-41	373	16.1	15.7		
	42-54	423	16.5	16.2		
	54-65	495	16.9	16.9		

*mean values **median values

between AC of males and females. Geographical differences in AC were apparent. Arm circumferences of black children studied by Flynn et al. (50) exceeded by 1.0-1.3 cm those of white children.

In addressing the Western Hemisphere Nutrition Congress V in 1977, Waterlow (16) recommended basing diagnosis of undernutrition on both AC and weight-for-age. At the Tenth International Congress of Nutrition, Shakir (115) recommended cutoff limits for levels of nourishment: 14.0 cm, normal; 12.5-14.0 cm, mild to moderate PEM; 12.5 cm, critical PEM.

An AC of 16.5 cm was considered by Shakir (33) as a constant standard for Baghdad children ages 1-6 and one that could be used when present ages were unknown. Bangles of 12.6 cm and 14.1 cm inner circumferences were used as diagnostic values for identification of severe and moderately malnourished 6 month to 6 year old children in India (112). Normal Indian children, age 1-5 years (7) had median AC values of 13.1 cm for boys and 13.2 cm for girls, while those children classified as PEM were found to have median AC values of 12.2 cm for boys and 12.1 cm for girls. Trowbridge and Staehling (13) used 14.0 cm as the cutoff between nourished and malnourished children in El Salvador.

Diagnosis by CARE of severe malnutrition for children in developing countries with an AC of 13.5 cm or lower (12) agreed with diagnosis of severe malnutrition by weight-for-age or weight-for-height criteria. Although there was agreement between the AC standard and the other measurements of 3-5 year old children, a larger proportion of acutely malnourished 1-3 year old children were identified because the 1-3 year old children had smaller AC than did 3-5 year old children.

Correlation of AC indicators with nutritional status. Several nutritional indices based on AC have been designed for use with children: age-constant AC, AC-for-age, AC-for-height, AC-for-head circumference, and AC-for weight. Rao and Singh (7) found that simple, age-constant AC was not as sensitive an indicator as other indices in a less well nourished population.

Age-constant AC. Age-constant or age-independent AC is based on the theory that this measurement changes little between the ages of 1-5. As shown by the 50th percentile values for AC for children (appendix D), the AC increases approximately 11% in girls and 15% in boys between the ages of 1-5 (9). It is an average of 0.5 cm larger in normal children 3-5 years old than in those 1-3 years old (7,12). Thus a deficit AC in older preschool children indicates more severe malnourishment than it does in younger children.

Children diagnosed as malnourished by AC appear to be nutritionally vulnerable due to thinness and to a very likely low weight as well. An age-constant AC favors inclusion of 1-3 year old children in the "at nutritional risk" category (12). The low AC criterion of 12.5 cm correctly identifies 100% of young children who are acutely malnourished according to clinical evaluation (90). Simple AC can be used with little loss of sensitivity to identify children with low weight-for-age and low weight-for-height in areas where ages are not known accurately (13).

Arm circumference-for-age. Trowbridge and Staehling (13) used 60% of median weight-for-age to define true malnutrition and compared AC-for-age with age-constant AC. Arm circumference-for-age provided a slightly greater sensitivity to malnutrition than did simple AC, but it was not statistically significant.

Arm circumference-for-head circumference. This ratio did not yield statistically significant different results from that of AC alone (33). This index appeared to Keller et al. (17) to offer no advantage.

Arm circumference-for-height. Arm circumference-for-height was the least sensitive of three indicators tested by Trowbridge and Staehling (13). Both AC-for-age and age-constant AC defined malnutrition more accurately than did AC-for-height. Arm circumference-for-height was not statistically different from AC alone in a study by Shakir (33). A weak coefficient of correlation existed between AC and height which decreased with age from r=0.48 for ages 1-2 to r=0.34 for ages 4-6 (17).

Anderson (12) tested two circumferences that seemed promising for field use--age-constant AC and AC-for-height. Data were collected by CARE in 1976 in five developing countries to compare measurements of weight, height, and AC on 7304 children age 9-66 months with various previously developed nutritional status indices. A positive correlation was shown between AC and weight-for-age and weight-for-height; the correlation increased as the rate of height deficit increased among countries.

In India and Pakistan with high rates of sever malnutrition and stunting, AC had a positive correlation with weight-for-height, which was stronger than the correlation between weight-for-age and weight-for-height. In Colombia and the Dominican Republic, these correlations were equal. In Costa Rica, where stunting was minimal, the correlation of AC with weight-for-height was not as strong as the correlation of weight-for-age with weight-for-height. These findings supported the usefulness of measuring AC in areas of stunted growth; i.e., where more than 30% of the preschool children attain less than 82.5% (90) or less than 90% (12) of a standard height-for-age. Conversely, if children are not stunted, AC-for-height is not a useful measure. Anderson (12) did not recommend the use of AC-for-height as a measure of malnutrition because she found a less than 50% agreement between these indicators: $<$85% reference AC-for-height; $<$60% weight-for-age; and $<$80% weight-for-height. A 54-75% agreement existed between age-constant AC and AC-for-height at $<$85% reference AC-for-height (table 7).

TABLE 7

Rates of malnutrition by arm circumference measurements in children, studied by CARE, ages 9-66 months (12)

Country	Mean AC	Age-constant AC	AC-for-height	Agreement of AC and AC-for-height
	cm ± SD	% < 13.5 cm	% <85%	%
Colombia	15.4 ± 1.3	5.4	2.9	54%
Costa Rica	16.4 ± 1.4	1.2	0.9	75%
Dominican Republic	15.8 ± 1.4	3.5	2.4	67%
India	14.1 ± 1.2	29.4	19.1	65%
Pakistan	14.2 ± 1.3	24.7	16.3	66%

QUAC. The QUAC (Quaker arm circumference) stick reported by Shakir (116) and by Loewenstein and Phillips (113) provides a quick measurement of AC-for-height. The height measuring stick is marked off in AC values in three colors according to 85%, 80%, and 75% of a standard AC-for-height, over a height range of 70-132 cm. The QUAC stick is based on the principle that AC reflects the soft tissue mass of the body and that height is not reduced in acute malnutrition. Acute episodes of soft tissue mass loss can be identified. The QUAC stick measurement is independent of age. Both 85% and 80% of a standard AC-for-height have been used as a suitable upper borderline limit for PEM. When compared with the Boston standards of 80% weight-for-age, a 80% QUAC value was considered the upper borderline limit for PEM and a 60% QUAC value was the level for severe PEM. The QUAC value of 85% sometimes classified children as malnourished when they were not classified so by weight-for-age standards. Shakir (116) considered this overdiagnosis better than missing a diagnosis of malnutrition. A screening survey identified 20% of a juvenile population at the 75% QUAC level who were severely malnourished (113).

Arm circumference-for-weight. Skewness seen in AC data is not unexpected because it reflects the dependence of AC on body weight and triceps skin fold thickness (54). Arm circumference may be expected to give roughly the same information as weight. There was a strong positive correlation between AC and weight (12); it decreased with age, from r=0.72 at age 1-2 to r=0.52 at age 4-7 (17). Keet (55) showed a correlation of r=0.92 between 1-5 years of age.

Bangles. Jelliffe and Jelliffe's claim (37) that bangles gave similar and accurate information to tape measurements for identification of malnutrition was not confirmed by Ramachandran and coworkers (112), who studied children aged 6 months to 6 years in India. Bangles of inner diameters of 4 cm and 4.5 cm and respective inner circumferences of 12.6 cm and 14.1 cm were used for diagnostic value in identification of moderate and severely malnourished children. With the left arm in a horizontal position, the bangle was passed to mid arm to evaluate if the mid AC was below or above 12.6 cm.

The children were cross-classified as normal or malnourished using Harvard weight-for-age grades of: >90%, Normal; 75-90%, Grade I PEM; 60-75%, Grade II PEM; and <60%, Grade III PEM. The standard of weight-for-age was used since it is known that among anthropometric measurements, weight has the closest relation to PEM (70,116). The Harvard standard was considered valid considering that the well-to-do children in India were as tall and heavy as North American preschool children.

The 12.6 cm bangle test was found to be unsatisfactory on children 3-6 years of age, because only one half (49.8%) of the children with Grades II and III PEM were identified correctly. The false negative rate was 50.2% and the false positive rate was 12.1%. The test also was unsatisfactory for children under 3 years of age. Nearly 40% of the children who were normal or mildly malnourished were incorrectly identified as moderately or severely malnourished. The recommendation was made by Shakir (116) to continue use of a tape along with a weight-for-age chart.

