nchs

Executive Summary of Workshop to Consider Secular Trends and Possible Pooling of Data in Relation to the Revision of the NCHS Growth Charts

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Center for Health Statistics

CDC
CENTERS FOR DISEASE CONTROL AND PREVENTION

EXECUTIVE SUMMARY
OF
WORKSHOP TO CONSIDER SECULAR TRENDS AND POSSIBLE POOLING OF DATA IN RELATION TO THE REVISION OF THE NCHS GROWTH CHARTS

Sponsored by the Division of Health Examination Statistics,

National Center for Health Statistics

Hyattsville, Maryland

November 1995

Prepared under Professional Services Contract (Order #0009530411)

Alex F Roche

Preface

The National Center for Health Statistics, Centers for Disease Control and Prevention (NCHS/CDC) has a key role in nutrition monitoring through conducting national surveys of the nutritional and health status of the U S population As part of the Federal Government's 10-Year Comprehensive Plan for the National Nutrition Monitoring and Related Research Program, NCHS/CDC also has lead responsibility to develop a core set of standardized nutritional status indicators and appropriate interpretive criteria for the general population and for subgroups of the population The assessment and interpretation of weight, recumbent length, stature and head circumference are critical components of this core nutritional status package for infants, children, and adolescents The third National Health and Nutrition Examination Survey (NHANES III) was specifically designed to oversample infants and children ages 2 months–5 years to provide data that would be used to revise the 1977 NCHS Growth Charts

Introduction

At a workshop convened by the Division of Health Examination Statistics, NCHS in December 1992, a set of near-unanimous recommendations was made concerning the proposed revision of the 1977 NCHS Growth Charts At that first workshop, there was considerable discussion concerning the possible exclusion of data for low birthweight (LBW) infants during the revision of the charts for the age range birth–3 years Because divergent views had been expressed, a special workshop to address this issue was organized and sponsored by the Division of Health Examination Statistics, NCHS This "Low Birthweight Workshop" was held at NCHS and in College Park, Maryland, in October 1994 The participants at the second workshop were experts selected because of their knowledge of infant growth, particularly the growth of LBW infants They discussed conceptual and logistical aspects of the possible exclusion of data for LBW infants from the revised charts and the implications of this exclusion for clinicians, those who work in assistance programs, and research workers The recommendation to exclude data from LBW infants when revising the growth charts was made at that time

Analyses made at NCHS have shown considerable secular increases for children and adolescents in weight and body mass index (BMI) between earlier NCHS surveys and NHANES III (1988–94) This led to a third workshop to consider secular trends and the pooling of data from NCHS surveys This workshop was held in November 1995, at NCHS and in College Park, Maryland The participants and guests at this workshop are listed in appendix A After the advantages and disadvantages had been discussed fully, a recommendation to pool data from all NCHS surveys was made

Pooling data from different NCHS surveys is feasible and it is desirable because the estimates of percentile levels will have smaller tolerance limits The method of pooling was discussed It was tentatively concluded that the pooling process should use the original observed data adjusted by their sample weights This would result in equal weighting by survey

It should be noted that the estimated percentiles for weight and BMI from the pooled data will not match the current distributions of these measures in the U S population The percentile estimates from the pooled data will be somewhat lower, particularly for upper percentile levels in older children These lower levels could be advantageous in clinical practice and in public health medicine The pooled data set will be large enough to allow estimates of the 3d and 97th percentiles with acceptable tolerance limits It was recommended that these percentiles be added to the revised charts unless the 3d and 5th percentiles are sufficiently close together so that a choice should be made between them

There was general consensus that plans for the revision of the 1977 NCHS Growth Charts had been discussed fully at the three workshops and that recommendations had been made for which there was wide agreement It is now time for NCHS to make final decisions and act to achieve the revisions that are needed

Contents

Glossary

BMI	=	Body mass index (weight/stature^2, kg/m^2)
CDC	=	Centers for Disease Control and Prevention
EPSDT	=	Early and Periodic Screening, Diagnosis, and Treatment Program
IHDP	=	Infant Health and Development Program
LBW	=	low birthweight (less than 2,500 grams)
NCHS	=	National Center for Health Statistics
NCYFS	=	National Children and Youth Fitness Survey
NHANES I, II, and III	=	the first, second, and third National Health and Nutrition Examination Surveys (1971–74, 1976–80, and 1988–94, respectively)
NHES II	=	National Health Examination Survey Cycle II (6–11 years, 1963–65)
NHES III	=	National Health Examination Survey Cycle III (12–17 years), 1966–70)
NHLBI	=	National Heart, Lung, and Blood Institute
Ped NSS	=	CDC Pediatric Nutrition Surveillance System
RMSE	=	root mean square errors
SMI	=	sexual maturity index
WIC	=	Special Supplemental Nutritional Program for Women, Infants, and Children

Highlights Recommendations from the secular trend/pooling workshop

Because participants in the Secular Trend/Pooling Workshop had access to the executive summaries from the previous two workshops that related to the revision of the 1977 NCHS Growth Charts (December 1992, October, 1994), and because many of those present had participated in the earlier workshops, some topics other than secular trends and pooling were discussed As a result of these discussions, and those directly relevant to secular trends and to the pooling of data bases, the following was recommended

- The revised charts should, as far as possible, be based on data from national U S surveys and the National Vital Statistics System, including the national distributions of birthweights for 1968–80 and for 1985–94 These periods cover the distributions of birth dates in NHANES I, II, and III
- Natality data from the National Vital Statistics System, NCHS for 1968–80 and for 1985–94 be used to obtain percentiles for weight at birth Nevertheless, if these distributions are closely similar to those from NHANES I, II, and III, the latter could be used so that the data base will be more consistent across ages
- The revision of the 1977 NCHS Growth Charts should be based on pooled data from National Health Examination Survey, Cycle II (NHES II), National Health Examination Survey, Cycle III (NHES III), and the first, second, and third National Health and Nutrition Examination Surveys (NHANES I, NHANES II, and NHANES III)
- This pooling be based, at least tentatively, on the original sample weights for individuals without differential weighting by survey
- Ages at NCHS examinations be used instead of ages at interviews
- Data from the Iowa studies (Fomon, 1993) be used at ages from birth to 3 months when there is a lack of NCHS data, and data from the Iowa studies and the Fels Longitudinal Study (Guo et al , 1991, Roche, 1992) be used at ages from 3 to 6 months with gradual merging of these data sets to NCHS data
- Data from LBW infants (birthweight less than or equal to 2,500 grams) be excluded during the development of the charts for ages birth–3 years, but that data for infants with large birthweights (greater than 4,500 grams) be included
- The variables in the 1977 NCHS Growth Charts be retained except that BMI should replace weight-for-stature in the charts for ages 2–18 years
- z scores should not be included but the 3d and 97th percentiles should be added to the charts If, however, these added percentiles are very close to the 5th and 95th percentiles, respectively, the 5th and/or the 95th percentile levels should be omitted
- Locally weighted regression be used to smooth the percentile estimates across age
- Percentiles for ages at which particular stages of secondary sex characteristics occur and percentiles for ages at menarche be added to the charts with factors to adjust observed statures for unusual rates of sexual maturation
- The reference percentiles for stature should not be modified in an attempt to mimic the expected growth of slowly and rapidly maturing children
- Racial-ethnic-specific charts should not be developed but tabular data for racial-ethnic groups should be made available
- Detailed guidelines should be made available when the revised charts are distributed

There was no dissent from these recommendations, many of which had been made in the previous workshops