Correlation between arm circumference indicators. Age-constant AC, when compared with AC-for-age and 80% weight-for-age, gave comparable results (table 8), except in the first year of life (33). Under age 1, age-constant AC tended to overdiagnose more normal children as malnourished. This misdiagnosis was in favor of the child. Children 13-72 months of age were equally identified by >85% and <76% AC-for-age or by >14.0 cm and <12.5 cm age-constant AC. The center ranges of 76-85% AC-for-age or 12.5-14.0 cm age-constant AC were inconsistent in identifying children who had been 80% weight-for-age.

TABLE 8

Comparison of 80% weight-for-age with percentages of arm standards on Baghdad children, age 13-72 months (33)

			% AC-for-age St.			Age-constant AC St.		
Age, months	% Wt-for-age Boston St.	N	>85%	76-85%	<76%	>14.0 cm	12.5-14.0 cm	<12.5 cm
13-60	over 80%	360	294	66	0	288	72	0
	under 80%	187	4	48	135	2	48	137
61-72	over 80%	71	64	7	0	57	14	0
	under 80%	12	1	9	2	2	8	2

Conclusions on the use of AC measurements. The AC alone was as useful to predict malnutrition as height, weight, skin folds, and various ratios of AC to nonlabile measurements. Nutritional edema in a child did not affect AC measurements, but did automatically label a child as severely malnourished. Arm circumference measurements have been used for detection of undernourishment and for calculation of arm muscle mass. Little research has been done with AC measurements to predict obesity.

Mean AC values varied with the population studied and ranged from 12.6-17.4 cm for the age group 12-60 months. Cutoff limits to identify severe malnutrition also varied. Arm circumference changes little over the preschool years, although there is a change in the muscle-fat proportion. The constancy of AC between 1-5 years of age makes it an age-independent index.

While most authors agreed that AC was a valuable tool, its sensitivity to nutritional status was questioned in the less well nourished population than those from which the standards were drawn. Comparable results were obtained from age-constant AC and AC-for-age. Arm circumference identified children with low weights. The correlation of AC with weight increased with incidence of stunting, but it also decreased with age of the child. Arm circumference-for-height, by measurement of both or by use of the QUAC stick, was not useful except in stunted populations. Children tended to be overdiagnosed as malnourished with AC-for-height. Arm circumference-for-head circumference did not result in any statistically significant results, so was considered of little value for nutritional assessment. Bangles tended to classify normal or mildly malnourished children as moderately or severely malnourished. If arm circumference is chosen as a parameter of nutriture, it should be used with a weight-for-age chart.

ARM MUSCLE MEASUREMENTS

The triceps skin fold (TSF) and arm circumference (AC) are two practical measurements for assessing nutritional status, but each measurement has its limitations. The skin fold does not measure satisfactorily the amount of fat that is the principal energy reserve of the body. A thin ring of fat on a muscular arm may contain as much fat as a thicker ring on a puny muscle (102). Since AC measures fat and muscle combined (114), it does not give a precise diagnosis, but it may reflect a difference in fat stores (52). Combined values for TSF and AC are used to derive estimates of muscle mass which give an indication of the body's muscle or its main protein reserves.

Data from the cross-sectional sample of the Ten-State Nutrition Survey of 1968-1970 (18) which included individuals of low, middle, and upper income groups were used to derive three estimates of muscle size (9):

1) arm muscle diameter (mm) = $\frac{\text{AC (mm)}}{\pi}$ - TSF (mm)

2) arm muscle circumference (mm) = AC (mm) - π(TSF (mm))

3) arm muscle area (mm^2) = $\frac{\pi}{4}$ (arm diameter^2)

The percentiles for AC and TSF, mid arm muscle circumference, arm muscle area, and arm muscle diameter were developed by Frisancho (9) and are given in appendix D, E. During the early childhood years, there is an increase of nearly 35% in arm muscle area. At the same time, the diameter and circumference of muscle increase only 16%, leading to an underestimation of tissue changes.

A nomogram developed by Gurney and Jelliffe (102) provides a convenient calculation of arm muscle circumference, arm muscle area, and arm area (appendix J). The value that is intersected by a line that joins the AC and TSF is the arm muscle circumference. The arm area and arm muscle area are alongside their respective circumferences. The arm muscle area on the nomogram is determined as the difference between the arm and muscle areas.

Relation to protein reserves. Growth in size of muscularity is related to greater stature (117). The measurements of muscularity in children serve as a general index of nutritional status. If skeletal musculature is maintained, the muscle size indicates that protein requirements are met for growth and maintenance of body tissues. Greater muscle size is related to greater protein reserves. Conversely, small muscular measurements reflect less protein reserves than do the large muscular measurements (9).

In developing countries, the fat layer makes only a small contribution to arm volume and AC is an adequate indicator of arm muscle mass. Studies of children in the U.S. indicate this is not true. Of pediatric patients with an arm muscle area smaller than the 5th percentile (25), only 60% had an AC less than the 5th percentile, indicating the importance of calculating the muscle area. In children with high calorie intakes, loss of muscle mass may be masked by subcutaneous fat (52).

Poor muscle development or muscle wasting are cardinal features of all forms of PEM, especially those of early childhood (6). The reduction in muscle size occurs as a compensatory mechanism to provide amino acids for gluconeogenesis and hepatic synthesis of plasma proteins (117). Brooke and Wheeler (35) rehabilitated 25 Jamaican children with relatively severely affected arm muscle area, weight, and skin fold thickness. The acute nature of the malnutrition was assessed by relatively unaffected head circumference and body length. After seven weeks on a high fat diet, accelerated growth of lean tissues as well as adipose tissue was striking.

The arm muscle area rose from a mean of 6.8 cm^2 to 9.9 cm^2 or from 54% to 78% of normal (12.7 cm^2) for mean age of 1.3 years. During rehabilitation skin folds increased 120% and the increase in arm muscle area exactly paralleled that of weight gain. Since fat stores were severely depleted, the accelerated growth of lean tissue indicated that surplus of energy was available beyond the formation of adipose tissue for the high energy cost of new tissue synthesis, reflected both as stored energy and energy consumed in oxidative synthetic processes.

Use of standards. In their survey of hospitalized pediatric patients, Merritt and Suskind (25) computed AC and TSF percentiles for age from the percentiles of the Ten-State Nutrition Survey (18) and from arm muscle area percentiles from data of Frisancho (9). Patients with arm measurements below the 15th percentile with first degree malnutrition were placed in an "at risk" category. Patients with arm values below the 5th percentile for age were defined as Grades II and III malnutrition and classified as "probably malnourished". Arm muscle area was comparatively sensitive to weight-for-height ($P < 0.05$). The significant relationship of the weight-for-height and arm muscle area and total lymphocyte count suggested that many of the patients had reduced lean body mass and were at risk of nosocomial infection. A relation with serum albumin level was suspected with arm muscle circumference although insufficient values were found in the charts to study the trend.

Although 50% of the surgical infants studied by Parsons et al. (24) had low total serum proteins (<6 gm/dl), none of them had reduced serum albumin levels (<3.5 gm/dl). Thus they were not considered high risk for being protein undernourished.

Conclusions on arm muscle measurements. The combined values of TSF and AC measurements were used to derive an estimation of muscle mass which was an indication of the main protein reserves of the body, the greater muscle size reflecting that protein requirements were met for growth. A nomogram developed by Gurney and Jelliffe (102) provided a convenient calculation of arm area, arm muscle area, and arm muscle circumference.

Poor muscle development or muscle wasting were cardinal features of all forms of PEM, especially those of early childhood. Persons with arm muscle measurements below the 15th percentile were categorized as "at risk" and persons with arm values below the 5th percentile for age as "probably malnourished". Arm muscle area was sensitive to weight-for-height. During rehabilitation, the increase in a muscle area paralleled that of weight gain. In areas where calorie stores were minimal, the fat layer (TSF) made only a small contribution to arm volume and AC was an adequate indicator of muscle mass. This was not true of children with higher calorie intakes, in whom loss of muscle mass may be masked by subcutaneous fat, indicating the importance of calculating a muscle diameter, circumference, or muscle area.

THIGH CIRCUMFERENCE

Reference standards for maximum thigh circumference (TC) were published by Zeitlin in 1979 (72) using percentile curves derived from measurements of a sample of 1080 economically favored newborn infants and children to 5 1/2 years from the Boston area and New Haven. Zeitlin also measured a sample of 513 6-48 month only low income Filipino children to test for sex differences in TC and for usefulness of the TC in identifying malnutrition. The measurements of the children in the lower nutritional status were not used for derivation of standards. A range of expected percentiles was determined around the median values at a series of three or six month age points to 60 months of age (appendix F).

Correlation with arm circumference (AC). The left thigh was measured at the maximum circumference in a plane perpendicular to the femur. The left AC and the skin folds of triceps, subscapular, and frontal thigh at the point of maximum circumference, weight, and length were measured. The TC was similar to the AC but was proven to be slightly more consistent. A correlation of r=0.83 was derived across the 0-5 year age range between TC and AC. The larger size of the thigh reduced the percent of error associated with the smaller circumference of the upper arm. Thigh circumference also was found to correlated with weight-for-age and weight-for-length according to standards of the National Center for Health Statistics at r=0.80 (75).

Unique aspects of TC. A single standard applicable to both sexes in the preschool period makes TC unique among anthropometric measurements (fig. 11). The mean TC of girls was 1.9 mm larger than for boys in the U.S. groups, but nonsignificantly lower in the Filipino sample. The mean weight-for-length of U.S. girls also was nonsignificantly higher and girls had a thigh skin fold which average 1.14 mm larger than that for boys. Analysis of variance of TC using data from the Boston and the Filipino samples failed to show significant sex differences. Thus there appeared no reason to create separate sets of standards for TC for the sexes in the 0-5 year age range.

Another unique aspect of the TC curve was its saddle shape. A maximum TC was exhibited at 12 months in well nourished children and at 18 months by children in the lowest percentiles. At 12 months a marginal

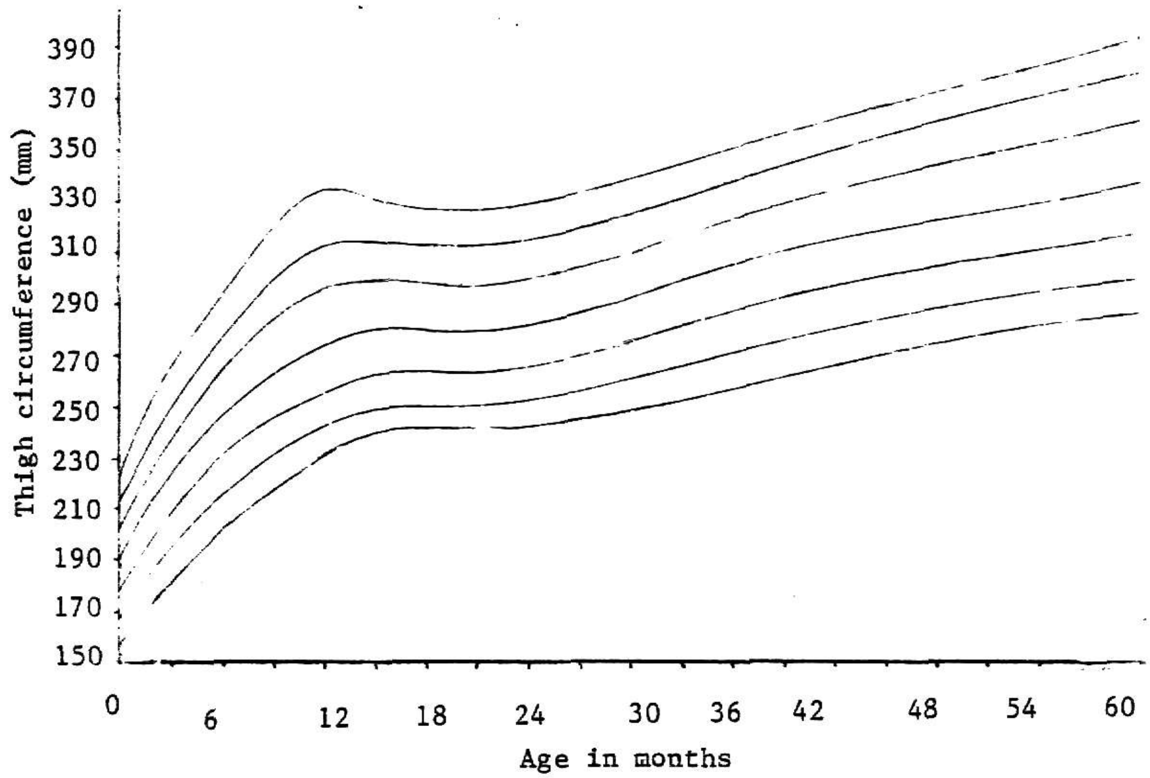

Fig. 11 Percentile curves of maximum thigh circumference, 0-5 years (72).

reduction in size of TC occurred in well nourished children, which ironically is the same 12-21 month age period when many child populations exhibit growth failure due to inadequate weaning practices and to infection.

Zeitlin (72) explained that the relatively constant TC between 12-21 months may reflect energy requirements for motor activity of children. Data indicated that thigh skin fold diminished by almost 2 mm as the child began to walk. The hypothesis offered was that thigh and buttocks serve as a depot of fat stores which are used to meet increased energy needs concurrent with the dramatic decline of appetite at 12 months of age. Preferential wasting of these fat stores spares other body tissues in infant malnutrition. Although the thigh skin fold diminishes, the muscle growth continues to increase in nourished children. Thus TC remains relatively constant between 12-21 months, followed by a slight but steady increase in size through 60 months of age.

The reference standards for TC were derived as a screening index in low income countries for selecting malnourished infants and young children to participate in nutrition intervention programs. They can be used to monitor nutritional status. A possible use is in monitoring obesity in the home in the absence of scales. Both TC and AC may be better descriptors of vulnerable target groups than other anthropometric measurements which are biased by age (15). Thigh circumference has the additional advantage of being free of sex bias and allows good measurement accuracy.

Conclusions on thigh circumference measurements. Since mid upper arm circumference correlates with maximum thigh circumference at r=0.83 and weight-for-age and weight-for-length correlates at r=0.80, the use of TC as a simplified index to monitor nutritional status should be explored further. Percentile curves were derived by Zeitlin in 1979. A single reference standard for TC was found applicable to both sexes aged 0-5 years. Like the arm circumference which shows little change in the preschool years, the TC remains almost constant at 27.8 cm between 12-21 months. The mean TC for both sexes age 0-5 years was 28.9 cm. It increased to 34.7 cm by 60 months of age.

The average thigh skin fold decreases by almost 2 mm between 12-21 months while the muscle growth continues to increase, thus giving an apparently constant TC. The decrease of skin fold implies that the thigh stores fat which is the preferential source of energy during the weaning and an in malnutrition. Zeitlin considered the AC a better selector of nutritional status than AC because the larger size of the thigh reduced measurement error and because it was applicable to both sexes.

SUMMARY AND CONCLUSIONS

Normal healthy children have a genetically determined physical growth pattern that is affected by environmental factors, including nutrition. The second year in particular is a period of rapid growth with high nutritional needs for swiftly increasing muscle mass. The purpose of this report was to review the literature regarding the use of anthropometric measurements to assess the nutritional status of pre-school children.

Standards developed for nourished children in western countries are considered to be relevant to children of most ethnic groups. Normal growth is likely to be represented by measurements between the 25th and 75th percentiles. Children who are growing normally are not expected to cross percentile lanes.

Height-for-age reflects chronic nutriture. Weight-for-height is an indicator of current nutritional status. Genetics contributes variation to both height and weight, but environmental factors are the determinant in body fatness. The various ratios of height and weight fail to distinguish between changes in adipose tissue and lean body mass of children. Weight gain may not be a wise index of satisfactory growth because the child may be adding excessive fat tissues.

Excessive calorie intake can alter skin fold thickness measurements with age. For populations characterized by a low degree of fatness, the measurement of subcutaneous fat may not be a sensitive indicator of nutritional status and growth. Authors disagreed whether arm circumference was an adequate predictor of nutritional status, but they generally accepted a lower limit of 12.5 cm to identify 1-5 year old children who are malnourished according to clinical evaluation.

If skeletal muscle is maintained, the muscle size indicates that protein requirements are met for growth and for maintenance of body tissues. The muscle protein is rapidly mobilized when calorie intake is inadequate. The loss of muscle mass may be masked by subcutaneous fat in children with high calorie intakes, indicating the importance of calculating a muscle diameter, muscle circumference, or muscle area.

Since thigh circumference correlated well with arm circumference, weight-for-age, and weight-for-height, the use of thigh circumference as a simple index of nutriture should be explored. The constancy of both circumferences throughout ages 1-5 years makes them age-independent indexes, which can be used when the child's age is unknown.