The use of the terms "reference data" and "standards" was discussed All agreed that the revised growth charts, like the 1977 NCHS Growth Charts, will be reference data and not standards, but some will interpret them as standards It is hoped that the guidelines accompanying the revised charts will help clarify this issue The best approach may be to emphasize that the revised growth charts present reference data and discuss the use of the charts without reference to the term "standards "

The need to revise the 1977 NCHS Growth Charts

The previous NCHS growth charts were developed between 1974 and 1976 (Hamill et al , 1977, 1979) Because these charts have been modified, the original NCHS growth charts will be referred to as the 1977 NCHS Growth Charts The data used to construct these charts were from NHES II, for subjects aged 6–11 years during1963–65, NHES III, for subjects ages 12–17 years during 1966–70, NHANES I, for subjects aged 1–17 years during 1971–74, and the Fels Longitudinal Study, for subjects aged birth–3 years during 1929–75 Stature data were available from ages 1 to 3 years from NHANES I, but they were not used in the development of the growth charts because of methodological concerns

Although there has been general agreement that the 1977 NCHS Growth Charts were better than those previously available, some deficiencies in them are apparent These deficiencies include the following

- The Fels data are not from a nationally representative sample, and they were collected during a span of 36 years
- The birthweight percentile values from the Fels data displayed in the charts are smaller than those for the current national distributions of birthweights with a difference of about 125 grams at the median level
- Most of the infants in the Fels sample were formula fed
- There is a disjunction between the percentile lines from Fels data for length and weight-for-length on the infant charts (for ages birth–3 years) and the corresponding percentile lines from NCHS data on the charts for older children (aged 2–18 years)
- There was probably a systematic error in the measurement of recumbent length at the Fels Research Institute until 1970
- The sample sizes were small especially at birth and during infancy
- The 3d and 97th percentiles were not included
- The percentiles may have been over-smoothed across age
- Weight-for-stature percentiles were not presented for statures commonly observed during pubescence
- The percentile levels in these charts may not reflect the present growth status of the U S population
- Indices of maturity were not taken into account

Some revisions were made to the 1977 NCHS Growth Charts by the National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention, Division of Nutrition These revisions, which were restricted to the age range from birth to 10 years, included the following

- Matching the birthweights in the growth charts to the national distributions of birthweights
- Normalizing the upper and lower halves of the distributions at each age Including data from NHANES II (for ages 1–17 years)
- Using smoothing procedures that differed from those used to develop the 1977 charts Matching curves fitted to serial percentile estimates with the growth patterns of individual infants
- Smoothing the transition between the percentile lines for infancy (ages birth–3 years) and childhood (ages 2–18 years) (Dibley et al , 1987a, b, Roche et al , 1989)

Progress made in revising the 1977 NCHS Growth Charts

The most important progress to date is to make data available from NHANES II and NHANES III These data will considerably enhance the analytic sample size

Methods to smooth estimated percentile estimates across age have been compared and the method of "locally weighted regression" has been recommended for this purpose (Guo, 1995a) Analyses have been made of the effects of varying sample sizes on the tolerance limits of estimated percentile levels and of the changes in the categorization of children aged 2 to 3 years depending on whether weight-for-length or BMI is used as an index of weight adjusted for stature (Guo, 1995b)

Funds have been provided by the National Institute of Child Health and Human Development to retrieve birth certificates for subjects aged 2 months–6 years in NHANES III These data, which are relevant to the identification of subjects with low birthweights (less than 2,500 grams, LBW), have been obtained and will be linked to the NHANES III data base Other work has related to the analysis of secular trends using data from NCHS surveys (Ogden, personal communication, Troiano et al , 1995) In overview, these have shown an absence of trends in recumbent length and stature but increases in weight and body mass index (BMI, kg/m^2) from NHANES II to NHANES III, but not from NHES II or NHES III to NHANES I and NHANES II These secular increases are similar to those that have occurred in adults (Kuczmarski et al , 1994) Other incomplete work includes the writing of interpretive guidelines

The revision plans for the growth charts as well as a progress report detailing the implementation of these plans have been described at scientific meetings (Annual Meeting, American Statistical Association, 1989, Experimental Biology, 1993) and have been presented to the Food and Nutrition Board of the National Academy of Sciences and to the Obesity Working Group, Department of Maternal and Child Health, Harvard University

Secular changes in growth The evidence from NCHS survey data

By strict definition, secular changes are increases in measures over periods of a decade or more that occur in a "closed system " The term "closed system" applies to a population not changed by migration The U S population has changed by migration, particularly immigration and, therefore, any observed changes among NCHS surveys represent effects of migration and true secular changes The latter are changes within a fixed population due to environmental alterations, not genetic ones

Natality data from the National Vital Statistics System show that there has not been a secular increase in median birthweights for the U S population from 1970 through 1993 (appendix B) Nevertheless, there has been an increase from 1975 to 1980 in the prevalence of birthweights greater than or equal to 4,000 grams This increase was maintained from 1980 through 1993 The present U S median birthweights are about 125 grams larger than those derived from the Fels Longitudinal Study data, which were incorporated in the 1977 NCHS Growth Charts National U S birthweight percentiles for years of birth that match those of subjects aged younger than 3 years in NHANES I (born during 1968 to 1974), in NHANES II (born during 1973 to 1980), and in NHANES III (born during 1985 to 1994) must be compared with birthweight percentiles from NHANES I, II, and III If the distributions of birthweights from NHANES I, II, and III closely match the corresponding national distributions, the NHANES I, II, and III values should be employed so that a more unified data set will be represented in the revised growth charts

Data from NHES II, NHES III, NHANES I, NHANES II, and NHANES III Phase 1 allow analyses of secular trends in the United States based on nationally representative samples measured from 1963 through 1991 At the time of the workshop, data from NHANES III Phase 2 were not available The sample sizes in each of these data sets, with an estimation for NHANES III Phase 2, are given in appendix C for age- and sex-specific groups Comparisons for infants and children younger than 6 years of age are restricted to NHANES I, NHANES II, and NHANES III Phase 1 because the NHES subjects were aged 6 years or older

Secular trends have been analyzed for ages 1–3 years using data from the Fels Longitudinal Study, as published in Hamill et al (1977), as a baseline The secular changes in length and stature are small, but the prevalence of lengths less than or equal to fifth percentile in girls aged 1 0 to 1 9 years decreased from NHANES I (9 5 percent) to NHANES II (8 0 percent) to NHANES III Phase 1 (3 3 percent)

For children and adolescents aged 6–17 years, the secular trends in stature from NHES II and NHES III to NHANES I, II, and III have been small or nonexistent, except for an increase of approximately 2 2 centimeters at the 85th percentile level for males between NHES and NHANES III The corresponding changes in weight from NHES II and NHES III to NHANES II have also been small, but the changes from NHES II and NHES III to NHANES III have been considerable at the 85th percentile levels for weight These increases were about 3 kilograms for those aged 6–11 years and even larger for those aged 12–17 years (6 5 kilograms for males, 5 4 kilograms for females) These increases were largest in post-pubertal groups (15–17 years of age), indicating that secular changes in the timing of pubescence were not a major determinant of these increases

Secular changes in BMI have been small among those aged 6 to 17 years, except in the upper parts of the distributions The increases from NHES II and NHES III to NHANES III at the 85th percentile level for males were larger at ages 12 to 17 years (2 3 kg/m^2) than at ages 6 to 11 years (1 2 kg/m^2) The increases in the 85th percentile levels for females from NHES II and NHES III to NHANES III were about 1 3 kg/m^2 for the 6–11-year and 12–17-year age groups It has also been reported that about 11 percent of the BMI values for subjects aged 6–17 years in NHANES III exceeded the 95th percentile levels from NHES II and NHES III (Troiano et al , 1995) There has also been a small increase in the percentage of children aged 4–5 years with weights-for-stature greater than 95th percentile of the current NCHS Growth Charts from 5 9 percent in NHANES II to 7 2 percent in NHANES III Phase 1