Alone, anthropometry cannot define nutritional status, but it may identify risks of malnutrition. It may aid in distinguishing chronic and acute stages of malnutrition. It may reveal the subtle mild and moderate forms of protein-energy malnutrition. Anthropometry is recommended to identify children at nutritional risk and to monitor their nutritional status.

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APPENDIX

APPENDIX

APPENDIX A

Percentiles of weight (kg) by sex and age, 1.5-18 years, from National Center for Health Statistics 1977 (75)

Sex and age	Smoothed* percentile						
	5th	10th	25th	50th	75th	90th	95th
	Weight in kilograms						
Male							
1.5 years	9.72	10.18	10.51	11.09	12.02	12.95	14.42
2.0 years	10.49	10.96	11.55	12.34	13.36	14.38	15.50
2.5 years	11.27	11.77	12.55	13.52	14.61	15.71	16.61
3.0 years	12.05	12.58	13.52	14.62	15.78	16.95	17.77
3.5 years	12.84	13.41	14.46	15.68	16.90	18.15	18.98
4.0 years	13.64	14.24	15.39	16.69	17.99	19.32	20.27
4.5 years	14.45	15.10	16.30	17.69	19.06	20.50	21.63
5.0 years	15.27	15.96	17.22	18.67	20.14	21.70	23.09
5.5 years	16.09	16.83	18.14	19.67	21.25	22.96	24.66
6.0 years	16.93	17.72	19.07	20.69	22.40	24.31	26.34
6.5 years	17.78	18.62	20.02	21.74	23.62	25.76	28.16
7.0 years	18.64	19.53	21.00	22.85	24.94	27.26	30.12
7.5 years	19.52	20.45	22.02	24.03	26.36	29.11	32.73
8.0 years	20.40	21.39	23.09	25.30	27.91	31.06	34.51
8.5 years	21.31	22.34	24.21	26.66	29.61	33.22	36.96
9.0 years	22.25	23.33	25.40	28.13	31.46	35.57	39.58
9.5 years	23.25	24.38	26.68	29.73	33.46	38.11	42.35
10.0 years	24.33	25.52	28.07	31.44	35.61	40.80	45.27
10.5 years	25.51	26.78	29.59	33.30	37.92	43.63	48.31
11.0 years	26.80	28.17	31.25	35.30	40.38	46.57	51.47
11.5 years	28.24	29.72	33.08	37.46	43.00	49.61	54.73
12.0 years	29.85	31.46	35.09	39.78	45.77	52.73	58.09
12.5 years	31.64	33.41	37.31	42.27	48.70	55.91	61.52
13.0 years	33.64	35.60	39.74	44.95	51.79	59.12	65.02
13.5 years	35.85	38.03	42.40	47.81	55.02	62.35	68.51
14.0 years	38.22	40.64	45.21	50.77	58.31	65.57	72.13
14.5 years	40.66	43.34	48.08	53.76	61.58	68.76	75.66
15.0 years	43.11	46.06	50.92	56.71	64.72	71.91	79.12
15.5 years	45.50	48.69	53.64	59.51	67.64	74.98	82.45
16.0 years	47.74	51.16	56.16	62.10	70.26	77.97	85.62
16.5 years	49.76	53.39	58.38	64.39	72.46	80.84	88.59
17.0 years	51.50	55.28	60.22	66.31	74.17	83.58	91.31
17.5 years	52.89	56.78	61.61	67.78	75.32	86.14	93.73
18.0 years	53.97	57.89	62.61	68.88	76.04	88.41	95.76
Female							
1.5 years	9.02	9.16	9.61	10.38	10.94	11.75	12.36
2.0 years	9.95	10.32	10.96	11.80	12.73	13.58	14.15
2.5 years	10.80	11.35	12.11	13.03	14.23	15.16	15.76
3.0 years	11.61	12.26	13.11	14.10	15.50	16.54	17.22
3.5 years	12.37	13.08	14.00	15.07	16.59	17.77	18.59
4.0 years	13.11	13.84	14.80	15.96	17.56	18.93	19.91
4.5 years	13.83	14.56	15.55	16.81	18.48	20.06	21.24
5.0 years	14.55	15.26	16.29	17.66	19.39	21.23	22.62
5.5 years	15.29	15.97	17.05	18.56	20.36	22.48	24.11
6.0 years	16.05	16.72	17.86	19.52	21.44	23.89	25.75
6.5 years	16.85	17.51	18.76	20.61	22.68	25.50	27.59
7.0 years	17.71	18.39	19.78	21.84	24.16	27.39	29.68
7.5 years	18.62	19.37	20.95	23.26	25.90	29.57	32.07
8.0 years	19.62	20.45	22.26	24.84	27.88	32.04	34.71
8.5 years	20.68	21.64	23.70	26.58	30.08	34.73	37.58
9.0 years	21.82	22.92	25.27	28.46	32.44	37.60	40.64
9.5 years	23.05	24.29	26.94	30.45	34.94	40.61	43.85
10.0 years	24.36	25.76	28.71	32.55	37.53	43.70	47.17
10.5 years	25.75	27.32	30.57	34.72	40.17	46.84	50.57
11.0 years	27.24	28.97	32.49	36.95	42.84	49.96	54.00
11.5 years	28.83	30.71	34.48	39.23	45.48	53.03	57.42
12.0 years	30.52	32.53	36.52	41.53	48.07	55.99	60.81
12.5 years	32.30	34.42	38.59	43.84	50.56	58.81	64.12
13.0 years	34.14	36.35	40.65	46.10	52.91	61.45	67.30
13.5 years	35.98	38.26	42.65	48.26	55.11	63.87	70.30
14.0 years	37.76	40.11	44.54	50.28	57.09	66.04	73.08
14.5 years	39.45	41.83	46.28	52.10	58.84	67.95	75.59
15.0 years	40.99	43.38	47.82	53.68	60.32	69.54	77.78
15.5 years	42.32	44.72	49.10	54.96	61.48	70.79	79.59
16.0 years	43.41	45.78	50.09	55.89	62.29	71.68	80.99
16.5 years	44.20	46.54	50.75	56.44	62.75	72.18	81.93
17.0 years	44.74	47.04	51.14	56.69	62.91	72.38	82.46
17.5 years	45.08	47.33	51.33	56.71	62.89	72.37	82.62
18.0 years	45.26	47.47	51.39	56.62	62.78	72.25	82.47

APPENDIX B

Percentiles of height (cm) by sex and age, 1.5-18 years, from National Center for Health Statistics 1977 (75)

Sex and age	Smoothed percentile						
	5th	10th	25th	50th	75th	90th	95th
	Stature in centimeters						
Male							
2.0 years	82.5	83.5	85.3	86.8	89.2	92.0	94.4
2.5 years	85.4	86.5	88.5	90.4	92.9	95.6	97.8
3.0 years	89.0	90.3	92.6	94.9	97.5	100.1	102.0
3.5 years	92.5	93.9	96.4	99.1	101.7	104.3	106.1
4.0 years	95.8	97.3	100.0	102.9	105.7	108.2	109.9
4.5 years	98.9	100.6	103.4	106.6	109.4	111.9	113.5
5.0 years	102.0	103.7	106.5	109.9	112.8	115.4	117.0
5.5 years	104.9	106.7	109.6	113.1	116.1	118.7	120.3
6.0 years	107.7	109.6	112.5	116.1	119.2	121.9	123.5
6.5 years	110.4	112.3	115.3	119.0	122.2	124.9	126.6
7.0 years	113.0	115.0	118.0	121.7	125.0	127.9	129.7
7.5 years	115.6	117.6	120.6	124.4	127.8	130.8	132.7
8.0 years	118.1	120.2	123.2	127.0	130.5	133.6	135.7
8.5 years	120.5	122.7	125.7	129.6	133.2	136.5	138.8
9.0 years	122.9	125.2	128.2	132.2	136.0	139.4	141.8
9.5 years	125.3	127.6	130.8	134.8	138.8	142.4	144.9
10.0 years	127.7	130.1	133.4	137.5	141.6	145.5	148.1
10.5 years	130.1	132.6	136.0	140.3	144.6	148.7	151.5
11.0 years	132.6	135.1	138.7	143.3	147.8	152.1	154.9
11.5 years	135.0	137.7	141.5	146.4	151.1	155.6	158.5
12.0 years	137.6	140.3	144.4	149.7	154.6	159.4	162.3
12.5 years	140.2	143.0	147.4	153.0	158.2	163.2	166.1
13.0 years	142.9	145.8	150.5	156.5	161.8	167.0	169.8
13.5 years	145.7	148.7	153.6	159.9	165.3	170.5	173.4
14.0 years	148.8	151.8	156.9	163.1	168.5	173.8	176.7
14.5 years	152.0	155.0	160.1	166.2	171.5	176.6	179.5
15.0 years	155.2	158.2	163.3	169.0	174.1	178.9	181.9
15.5 years	158.3	161.2	166.2	171.5	176.3	180.8	183.9
16.0 years	161.1	163.9	168.7	173.5	178.1	182.4	185.4
16.5 years	163.4	166.1	170.6	175.2	179.5	183.6	186.6
17.0 years	164.9	167.7	171.9	176.2	180.5	184.4	187.3
17.5 years	165.6	168.5	172.4	176.7	181.0	185.0	187.6
18.0 years	165.7	168.7	172.3	176.8	181.2	185.3	187.6
Female							
2.0 years	81.6	82.1	84.0	86.8	89.3	92.0	93.6
2.5 years	84.6	85.3	87.3	90.0	92.5	95.0	96.6
3.0 years	88.3	89.3	91.4	94.1	96.6	99.0	100.6
3.5 years	91.7	93.0	95.2	97.9	100.5	102.8	104.5
4.0 years	95.0	96.4	98.8	101.6	104.3	106.6	108.3
4.5 years	98.1	99.7	102.2	105.0	107.9	110.2	112.0
5.0 years	101.1	102.7	105.4	108.4	111.4	113.8	115.6
5.5 years	103.9	105.5	108.4	111.6	114.8	117.4	119.2
6.0 years	106.6	108.4	111.3	114.6	118.1	120.8	122.7
6.5 years	109.2	111.0	114.1	117.6	121.3	124.2	126.1
7.0 years	111.8	113.6	116.8	120.6	124.4	127.6	129.5
7.5 years	114.4	116.2	119.5	123.5	127.5	130.9	132.9
8.0 years	116.9	118.7	122.2	126.4	130.6	134.2	136.2
8.5 years	119.5	121.3	124.9	129.3	133.6	137.4	139.6
9.0 years	122.1	123.9	127.7	132.2	136.7	140.7	142.9
9.5 years	124.8	126.6	130.6	135.2	139.8	143.9	146.2
10.0 years	127.5	129.5	133.6	138.3	142.9	147.2	149.5
10.5 years	130.4	132.5	136.7	141.5	146.1	150.4	152.8
11.0 years	133.5	135.6	140.0	144.8	149.3	153.7	156.2
11.5 years	136.6	139.0	143.5	148.2	152.6	156.9	159.5
12.0 years	139.8	142.3	147.0	151.5	155.8	150.0	162.7
12.5 years	142.7	145.4	150.1	154.6	158.8	162.9	165.6
13.0 years	145.2	148.0	152.8	157.1	161.3	165.3	168.1
13.5 years	147.2	150.0	154.7	159.0	163.2	167.3	170.0
14.0 years	148.7	151.5	155.9	160.4	164.6	168.7	171.3
14.5 years	149.7	152.5	156.8	161.2	165.6	169.8	172.2
15.0 years	150.5	153.2	157.2	161.8	166.3	170.5	172.8
15.5 years	151.1	153.6	157.5	162.1	166.7	170.9	173.1
16.0 years	151.6	154.1	157.8	162.4	166.9	171.1	173.3
16.5 years	152.2	154.6	158.2	162.7	167.1	171.2	173.4
17.0 years	152.7	155.1	158.7	163.1	167.3	171.2	173.5
17.5 years	153.2	155.6	159.1	163.4	167.5	171.1	173.5
18.0 years	153.6	156.0	159.6	163.7	167.6	171.0	173.6

APPENDIX C

Percentiles for length, weight and head circumference for boys and girls, birth–36 months, from National Center for Health Statistics 1977 (58)