These findings provide strong support for the following conclusions

- There has not been a secular change in length or stature since NHES II and NHES III
- There have not been secular changes in weight and BMI from NHES II and NHES III to NHANES II
- There have been secular changes in weight and BMI from NHANES II to NHANES III Phase 1 that are more marked at older ages during childhood and more marked at the upper percentile levels

Secular changes in growth in the United States and Canada The evidence from outside NCHS

There have been many growth studies in the United States and Canada during the past 30 years, but most do not allow conclusions regarding secular trends because they were of nonrepresentative samples, many of which were small and incompletely described Relevant information is available, however, from some large-scale multicenter studies and from others that sampled a particular population on several occasions These studies were conducted during the period of data collection in NCHS surveys considered for pooling (1963 to 1994)

Yip et al (1993) reported data from the Early and Periodic Screening, Diagnosis and Treatment Program within the CDC Pediatric Nutrition Surveillance System (PedNSS) using data from Louisiana and Michigan There were regular increases from 1977 to 1990 in the mean z scores for weight, stature, and weight-for-stature of children aged 7–9 years There were also increases in the prevalence of weight-for-stature z scores greater than 2 0 at ages 5–6 years and 7–9 years from 1976 to 1989, but not from 1989 to 1992 In this study, increases were noted in the prevalence of BMI values greater than 20 kg/m^2 , these increases in prevalence were small for children aged 5–6 years, intermediate for those aged 7–8 years, and large for those aged 9 years and 14–15 years This positive association between age during childhood and secular increases in the prevalence of large values for BMI is in agreement with findings from comparisons among NCHS surveys

Analyses of PedNSS data were reported by Yip et al (1993) From 1980 to 1989, the mean z scores for stature in low-income white, black, and Hispanic-American infants and children (aged 6 months–10 years) did not alter relative to the data of Hamill et al (1977), as modified by Dibley et al (1987a, b) There were, however, considerable increases in the z scores for stature in Asian-American children These findings for Asian-American children are interesting but not of major importance in relation to possible pooling of NCHS survey data because Asian-American children are a small percentage of the total population In the data analyzed by Yip and colleagues, the means of weight-for-stature (length) did not show a secular trend, but there were slight increases from 1984 to 1989 in the prevalences of overweight (weight-for-stature greater than +2 0 z score) in black and Hispanic-American children but not in white or Asian-American children

Repeated surveys from 1972 to 1983 of Mexican-American children who were born in Texas and attended school in Brownsville, Texas, show increases in the mean statures of boys and girls aged 8–14 years (Malina, 1993, Malina et al , 1986a, b, and Malina, 1987) These increases average about 5 centimeters for boys but only 2 centimeters for girls Comparisons between the 1972 and 1983 surveys also show marked secular increases in mean weights at all ages from 8 to 17 years except at 16 years in males These increases average about 5 kilograms in males and 4 kilograms in females In these Brownsville groups, the means for BMI increased from 1972 to 1983 by about 1 2 kg/m^2 in each sex from ages 7 to 14 years, but the increases are smaller for ages older than 14 years

Owen et al (1974) reported data from a national U S sample of 3,441 children aged 1–5 years who were measured from 1968 to 1970 The percentiles for length, stature, and weight were similar to those in the 1977 NCHS Growth Charts Comparing these data with NHANES III Phase 1 findings is difficult because of variations between these studies in age groupings Nevertheless, it appears there have not been increases from this study to NHANES III Phase 1 in length or stature, but there have been increases in the 90th percentiles for weight that are larger for females than for males

The National Children and Youth Fitness Survey (NCYFS) was conducted in 1984 and 1986 (Part I, for subjects aged 10–18 years, Part II, for subjects aged 6–9 years) (Ross & Gilbert, 1985, Ross & Pate, 1987) The samples included 4,435 children aged 6–9 years and 4,678 children aged 10–18 years In this nationally representative multicenter study of U S children, the sampling strategy differed from that of the NCHS surveys The mean statures from NCYFS closely match the medians from NHES II, NHES III, NHANES I, NHANES II, and NHANES III Phase 1 except that the NCYFS estimates are slightly higher for ages 8–11 years These comparisons indicate a lack of secular trends in stature in the United States from 1971 through 1991 In each sex the mean weights from NCYFS tend to be about 2 kilograms larger than the medians from NHES II, NHES III, NHANES I, and NHANES II for ages 6–17 years and about 1 kilogram larger than the medians from NHANES III Phase 1 The NCYFS means for BMI are larger than the medians from NHANES II in each sex, the average difference is about 0 4 kg/m^2 Some of the differences observed when weight and BMI are compared among NCYFS and NCHS surveys result from comparing means and medians For corresponding estimates from NHANES I and II combined, the mean weights exceed the medians by about 2 kilograms and the BMI means exceed the corresponding medians by about 1 0 kg/m^2 The children and youth in NCYFS were weighed in gym clothes The values from NCHS surveys do not include clothing weight This methodological variation would account for only a small part of the observed difference

The National Growth and Health Study of the National Heart, Lung, and Blood Institute is a serial investigation of females during pubescence being conducted in Richmond, California, Cincinnati, Ohio, and the Washington, D C metropolitan area Campaigne et al (1994) reported data from this study that were recorded in 1986 for 613 subjects aged 9 years and 546 subjects aged 10 years The mean statures and weights for these groups were larger than the corresponding means for NHANES I and NHANES II combined (Frisancho, 1990) The differences in stature were about 1 8 centimeters for white subjects at ages 9 and 10 years, and for black subjects, the differences in stature were 2 3 centimeters at age 9 years and 1 7 centimeters at age 10 years The corresponding differences in weight for white subjects were 0 9 and 1 6 kilograms at ages 9 and 10 years, respectively, and 4 7 and 4 1 kilograms for black subjects at ages 9 and 10 years, respectively These findings suggest there have been secular increases for white and black Americans in stature and weight from 1971 to 1986, but the differences that were found may have been due to sampling bias or differences in measurement techniques

In the Bogalusa Heart Study, conducted in Louisiana, 8,927 males and 6,427 females aged 6 months–17 years were measured cross-sectionally in 1973 (Berenson, 1986) Subsequently, six consecutive cross-sectional samples from the same population were measured between 1973 and 1988 (Webber et al , 1994) The age-adjusted mean statures do not show secular increases, but the age-adjusted mean weights increased from 1984 to 1988 for black males and females but not for white males and females The percentage increases in weight were larger from ages 11 to 14 years than for other ages, and they were larger in the highest quartile There were also increases from 1984 to 1988 in the means for weight/stature^3 for all sex- and ethnic-specific groups, but the increase was small for black females

Some important studies of Canadian children are relevant to judgments of secular trends Nutrition Canada, which was conducted from 1970 to 1972, included 2,684 males and 2,584 females aged from birth to 17 years (Demirjian, 1980) This was a national probability sample, and sample weights were applied to the observed data to obtain national estimates The Canada Fitness Survey (1983), which was conducted in 1981, included 2,296 males and 1,774 females aged 7–17 years Comparisons between these surveys show secular increases for 1970–72 to 1981 in the mean statures of boys older than 9 years of age and of girls older than 7 years of age The average increase was about 2 centimeters except after age 13 years in females when the increase was about 3 centimeters There were also increases in mean weights at almost all ages in males that average about 1 5 kilograms except from 14–15 years of age when the increase was about 5 kilograms The mean weights for females differed little between the surveys except for those aged 14–17 years for whom there was an increase of about 3 kilograms