AGE months	PERCENTILES, BOYS 5th	10th	25th	50th	75th	90th	95th	MEASUREMENT	PERCENTILES, GIRLS 5th	10th	25th	50th	75th	90th	95th
BIRTH	**46.4**	**47.5**	**49.0**	**50.5**	**51.8**	**53.5**	**54.4**	**Length–cm**	**45.4**	**46.5**	**48.2**	**49.9**	**51.0**	**52.0**	**52.9**
	18¼	18¾	19¼	20	20½	21	21½	Length–in	17¾	18¼	19	19¾	20	20½	20¾
	2.54	**2.78**	**3.00**	**3.27**	**3.64**	**3.82**	**4.15**	**Weight–kg**	**2.36**	**2.58**	**2.93**	**3.23**	**3.52**	**3.64**	**3.81**
	5½	6¼	6½	7¼	8	8½	9¼	Weight–lb	5¼	5¾	6½	7	7¾	8	8½
	32.6	**33.0**	**33.9**	**34.8**	**35.6**	**36.6**	**37.2**	**Head C–cm**	**32.1**	**32.9**	**33.5**	**34.3**	**34.8**	**35.5**	**35.9**
	12¾	13	13¼	13¾	14	14½	14¾	Head C–in	12¾	13	13¼	13½	13¾	14	14¼
1	**50.4**	**51.3**	**53.0**	**54.6**	**56.2**	**57.7**	**58.5**	**Length–cm**	**49.2**	**50.2**	**51.9**	**53.5**	**54.9**	**56.1**	**56.9**
	19¾	20¼	20¾	21½	22¼	22¾	23	Length–in	19¼	19¾	20½	21	21½	22	22½
	3.16	**3.43**	**3.82**	**4.29**	**4.75**	**5.14**	**5.38**	**Weight–kg**	**2.97**	**3.22**	**3.59**	**3.98**	**4.36**	**4.65**	**4.92**
	7	7½	8½	9½	10½	11¼	11¾	Weight–lb	6½	7	8	8¾	9½	10¼	10¾
	34.9	**35.4**	**36.2**	**37.2**	**38.1**	**39.0**	**39.6**	**Head C–cm**	**34.2**	**34.8**	**35.6**	**36.4**	**37.1**	**37.8**	**38.3**
	13¾	14	14¼	14¾	15	15¼	15½	Head C–in	13½	13¾	14	14¼	14½	15	15
3	**56.7**	**57.7**	**59.4**	**61.1**	**63.0**	**64.5**	**65.4**	**Length–cm**	**55.4**	**56.2**	**57.8**	**59.5**	**61.2**	**62.7**	**63.4**
	22¼	22¾	23½	24	24¾	25½	25¾	Length–in	21¾	22¼	22¾	23½	24	24¾	25
	4.43	**4.78**	**5.32**	**5.98**	**6.56**	**7.14**	**7.37**	**Weight–kg**	**4.18**	**4.47**	**4.88**	**5.40**	**5.90**	**6.39**	**5.74**
	9¾	10½	11¾	13¼	14½	15¾	16¼	Weight–lb	9¼	9¾	10¾	12	13	14	14¾
	38.4	**38.9**	**39.7**	**40.6**	**41.7**	**42.5**	**43.1**	**Head C–cm**	**37.3**	**37.8**	**38.7**	**39.5**	**40.4**	**41.2**	**41.7**
	15	15¼	15¾	16	16½	16¾	17	Head C–in	14¾	15	15¼	15½	16	16¼	16½
6	**63.4**	**64.4**	**66.1**	**67.8**	**69.7**	**71.3**	**72.3**	**Length–cm**	**61.8**	**62.6**	**64.2**	**65.9**	**67.8**	**69.4**	**70.2**
	25	25¼	26	26¾	27½	28	28½	Length–in	24¼	24¾	25¼	26	26¾	27¼	27¾
	6.20	**6.61**	**7.20**	**7.85**	**8.49**	**9.10**	**9.46**	**Weight–kg**	**5.79**	**6.12**	**6.60**	**7.21**	**7.83**	**8.38**	**8.73**
	13¾	14½	15¾	17¼	18¾	20	20¾	Weight–lb	12¾	13½	14½	16	17¼	18½	19¼
	41.5	**42.0**	**42.8**	**43.8**	**44.7**	**45.6**	**46.2**	**Head C–cm**	**40.3**	**40.9**	**41.6**	**42.4**	**43.3**	**44.1**	**44.6**
	16¼	16½	16¾	17¼	17½	18	18¼	Head C–in	15¾	16	16½	16¾	17	17¼	17½
9	**68.0**	**69.1**	**70.6**	**72.3**	**74.0**	**75.9**	**77.1**	**Length–cm**	**66.1**	**67.0**	**68.7**	**70.4**	**72.4**	**74.0**	**75.0**
	26¾	27¼	27¾	28½	29¼	30	30¼	Length–in	26	26½	27	27¾	28½	29¼	29½
	7.52	**7.95**	**8.56**	**9.18**	**9.88**	**10.49**	**10.93**	**Weight–kg**	**7.00**	**7.34**	**7.89**	**8.56**	**9.24**	**9.63**	**10.17**
	16½	17½	18¾	20¼	21¾	23¼	24	Weight–lb	15½	16¼	17½	18¾	20¼	21¼	22½
	43.5	**44.0**	**44.8**	**45.8**	**46.6**	**47.5**	**48.1**	**Head C–cm**	**42.3**	**42.8**	**43.5**	**44.3**	**45.1**	**46.0**	**46.4**
	17¼	17¼	17¾	18	18¼	18¾	19	Head C–in	16¾	16¾	17¼	17½	17¾	18	18¼
12	**71.7**	**72.8**	**74.3**	**76.1**	**77.7**	**79.8**	**81.2**	**Length–cm**	**69.8**	**70.8**	**72.4**	**74.3**	**76.3**	**78.0**	**79.1**
	28¼	28¾	29¼	30	30½	31½	32	Length–in	27½	27¾	28½	29¼	30	30¾	31¼
	8.43	**8.84**	**9.49**	**10.15**	**10.91**	**11.54**	**11.99**	**Weight–kg**	**7.84**	**8.19**	**8.81**	**9.53**	**10.23**	**10.87**	**11.24**
	18½	19½	21	22½	24	25½	26½	Weight–lb	17¼	18	19½	21	22½	24	24¾
	44.8	**45.3**	**46.1**	**47.0**	**47.9**	**48.8**	**49.3**	**Head C–cm**	**43.5**	**44.1**	**44.8**	**45.6**	**46.4**	**47.2**	**47.6**
	17¾	17¾	18¼	18½	18¾	19¼	19½	Head C–in	17¼	17¼	17¾	18	18¼	18½	18¾
18	**77.5**	**78.7**	**80.5**	**82.4**	**84.3**	**86.6**	**88.1**	**Length–cm**	**76.0**	**77.2**	**78.8**	**80.9**	**83.0**	**85.0**	**86.1**
	30½	31	31¾	32½	33¼	34	34¾	Length–in	30	30½	31	31¾	32¾	33½	34
	9.59	**9.92**	**10.67**	**11.47**	**12.31**	**13.05**	**13.44**	**Weight–kg**	**8.92**	**9.30**	**10.04**	**10.82**	**11.55**	**12.30**	**12.76**
	21¼	21¾	23½	25¼	27¼	28¾	29½	Weight–lb	19¾	20½	22¼	23¾	25½	27	28¼
	46.3	**46.7**	**47.4**	**48.4**	**49.3**	**50.1**	**50.6**	**Head C–cm**	**45.0**	**45.6**	**46.3**	**47.1**	**47.9**	**48.6**	**49.1**
	18¼	18½	18¾	19	19½	19¾	20	Head C–in	17¾	18	18¼	18½	18¾	19¼	19¼
24	**82.3**	**83.5**	**85.6**	**87.6**	**89.9**	**92.2**	**93.8**	**Length–cm**	**81.3**	**82.5**	**84.2**	**86.5**	**88.7**	**90.8**	**92.0**
	32½	32¾	33¾	34½	35½	36¼	37	Length–in	32	32½	33¼	34	35	35¾	36¼
	10.54	**10.85**	**11.65**	**12.59**	**13.44**	**14.29**	**14.70**	**Weight–kg**	**9.87**	**10.26**	**11.10**	**11.90**	**12.74**	**13.57**	**14.08**
	23¼	24	25¾	27¾	29¾	31½	32½	Weight–lb	21¾	22½	24½	26¼	28	30	31
	47.3	**47.7**	**48.3**	**49.2**	**50.2**	**51.0**	**51.4**	**Head C–cm**	**46.1**	**46.5**	**47.3**	**48.1**	**48.8**	**49.6**	**50.1**
	18½	18¾	19	19¼	19¾	20	20¼	Head C–in	18¼	18¼	18½	19	19¼	19½	19¾
30	**87.0**	**88.2**	**90.1**	**92.3**	**94.6**	**97.0**	**98.7**	**Length–cm**	**86.0**	**87.0**	**88.9**	**91.3**	**93.7**	**95.6**	**96.9**
	34¼	34¾	35½	36¼	37¼	38¼	38¾	Length–in	33¾	34¼	35	36	37	37¾	38¼
	11.44	**11.80**	**12.63**	**13.67**	**14.51**	**15.47**	**15.97**	**Weight–kg**	**10.78**	**11.21**	**12.11**	**12.93**	**13.93**	**14.81**	**15.35**
	25¼	26	27¾	30¼	32	34	35¼	Weight–lb	23¾	24¾	26¾	28½	30¾	32¾	33¾
	48.0	**48.4**	**49.1**	**49.9**	**51.0**	**51.7**	**52.2**	**Head C–cm**	**47.0**	**47.3**	**48.0**	**48.8**	**49.4**	**50.3**	**50.8**
	19	19	19¼	19¾	20	20¼	20½	Head C–in	18½	18½	19	19¼	19½	19¾	20
36	**91.2**	**92.4**	**94.2**	**96.5**	**98.9**	**101.4**	**103.1**	**Length–cm**	**90.0**	**91.0**	**93.1**	**95.6**	**98.1**	**100.0**	**101.5**
	36	36½	37	38	39	40	40½	Length–in	35½	35¾	36¾	37¾	38½	39¼	40
	12.26	**12.69**	**13.58**	**14.69**	**15.59**	**16.66**	**17.28**	**Weight–kg**	**11.60**	**12.07**	**12.99**	**13.93**	**15.03**	**15.97**	**16.54**
	27	28	30	32½	34¼	36¾	38	Weight–lb	25½	26½	28¾	30¾	33¼	35¼	36½
	48.6	**49.0**	**49.7**	**50.5**	**51.5**	**52.3**	**52.8**	**Head C–cm**	**47.6**	**47.9**	**48.5**	**49.3**	**50.0**	**50.8**	**51.4**
	19¼	19¼	19½	20	20¼	20½	20¾	Head C–in	18¾	18¾	19	19½	19¾	20	20¼

APPENDIX D

Percentiles for upper arm circumference (mm) and triceps skin fold (mm) for white preschool children from the Ten-State Nutrition Survey of 1968-1970 (9)

Age group, years	Males 5th	Males 15th	Males 50th	Males 85th	Males 95th	Females 5th	Females 15th	Females 50th	Females 85th	Females 95th
				Arm circumferenec percentiles (mm)						
0.0-0.4	113	120	134	147	153	107	118	127	145	150
0.5-1.4	128	137	152	168	175	125	134	146	162	170
1.5-2.4	141	147	157	170	180	136	143	155	171	180
2.5-3.4	144	150	161	175	182	137	145	157	169	176
3.5-4.4	143	150	165	180	190	145	150	162	176	184
4.5-5.4	146	155	169	185	199	149	155	169	185	195
5.5-6.4	151	159	172	188	198	148	158	170	187	202
				Triceps skinfold percentiles (mm)						
0.0-0.4	4	5	8	12	15	4	5	8	12	13
0.5-1.4	5	7	9	13	15	6	7	9	12	15
1.5-2.4	5	7	10	13	14	6	7	10	13	15
2.5-3.4	6	7	9	12	14	6	7	10	12	14
3.5-4.4	5	6	9	12	14	5	7	10	12	14
4.5-5.4	5	6	8	12	16	6	7	10	13	16
5.5-6.4	5	6	8	11	15	6	7	10	12	15

APPENDIX E

Percentiles for upper arm muscle diameter, arm muscle circumference, and arm muscle area of whites derived from the Ten-State Nutrition Survey of 1968-1970 (9)