Data from two mixed longitudinal samples in Saskatoon, Canada (1965–73 and 1991–94) provide information about secular trends during a 23-year time interval (personal communication by Donald A Bailey to Robert M Malina) In each of these samples, there were about 60 to 80 subjects of each sex per annual age group Comparisons between these samples show increases of about 5 centimeters in mean statures at ages 8–17 years in each sex There were also increases in mean weights that became larger with age up to 17 years, 2–6 kilograms for males and 5–8 kilograms for females Despite these large secular increases, the mean statures and weights for the 1991–94 Saskatoon sample were smaller than the corresponding medians from NHANES III Phase 1

In summary, the evidence from NCHS surveys and from other U S studies supports the fact that there has been little or no secular trend in stature from the time of the data collection in NHES II and NHES III (from 1963 to 1970) to that in NHANES III Phase 1 (from 1988 to 1991) Also, there is no evidence of an increase in weight or BMI between the time of NHES II and NHES III data collection and that of NHANES II (from 1976 to 1980), but there have been increases from NHANES II to NHANES III Phase 1 (from 1988 to 1991) that are larger at upper percentile levels and appear out at older ages in the age range 1–17 years Canadian studies show similar secular increases in weight to those found in NCHS surveys, but they also show secular increases in stature

<u>The statistical effects of increasing the sample sizes for revision of the 1977 NCHS Growth Charts</u>

Pooling data from the various NCHS surveys (NHES II, NHES III, NHANES I, NHANES II, and NHANES III) will provide considerably larger data sets than those used to construct the 1977 NCHS Growth Charts for ages 2–18 years because NHANES II and NHANES III data were not used previously Pooling between NCHS surveys must, to some extent, be age dependent The youngest subjects in NHES II were aged 6 years, but the youngest subjects in NHANES I, NHANES II, and NHANES III were aged 12, 6, and 3 months, respectively If data from all these NCHS surveys were combined, the sample sizes, in comparison with those used in the 1977 NCHS Growth Charts, would be multiplied by about 4 for 3–5 years and by about 2 for 6–17 years (appendix C) This would result in samples ranging from 912 to 1,266 within each sex for each annual interval for ages 2–17 years

The use of data from the Iowa Studies and the Fels Longitudinal Study in combination with data from NHANES I, NHANES II, and NHANES III for the age range birth–3 years will increase the sample sizes available to revise the growth charts for infants and younger children by a factor of 3 to 4 The Iowa Studies and the Fels Longitudinal Study are described in appendix D

The tolerance limits of the estimated percentile values will be reduced due to these larger sample sizes Decreases in tolerance limits, which indicate increases in precision, are particularly important for outlying percentiles (3d, 5th, 95th, and 97th), because these percentiles are commonly used in clinical decision making and in population studies

The effects of variations in sample size on the tolerance limits of estimated percentile values have been demonstrated using data from NHANES III Phase 1 (Guo, 1995b) Within age- and sex-groups, means and standard deviations (SD's) were calculated for weight, stature, and BMI The normality of the distributions was tested and, as necessary, the distributions were normalized using Box-Cox transformations (1964) Means and SD's were calculated for the transformed distributions and used to generate samples of 1,000 using a random number generator These samples were transformed to their original scales after which random samples were chosen from them that ranged in size from 120 to 500 The nonparametric method of Wilks (1941) was used to determine the upper and lower 90-percent tolerance limits for the 3d and 97th percentiles of weight, stature, and BMI at ages 3, 8, 13, and 18 years in each sex The 90-percent tolerance limits are the upper and lower boundaries between which 90 percent of the estimates for the chosen percentile level will fall

At all ages these tolerance limits were small for the 3d percentiles of weight and BMI even when the sample size was only 120, but the tolerance limits for stature at the 3d-percentile level increased as samples smaller than 200 were considered The tolerance limits were considerably larger for the 97th percentiles than for the 3d percentiles, and there were large increases in these limits when sample sizes smaller than 350 were considered There were also irregular changes in the estimated percentile values when estimates from samples varying in size from 120 to 350 were compared These findings led to the conclusion that sample sizes of about 500 were needed Because the percentile estimates should be made at intervals of 6 months or less, it was recommended that data be pooled among NHES II, NHES III, NHANES I, NHANES II, and NHANES III The sample sizes that would result are given in appendix C

The inclusion of the 3d and 5th percentiles in the revised growth charts would be problematic if these percentiles were very close Similar considerations relate to the 95th and 97th percentiles Preliminary analyses of data from NHANES III Phase 1 using the sample weights have provided unsmoothed estimates of the 3d, 5th, 95th, and 97th percentiles that are included in appendix E These findings indicate that there will be sufficient separation to include these pairs of outlying percentiles except for the 3d and 5th percentiles for stature at ages younger than 6 years in males and the 3d and 5th percentiles for weight in each sex at ages younger than 8 years If these preliminary analyses are replicated in the total pooled data set after smoothing, it may be appropriate to include the 3d, 95th, and 97th percentiles at all ages but omit the 5th percentiles

Consideration was given to a suggestion by Cole (1994) that the percentile lines on growth charts be equally spaced He proposed a separation of 0 67 z scores to obtain percentiles at the 0 4, 2, 9, 25, 50, 75, 91, 98, and 99 6 levels using the properties of normal distributions after normalizing the actual distributions The implementation of this suggestion was not recommended mainly because it involves normalizing the data and some of the percentile lines would be very close together, particularly at young ages

<u>The potential for misclassification if the percentile curves for weight and BMI are shifted</u>

There will be shifts in the percentiles for birthweight when either national U S data or pooled data from NHANES I, II, and III replace the data from the Fels Longitudinal Study that were used in the 1977 NCHS Growth Charts These shifts in birthweights will eliminate the tendency to overestimate the percentile levels assigned to individuals and groups when reference percentiles from Fels data are used

The accurate identification of overweight children is important because weight and BMI tend to track from childhood to adulthood, although there is little tracking from infancy to adulthood (Cronk et al , 1982, Guo et al , 1994, Kouchi et al , 1985, Rolland-Cachera et al , 1987, Siervogel et al , 1991) This tracking is of practical importance because large values for weight and BMI in adulthood are associated with increased risks for some common and serious diseases (for example, diabetes mellitus)

It is likely that the upper percentiles for BMI in the revised growth charts will be used to classify individuals as overweight for purposes associated with prevention, diagnosis, and management (Himes & Dietz, 1994) Therefore, the following discussion of misclassification applies mainly to overweight in children, although similar considerations apply to the use of the 3d or 5th percentile levels for weight and BMI to classify individuals or groups as underweight

It has been noted earlier that secular changes are absent or slight between NCHS surveys for length and stature and that they are slight for weight and BMI from NHES II and NHES III to NHANES I and II There have, however, been considerable increases in weight and in BMI from the earlier NCHS surveys to NHANES III, particularly at the upper percentiles and at older ages within the age range 2–17 years Therefore pooling data from different NCHS surveys including NHANES III will lead to smaller values for the upper percentiles of weight and BMI than those that would be estimated from NHANES III only

The inclusion of percentiles for weight and BMI in the revised NCHS/CDC Growth Charts that are slightly lower than those that would be derived from NHANES III data alone would be desirable from the public health and clinical viewpoints If NHANES III data were used alone, fewer children would be identified as overweight (less than 95th percentile for weight or BMI) Because the percentile levels on growth charts are commonly interpreted as indicators of physiological normality, small increases in the percentile values for weight and BMI are preferable to large increases that would markedly reduce the prevalence of values considered indicative of physiological abnormality Ideally, physiological abnormality should be interpreted less in regard to rank within the population and more in regard to the metric values of weight or BMI associated with present and future health The relationships of weight and BMI to present and future health are modified by many factors and, consequently, metric cut-off levels are not available at present

If present trends continue and if only NHANES III data were used to revise the 1977 NCHS Growth Charts, the percentile levels assigned to individuals and groups in the future would be slightly overestimated because the true population percentile levels would become larger than those in the revised charts Screening using the 95th percentile of BMI from pooled NCHS data as a cut-off value, as an example, would result in a greater increase in the number of false positives relative to true rank within the population because some children with BMI values greater than 95th percentile of the pooled reference data would have BMI values less than 95th percentile for the current U S population The workshop participants considered that this increase in the false positive rate would not cause problems in clinical practice, research, or public health medicine

If data from all NCHS surveys were pooled, sensitivity and the negative predictive value (true negatives/true plus false negatives) for overweight (greater than 95th percentile for weight or BMI) would decreased, while specificity and the positive predictive value (true positives/true plus false positives) would be increased The extent of these changes would be related to the size of the differences between the 95th percentile values in the revised charts and the actual 95th percentile values for the U S population

Statistical aspects of combining data from various NCHS surveys

Combining data from various NCHS surveys is complicated, because these surveys differed in the oversampling of particular age groups and ethnic groups and in the response rates In each survey sample weights were calculated according to the sampling strategy, the response rate, and the number of U S children within specified categories These sample weights were applied to the recorded data to obtain national estimates Also, the total number of children in the United States increased from 1963 to 1994

If data from NHES II, NHES III, and NHANES I, II, and III were combined, it must be decided whether these survey samples should be weighted differentially or equally Differential weighting by survey could take into account the time that has passed since the data were collected and the number of U S children interviewed at the time of each survey The response rates might be considered also, because low response rates tend to cause bias and inflate the variance

The method of pooling will have less effect on the percentiles for length, head circumference, and stature, because the summary statistics for these variables differ little among surveys Large weight, BMI, and, presumably, weight-for-length differences exist between NHANES III Phase 1 and earlier surveys, especially for upper percentile values and during the teenage years

The possible methods to pool NCHS survey data include

- Average the data from the various surveys ignoring the sample weights This method was considered undesirable because national estimates would not be obtained
- Average the national estimates from the various surveys This was considered acceptable in the absence of an intrinsic reason to weight the surveys differentially, but the advantage of the large data sets in NHES from ages 6 to 17 years would be lost
- Weight the surveys for the years in which data were collected giving larger weights to the more recent surveys The NHANES III data base would be predominant if this method were applied This method was considered illogical unless it was based on factors derived from the rates of change in percentile levels with calendar years The application of these rates of change would be complex because they would differ by variable, age, and sex
- Create a new set of sample weights for the pooled data set that would allow estimates for a hypothetical reference population It would be difficult to conceptualize and implement this method mainly because of variations in sampling strategies and in response rates among the surveys
- Retain the original sample weights for individuals and estimate percentile levels using the weighted data for each person in each survey Each weighted data point would be considered an independent observation The sample weights would be truncated to the range from the 10th to the percentile by assigning the 10th or 90th percentile values to sample weights smaller or larger than this range This truncation would reduce the unwanted effects that result when very large sample weights are applied to outlying observed values With this approach the surveys would be weighted equally and the sample weights would reflect the sampling strategy and the response rate for each survey

It was recommended that further consideration be given to the choice of a pooling method, although the use of weighted data for individuals, derived from the original sample weights, appeared appropriate.

Methods for smoothing empirical percentile estimates across age

In the present context, smoothing refers to changes made in empirical percentiles at a series of ages so that the values become regular across age for each percentile level; for example, 75th percentile. Smoothing, which is necessary to make the percentile estimates appropriate for clinical use and research applications, should be based on a mathematical function so that it will be reproducible.

The chosen method must allow the incorporation of the sample weights and be flexible in the sense that the positions of a few points do not determine the whole curve. The curve generated by the mathematical function should fit well to the observed data but not over smooth them. The goodness of fit to the estimated percentile values at a series of ages can be judged by the root mean square errors (RMSE's). The root mean square error is the square root of the mean of the squared residuals where the residuals are the differences between the percentile values calculated for each age and the corresponding values estimated from the mathematical function. The fit should be such that the RMSE is smaller than the tolerance limits and larger than the measurement errors. It is also desirable that the set of smoothed curves be aesthetically pleasing. Consequently, attention should be given also to the regularity of the spaces between adjacent percentile lines.

Guo (1995a) compared kernel regression, the Tukey method (1977), restricted cubic splines, the method of Cole (1993), the method of Healy and associates (1988), and a locally weighted regression method. She concluded that the locally weighted regression method, which is a modification of the method of Healy and Rasbash, was the method of choice.

The locally weighted regression method was applied to NHANES III Phase 1 data within sex to sets of 400 values adjusted for the sample weights. In each step 15 more points at the immediately older ages were included and 15 of the previous points that were youngest in age were excluded. Consequently, the sample size remained 400 but the median age increased slightly. Each percentile was estimated in this way at about 50 ages within each annual age interval by fitting a curvilinear function to each data set after the data points had been weighted inversely to the differences in age at measurement between each point and the age for which the percentile was to be estimated. This number of estimates could be altered by including/excluding more or less than 15 points in each calculation. After these steps estimated percentile values were available for many ages, and, because they were obtained from overlapping samples, they were smoothed considerably. Nevertheless, additional slight smoothing is required to make the percentile curves aesthetically pleasing. A nonparametric function such as kernel regression is recommended for this step.

The addition of maturational data to the revised NCHS/CDC Growth Charts

There may have been secular changes in the rates of maturation of children since the time of data collection in NHES II and NHES III. Acceleration of the rates of maturation during the past 150 years is well documented in developed countries for age at menarche, age at peak height velocity, and age at cessation of growth in stature (Roche, 1979; Roede & van Wieringen, 1985; van Wieringen, 1978; Vercauteren & Susanne, 1985).

It is probable that there have not been substantial changes in the rates of maturation from the time of data collection in NHES II and NHES III to the time of data collection in NHANES III because there has not been any significant trend in stature. Nevertheless, this possibility should be investigated by estimating the distributions of ages at which particular stages of secondary sex characteristics are present and the timing of menarche within surveys and then comparing these estimates between surveys.

Data relating to the timing of menarche are available for all the NCHS surveys except NHANES I. These data were obtained at 6 years of age and older in NHES II and NHES III and beginning at 8 years of age in NHANES II and NHANES III. Data for the presence of stages in the maturation of secondary sex characteristics are available for NHES II, NHES III, and NHANES III. Stages of secondary sex characteristics in these surveys (pubic hair in each sex, penis and scrotum in males, and breast in females) were recorded in NHES III beginning at 11 years of age and in NHANES III beginning at 8 years of age using standardized criteria (Reynolds & Wines, 1948, 1951; Roede & van Wieringen, 1985; Tanner, 1962). These data can be used to estimate, for the separate surveys and for the pooled survey data, the percentages of subjects who have reached particular stages of secondary sex characteristics at 6-month age intervals. These estimates, which should take the sample weights into account, could be used to test the significance of differences in the timing of maturation between surveys for matching age ranges of data collection.