Age midpoint	Arm muscle diameter, mm					Arm muscle circumference, mm					Arm muscle area, mm				
year	5th	15th	50th	85th	95th	5th	15th	50th	85th	95th	5th	15th	50th	85th	95th
								Males							
1	32	34	39	44	46	100	108	123	137	146	791	928	1201	1500	1690
2	35	37	40	44	46	111	117	127	138	146	978	1082	1284	1525	1686
3	36	38	42	46	48	114	121	132	145	152	1027	1163	1384	1670	1842
4	38	39	43	48	50	118	124	135	151	157	1106	1224	1451	1805	1973
5	39	41	45	50	53	121	130	141	156	166	1171	1342	1579	1930	2193
6	40	43	47	51	53	127	134	146	159	167	1275	1435	1700	2019	2220
								Females							
1	31	32	37	41	43	97	102	117	128	135	756	821	1084	1304	1460
2	34	36	40	44	46	105	112	125	140	146	885	991	1241	1551	1693
3	34	37	41	44	46	108	116	128	138	143	928	1068	1298	1516	1628
4	36	38	42	46	48	114	120	132	146	152	1040	1143	1390	1693	1828
5	38	40	44	48	51	119	124	138	151	160	1119	1227	1516	1825	2045
6	38	41	45	49	53	121	129	140	155	165	1163	1333	1563	1902	2174

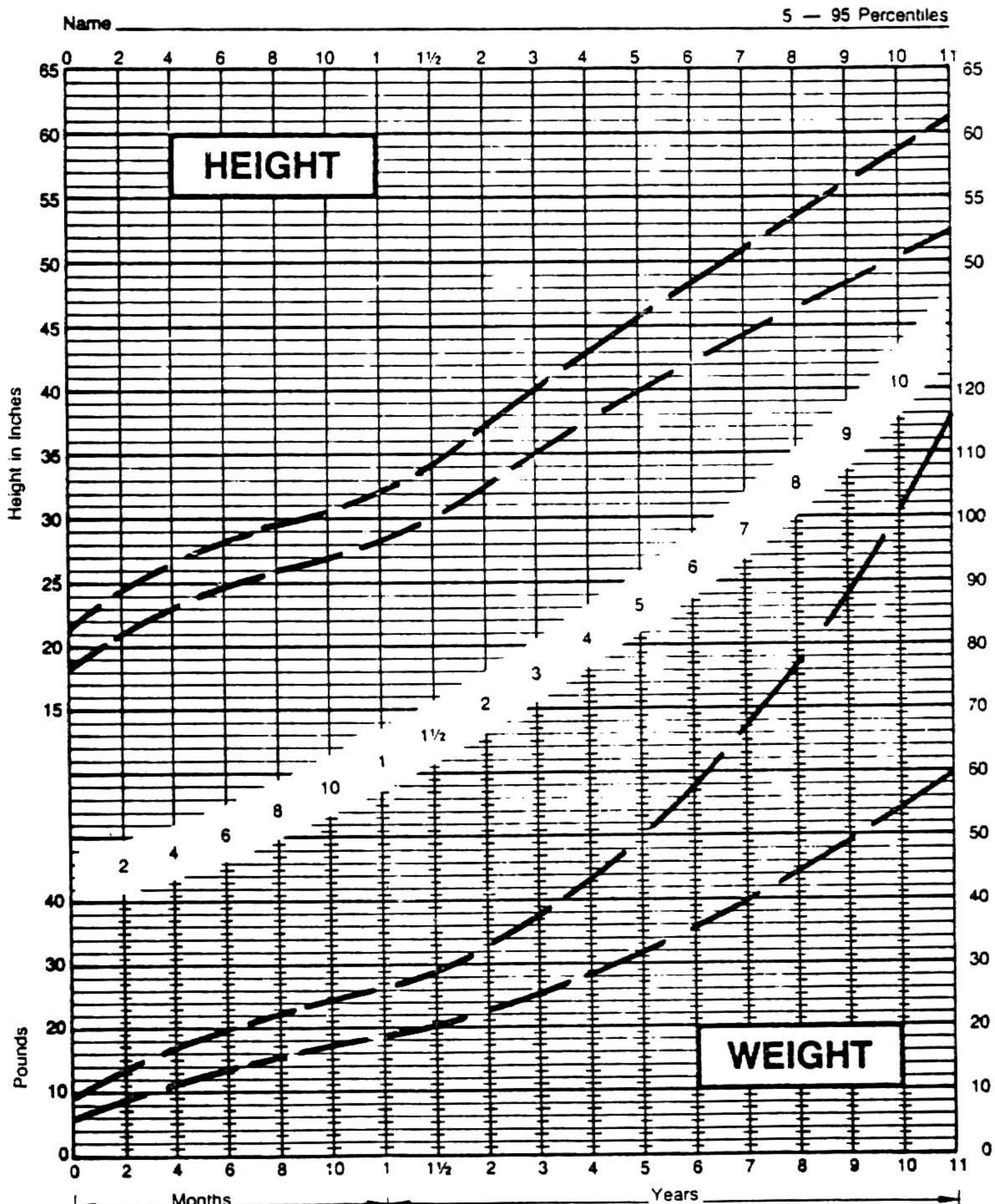
APPENDIX F

Percentiles for maximum thigh circumference,
0-60 month old children, from the
Boston and New Haven area (72)

Age months	3rd	10th	25th	50th	75th	90th	97th
0	157	167	178	190	203	211	223
3	181	194	208	223	237	249	265
6	201	216	232	248	264	277	295
9	218	230	245	260	284	298	317
12	231	243	256	275	296	313	340
18	242	250	264	280	298	313	327
24	243	253	265	281	300	314	328
30	248	260	276	293	309	325	340
36	256	270	286.5	304	323	337	350
42	266	280	296	314	334	348	360
48	275	288	303.5	322	343	360	372
54	280	293	311	328	352	370	382
60	285	299	316	336	360	378	392

APPENDIX G

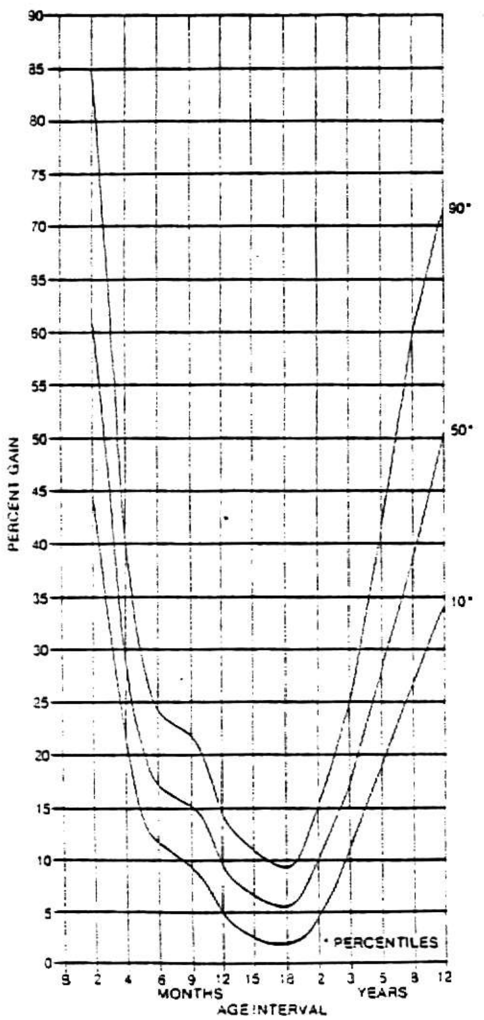
Continuous boy-girl growth chart, 0-11 year (48)



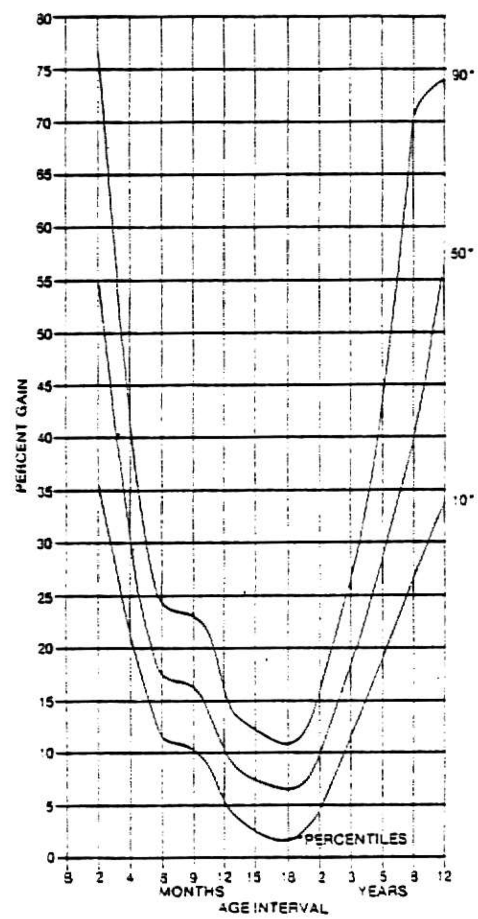
APPENDIX H

Curves of percentiles for weight velocity in boys and girls, birth-12 years, expressed as percent gain for each age interval (63)