Logistic regression can be applied to these percentages to estimate ages at which particular percentages of the population (5 percent, 10 percent) have reached menarche and each stage of sexual maturity as was done for menarche using NHES II data (MacMahon, 1973). These estimates, derived from all the relevant NCHS data, should be added to the revised NCHS/CDC Growth Charts as bar diagrams of selected percentiles (97th, 90th, 75th, 50th, 25th, 10th, 3d) to assist clinical judgments of the rates of maturation. The style of these proposed bar diagrams is shown in appendix F.

It is recommended that the ordering of percentiles be the same as in Tanner and Davies (1985) to avoid the confusion that might be caused by an inversion of this order. Thus, the 97th percentile for menarche at about 10.85 years of age indicates that 97 percent of the group had not reached menarche at this age. Correspondingly, the 3d percentile at about 14.55 years of age indicates that only 3 percent of the group had not achieved menarche at this age.

As for ages at menarche, the 97th percentile for a particular stage of secondary sex characteristics would be the age at which 97 percent of the group had not reached that stage. In the format used by Tanner and Davies, one has to count the divisions on the bar diagrams for all stages except stage 2 to determine which percentile is shown. The utility of these bars would be increased by repeating the percentile designations for each stage but this would require more space One style in which these bar diagrams could be presented is shown in appendix G

It was recommended that the data for stages of secondary sex characteristics recorded in NHES II and NHANES III be used to calculate adjustments that could be made to the observed statures of children to account for their levels of sexual maturity In some unusual conditions, the rate of development of pubic hair differs markedly from that of the penis and scrotum or from that of the breast This disharmonic maturation reflects the various endocrine controls of the different aspects of sexual maturation (Rosenfeld, 1982) Generally, however, the stages of maturation are closely correlated between these organs (Largo & Prader, 1983a, b, Marshall & Tanner, 1969, 1970, Taranger et al , 1976) Consequently, it is considered acceptable and logistically practicable to sum the numbers of the assigned stages for individuals to obtain sexual maturity indices (SMI) This approach is more practical than the use of adjustments for the stages of maturation of separate secondary sex organs

This approach corresponds to that used by Wilson et al (1987) who analyzed NHES II data (appendices H and I) These authors developed percentiles of stature for NHES II subjects (ages 11–17 years) who had SMI values in the 20th–80th-percentile range, and they calculated adjustments to the observed statures for those who had matured rapidly (greater than 80th percentile of SMI) or slowly (less than 20th percentile of SMI) It would be more appropriate to calculate adjustments to the revised NCHS/CDC Growth Charts derived from all NCHS subjects without selection for the rates of maturation These adjustment factors would be near zero for subjects who are about average in rates of maturation

Using the data of Wilson et al (1987), (appendix H) males with a SMI of 2 0 at 12 years of age are maturing slowly and the median stature of such males is 4 centimeters smaller than that of males the same age who are maturing at an average rate Consequently, the stature of such a male can be adjusted for his rate of maturation by adding 4 centimeters to his observed stature This procedure is useful in clinical practice If the observed stature of a slowly maturing male is less than the 5th percentile, and the adjusted value is more than the 10th percentile, there will be less concern about his present stature and less need for laboratory investigations to exclude the presence of disease Other relevant data have been provided by Coy et al (1986) who reported differences in median statures between mature and immature females at 13, 14, and 15 years of age after classifying females as mature if they had reached menarche and breast development was stage 5 (Tanner, 1962) The deficits in stature for immature females were 4 centimeters at 13 years of age and 4 centimeters at 14 years of age

These adjustment factors would be applied analogously to the adjustments that can be made to observed statures for mid-parent stature that were developed by Himes et al (1981) The basic concept is that the growth of a child should be judged by comparison with the population to which the child belongs It is well known that tall parents tend to have tall children, and the opposite is also true Therefore, the data of Himes and colleagues, which allow the stature of a child to be judged in relation to that of children whose parents have statures similar to those of the parents of the child being assessed, provide greater specificity and sensitivity when growth charts are used to identify statures that indicate the likely presence of disease The estimated adjustments to observed statures for unusual rates of maturation and for parental stature are not based on independent effects Therefore, the adjustment factors for unusual timing of secondary sex characteristics and menarche and for unusual parental statures should not be summed

The inclusion in the revised NCHS/CDC Growth Charts for ages 2–18 years of percentiles for ages at menarche and at which particular stages of sexual maturity are observed, with factors to adjust the observed statures for unusual rates of maturation, would allow clinicians and research workers to record and apply maturational data It was suggested at the workshop that adjustment factors also be provided based on whether females are pre- or post-menarcheal This would require categorizing females aged about 11 0 to 14 0 years into pre- and post-menarcheal groups and then calculating the median differences in stature between these groups within age classes It was considered that these analyses would add little, because the menarcheal data would relate to a narrow age range, and they would be highly correlated with the data for secondary sex characteristics For these reasons and in accord with a recommendation to make the format simple that was made at the 1992 Workshop on the revision of the 1977 NCHS Growth Charts, the participants at the Workshop on Secular Trends and Pooling concluded that possible adjustments to stature based on menarcheal status should not be included in the revised growth charts

Tanner and Davies (1985) modified the 1977 NCHS percentiles for stature for the age range 2–18 years Their aim was to make the percentile curves similar to the patterns of change in individuals and to provide reference data for slowly and rapidly maturing children They fitted the Preece-Baines (1978) model to the unsmoothed serial percentile estimates, although this model does not fit well to serial data (Guo et al , 1992) Tanner and Davies constructed a median curve in this way and estimated other percentiles of stature for children maturing at average rates and percentiles for slowly and rapidly maturing children categorized as being 2 SD's late and 2 SD's early, respectively, in the timing of peak height velocity These estimated curves were derived from adjustments to the median curve using associations reported from European and U S data, most of which were collected in the 1960's or earlier and many of which were derived from small samples Hauspie and Wacholder (1986), however, because they used longitudinal data, were able to avoid making a large number of assumptions when they presented reference data for stature increments in groups that differed in their rates of maturation It is difficult to apply the charts of Tanner and Davies or those of Hauspie and Wacholder because of the uncertain identification of children in whom peak height velocity will be early or late (Sullivan, 1983) Furthermore, this approach is strictly applicable only to children who are delayed or advanced by 2 SD's in the timing of peak height velocity

<u>The possible exclusion of infants based on birthweight</u>

The possible exclusion of data from LBW infants when the NCHS Growth Charts for birth–3 years are revised was the topic of a previous workshop This topic was discussed again at the Workshop on Secular Trends and Pooling, and it was recommended that data from LBW infants be excluded This can be done for NHANES III using birth certificate data and for NHANES I and II using data from maternal reports The literature indicates that maternal reports of birthweight are highly accurate (Roche, 1994) The accuracy of maternal reports in NHANES III should be analyzed, however, using paired birth certificate and maternal recall data

It was suggested that infants of large birthweight (greater than 4,500 grams) be excluded The prevalence of such infants is about 1 5 percent (Ventura & Martin, 1993) Concern was expressed about this possible exclusion because charts suitable for clinical use that could be applied to monitor the growth of these infants are not available Furthermore, there are no known functional outcomes of overweight during infancy or early childhood that would warrant the exclusion of overweight infants Consequently, it was recommended that data for infants with large birthweights not be excluded during the revision of the 1977 NCHS Growth Charts

Dissemination of the revised NCHS/CDC Growth Charts and related materials

Although not directly relevant to the topic of the Secular Trend and Pooling Workshop, the dissemination of the revised growth charts and related materials was discussed It was concluded that this dissemination should be linked to scientific presentations at meetings and in journals The workshop participants considered that electronic dissemination of data was essential The material disseminated should include summary statistics for the pooled NCHS data base (smoothed and unsmoothed) used in the revision of the 1977 NCHS Growth Charts and summary statistics for other anthropometric variables such as circumferences and skinfold thicknesses from NHANES III, with and without the exclusion of data from LBW infants These summary statistics should include z scores and a large selection of percentile values, in tabular and graphic formats, and they should be for the total NHANES III sample and also for major racial-ethnic-specific groups (white, black, and Mexican-American) Software similar to that in Epi/Info (Dean et al , 1994) should be written and made available This revised software would relate to the pooled data set used in the revision of the NCHS/CDC Growth Charts and also to NHANES III data only This software should be applicable to data for individuals and to batch data The guidelines for the use and interpretation of the revised charts should be distributed electronically and in hard copy

The distribution of hard copies of the charts was discussed It is hoped that CDC will provide camera-ready negatives to State departments of health Hard copies may also be distributed by the Special Supplemental Nutrition Program for Women, Infants, and Children, the Maternal and Child Health Bureau, some pharmaceutical companies, and, possibly, commercial groups

Summary

There was a general attitude among the workshop participants that the matters they had discussed and those discussed in previous NCHS workshops relating to the revision of the 1977 NCHS Growth Charts have received full consideration It was believed unlikely that further information will become available that would alter the recommendations made at this and earlier workshops Therefore, the participants in the Secular Trend and Pooling Workshop concluded that the time had come to make strong emphatic recommendations that should lead to early decisions by NCHS If such decisions are delayed, progress in the should lead to early decisions by NCHS If such decisions are delayed, progress in the revision of the 1977 NCHS Growth Charts will be slowed and any present momentum will be reduced or lost

Literature cited

Abraham S, Johnson CL, Najjar F Weight and height of adults 18–74 years of age DHEW Pub No (PHS) 79-1659 Vital and Health Statistics, series 11 no 211 Washington, D C , U S Government Printing Office, 1979

Berenson GS Causation of cardiovascular risk factors in children Perspectives on cardiovascular risk in early life New York Raven Press 1986

Box GEP, Cox DR An analysis of transformations J Royal Stat Soc Series B 26 211–52 1964

Campaigne BN, Morrison JA, Schumann BC, et al Indexes of obesity and comparisons with previous national survey data in 9- and 10-year-old black and white girls The National Heart, Lung, and Blood Institute Growth and Health Study J Ped 124 675–80 1994

Canada Fitness Survey Fitness and lifestyle in Canada Ottawa, Canada Canada Fitness Survey and Fitness Canada 1983

Cole TJ Do growth chart centiles need a face lift? Brit Med J 308 641–2 1994

Cole TJ The use and construction of anthropometric growth reference standards Nutr Res Rev 6 19–50 1993

Coy JF, Lowry RK, Ratkowsky DA Longitudinal growth study of Tasmanian children, 1967–1983 Med J Austr 144 677–9 1986

Cronk CE, Roche AF, Chumlea WC, Kent R Longitudinal trends of weight/stature^2 in childhood in relationship to adulthood body fat measures Hum Biol 54 751–64 1982

Dean AG, Dean JA, Coulombier D, et al Epi Info, Version 6 A word processing, database, and statistics program for epidemiology on microcomputers Atlanta, Georgia Centers for Disease Control and Prevention 1994

Demirjian A Anthropometry Report Height, weight and body dimensions Ministry of National Health and Welfare Ottawa 1980

Dibley MJ, Goldsby JB, Staehling NW, Trowbridge FL Development of normalized curves for the international growth reference Historical and technical considerations Am J Clin Nutr 46 736–48 1987a

Dibley MJ, Staehling N, Nieburg P, Trowbridge FL Interpretation of Z-score anthropometric indicators derived from the international growth reference Am J Clin Nutr 46 749–62 1987b

Fomon SJ Nutrition of normal infants St Louis, Missouri Mosby 1993

Fomon SJ, Filer LJ, Jr, Ziegler EE, Bergmann KE, Bergmann RL Skim milk in infant feeding Acta Paed Scand 66 17–30 1977

Fomon SJ, Thomas LN, Filer LJ, Jr, et al Food consumption and growth of normal infants fed milk-based formulas Acta Paed Scand Suppl 223 1–36 1971

Fomon SJ, Ziegler EE, Nelson SE, Edwards B Cow milk feeding in infancy Gastrointestinal blood loss and iron nutritional status J Pediat 98 540–5 1981

Frisancho AR Anthropometric standards for the assessment of growth and nutritional status Ann Arbor, Michigan University Michigan Press 148, 168 1990

Guo S The development of age-specific percentiles and the comparison of smoothing procedures The revision of the National Center for Health Statistics/Centers for Disease Control Growth Charts 1995a

Guo SS The statistical effects of varying sample sizes and changing from weight-for-recumbent length to BMI in the revised NCHS/CDC Growth Charts 1995b

Guo SS, Roche AF, Chumlea WC, et al The predictive value of childhood body mass index values for overweight at age 35 y Am J Clin Nutr 59 810–9 1994

Guo S, Roche AF, Fomon SJ, et al Reference data on gains in weight and length during the first two years of life J Pediat 19 355–62 1991

Guo S, Siervogel RM, Roche AF, Chumlea WC Mathematical modelling of human growth A comparative study Am J Hum Biol 4 93–104 1992

Hamill PVV, Drizd TA, Johnson CL, et al NCHS growth curves for children birth–18 years United States DHEW Pub No (PHS) 78-1650, series 11 no 165 Washington, DC U S Government Printing Office 1977

Hamill PVV, Drizd TA, Johnson CL, et al Physical growth National Center for Health Statistics percentiles Am J Clin Nutr 32 607–29 1979

Hauspie RC, Wachholder A Clinical standards for growth velocity in height of Belgian boys and girls, aged 2 to 18 years Int J Anthrop 1 339–47 1986

Healy MJR, Rasbash J, Yang M Distribution-free estimation of age-related centiles Ann Hum Biol 15 17–22 1988

Himes JH, Dietz WH Guidelines for overweight in adolescent preventive services Recommendations from an expert committee Am J Clin Nutr 59 307–16 1994

Himes JH, Roche AF, Thissen D Parent-specific adjustments for assessment of recumbent length and stature Basel, Monogr Paed 13, Karger 1981

Kouchi M, Mukherjee D, Roche AF Curve fitting for growth in weight during infancy with relationships to adult status, and familial associations of the estimated parameters Hum Biol 57 245–65 1985

Kuczmarski RJ, Flegal KM, Campbell SM, Johnson CL Increasing prevalance of overweight among U S adults JAMA 272 205–11 1994

Largo RH, Prader A Pubertal development in Swiss boys Helv Paed Acta 38 211–28 1983a

Largo RH, Prader A Pubertal development in Swiss girls Helv Paed Acta 38 229–43 1983b

MacMahon B Age at menarche DHEW Pub No (HRA) 74-1615 Vital and health statistics, series 11 no 133 Washington DC U S Government Printing Office 1973

Malina RM Ethnic variation in the prevalence of obesity in North American children and youth Crit Rev Food Sci Nutr 33 389–96 1993

Malina RM, Martorell R, Mendoza F Growth status of Mexican American children and youths Historical trends and contemporary issues Yearbook Phys Anthrop 29 45–79 1986a