Weight velocity in boys



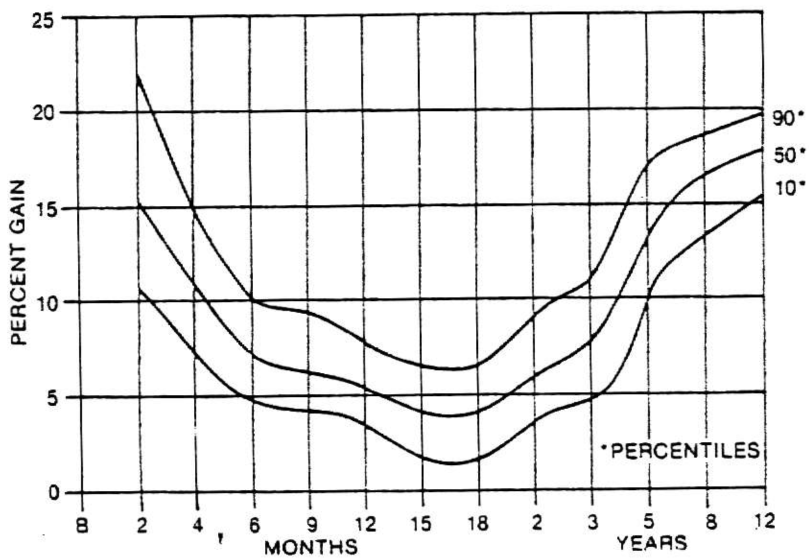
Weight velocity in girls



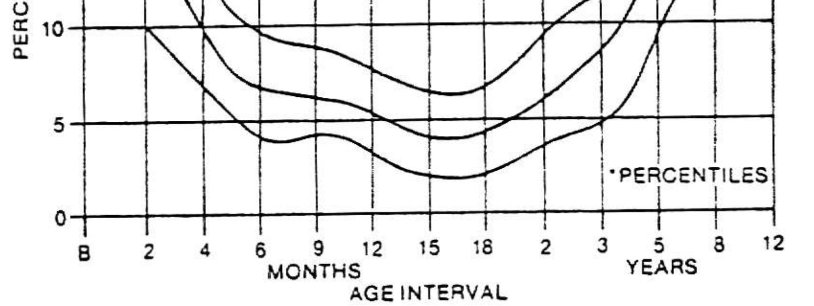
APPENDIX I

Curves of percentiles for height velocity in boys and girls, birth-12 years, expressed as percent gain for each age interval (63)

Height velocity in boys

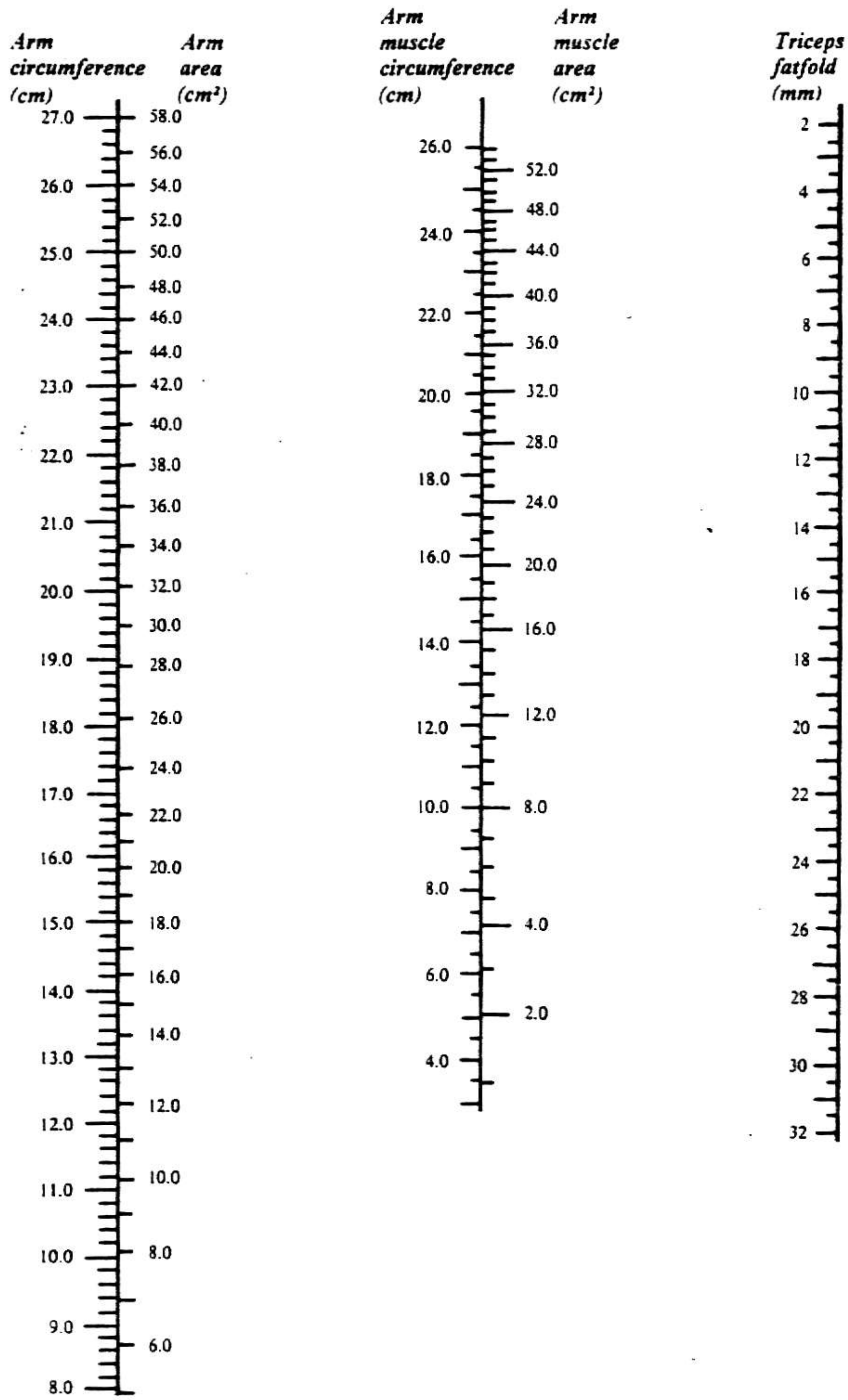


Height velocity in girls



APPENDIX J

Nomogram for rapid calculation of muscle circumference
and cross-sectional muscle and fat areas:
Nomogram for children (102)



To obtain muscle circumference:

1. Lay ruler between values of arm circumference and fatfold.
2. Read off muscle circumference on middle line.

To obtain tissue areas:

1. The arm areas and muscle areas are alongside their respective circumferences.
2. Fat area = arm area – muscle area.

ANTHROPOMETRY IN THE NUTRITIONAL ASSESSMENT OF PRESCHOOL CHILDREN

by

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B. S., Marymount College of Kansas, 1963

AN ABSTRACT OF A MASTER'S REPORT

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requirements for the degree

MASTER OF SCIENCE

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Normal healthy children have a genetically determined physical growth pattern that is affected by environmental factors, including nutrition. The second year, in particular, is a period of rapid growth with high nutritional needs for swiftly increasing muscle mass. The purpose of this report was to review the literature regarding the use of anthropometric measurements to assess the nutritional status of preschool children.

Standards developed for nourished children in western countries generally were considered to be relevant to children of most ethnic groups. Height-for-age reflects chronic nutriture. Weight-for-height is an indicator of current nutritional status. The various ratios of height and weight failed to distinguish between changes in adipose tissue and lean body mass of children. Weight gain may not be a wise index of satisfactory growth, because the child may be adding excessive fat tissues. Calorie intake can alter skin fold thickness measurements with age. Authors generally disagreed whether arm circumference was an adequate predictor of nutritional status. The loss of muscle mass may be masked by subcutaneous fat in children with high calorie intakes; therefore, it is important to calculate a muscle diameter, muscle circumference, or muscle area. Since arm circumference correlates well with thigh circumference, the use of thigh circumference as a simple index of nutriture should be explored. The constancy of both arm and thigh circumferences throughout the 1-5 year age period makes them age-independent indexes. Anthropometry is recommended to aid the identification of children at nutritional risk and to monitor their nutritional status.