Malina RM, Zavaleta AN, Little BB Estimated overweight and obesity in Mexican American school children Int J Obes 10 483–491 1986b

Malina RM, Zavaleta AN, Little BB Secular changes in the stature and weight of Mexican American school children in Brownsville, Texas between 1928 and 1983 Hum Biol 59 509–22 1987
Marshall WA, Tanner JM Variations in the pattern of pubertal changes in girls Arch Dis Childh 44 291–303 1969
Marshall WA, Tanner JM Variations in the pattern of pubertal changes in boys Arch Dis Childh 45 13–23 1970
Najjar MF, Rowland M Anthropometric reference data and prevalence of overweight United States, 1976–80 DHHS Pub No (PHS) 87-1688 Vital and health statistics, series 11 no 238 Washington DC U S Government Printing Office 1987
Nelson SE, Rogers RR, Ziegler EE, Fomon S Gain in weight and length during early infancy Early Hum Dev 19 223–39 1989
Owen GM, Kram KM, Garry PJ, et al A study of nutritional status of preschool children in the United States, 1968–1970 Pediatrics 53 597–646 1974
Preece MA, Baines MJ A new family of mathematical models describing the human growth curve Ann Hum Biol 5 1–24 1978
Reynolds EL, Wines JV Individual differences in physical changes associated with adolescence in girls Am J Dis Child 75 329–50 1948
Reynolds EL, Wines JV Physical changes associated with adolescence in boys Am J Dis Child 82 529–47 1951
Roche AF Executive summary of NCHS Growth Chart Workshop December 1992 Washington DC National Center for Health Statistics 1994
Roche AF Growth, maturation, and body composition The Fels Longitudinal Study 1929–1991 Cambridge, United Kingdom Cambridge University Press, 1992
Roche AF Secular trends in human growth, maturation and development Chicago, Illinois Monogr Soc Res Child Development vol 44 1979
Roche AF, Guo S, Woteki C, Trowbridge FL Methods for the revision of the NCHS/CDC growth charts Birth to 36 months Proceeding of the 1989 annual meeting of the American Statistical Association 333–35 1989
Roche AF, Guo S, Moore WM Weight and recumbent length from 1 to 12 mo of age Reference data for 1 mo-increments Am J Clin Nutr 49 599–607 1989
Roede MJ, van Wieringen JC Growth diagrams 1980 Netherlands Third Nation-wide Survey Tijdeschrift voor Sociale Gezondheidszorg 63 1–34 1985
Rolland-Cachera MF, Deheeger M, Avon P, et al Tracking the development of adiposity from one month of age to adulthood Ann Hum Biol 14 219–29 1987
Rosenfeld RG Evaluation of growth and maturation in adolescence Pediat Review 4 175–83 1982
Ross JG, Gilbert GG Summary of findings from national children and youth fitness study I J Physical Educ Rec Dance 56 43–90 1985
Ross JG, Pate RR Summary of findings from National Children and Youth Fitness Study II J Phys Educ Rec Dance 58 49–96 1987
Siervogel RM, Roche AF, Guo S, et al Patterns of change in weight/stature^2 from 2 to 18 years Findings from long-term serial data for children in the Fels Longitudinal Growth Study Int J Obesity 15 478–485 1991

Sullivan PG Prediction of the pubertal growth spurt by measurements of standing height Eur J Orthod 5 189–197 1983

Tanner JM Growth at adolescence 2d ed Oxford, Blackwell Scientific Publications, 1962

Tanner JM, Davies PW Clinical longitudinal standards for height and height velocity for North American children J Ped 107 317–29 1985

Taranger J, Lichtenstein H, Svennberg-Redegren I Somatic pubertal development Acta Paed Scand 258 121–35 1976

Troiano RP, Flegal KJ, Kuczmarski RJ, et al Overweight prevalence and trends for children and adolescents Arch Pediatr Adolesc Med 149 1085–1091 1995

Tukey JW Exploratory data analysis Reading, Massachusetts Addison-Wesley 1977

van Wieringen JC Secular growth changes In Human Growth 1 Postnatal growth Falkner F, Tanner JM eds New York Plenum Press 445–73 1978

Ventura SJ, Martin JA Advance report of final natality statistics, 1991 Monthly vital statistics report, vol 42 no 3 Washington DC U S Government Printing Office 1993

Vercauteren M, Susanne C The secular trend of height and menarche in Belgium Are there any signs of a future stop? Eur J Pediat 144 306–9 1985

Vobecky JS, Vobecky J, Shapcott D, Demers P Nutrient intake patterns and nutritional status with regard to relative weight in early infancy Am J Clin Nutr 38 730–8 1983

Webber LS, Harsha DW, Nicklas TA, Berenson GS Secular trends in obesity in children In Prevention of atherosclerosis and hypertension beginning in youth Filer R, Lauer R, Luepher R eds Philadelphia, Pennsylvania Lea & Febiger 194–205 1994

Wilks SS Statistical prediction with special reference to the problem of tolerance limits Ann Math Statist 13 400 1941

Wilson DM, Kraemer HC, Ritter PL, Hammer LD Growth curves and adult height estimation for adolescents Am J Dis Child 141 565–70 1987

Yip R, Scanlon K, Trowbridge F Trends and patterns in height and weight status of low-income U S children Crit Rev Food Sci Nutr 33 409–21 1993

List of Appendices

APPENDIX A

LIST OF PARTICIPANTS AND GUESTS

COCHAIRPERSONS

DR ROBERT J KUCZMARSKI
National Center for Health Statistics/Center for Diseases Control and Prevention

DR ALEXANDER F ROCHE
Wright State University, Dayton, Ohio

PARTICIPANTS

DR NANCY F BUTTE
Children's Nutrition Research Center, United States Department of Argiculture, Houston, Texas

DR LESTER R CURTIN
National Center for Health Statistics/Centers for Disease Control and Prevention

DR FRANK FALKNER
University of California, Berkeley, California

MR CLIFFORD JOHNSON
National Center for Health Statistics/Centers for Disease Control and Prevention

DR SHUMEI GUO
Wright State University, Dayton, Ohio

DR JOHN H HIMES
University of Minnesota, Minneapolis, Minnesota

DR ROBERT M MALINA
Michigan State University, East Lansing, Michigan

DR CYNTHIA L OGDEN
National Center for Health Statistics/Centers for Disease Control and Prevention

DR RICHARD F TROIANO
National Center for Health Statistics, Centers for Disease Control and Prevention

DR RICHARD F TROIANO
National Center for Health Statistics, Centers for Disease Control and Prevention

<u>PARTICIPANTS VIA VIDEO-CONFERENCING FROM ATLANTA</u>

DR DEBORAH GALUSKA
Division of Nutrition, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention

DR LAURENCE GRUMMER-STRAWN
Division of Nutrition, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control

DR ZUGUO MEI
Division of Nutrition, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control

MR IBRAHIM PARVANTA
Division of Nutrition, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention

DR GERALDINE PERRY
Division of Nutrition, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention

DR KELLEY SCANLON
Division of Nutrition, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention

DR PAULA SCARIATI
Division of Nutrition, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention

DR BETTYLOU SHERRY
Division of Nutrition, National Center for Chronic Disease Prevention and Health Promotion, Centers for Disease Control and Prevention

GUESTS

DR RONETTE BRIEFEL
National Center for Health Statistics, Centers for Disease Control and Prevention

DR KATHERINE FLEGAL
National Center for Health Statistics, Centers for Disease Control and Prevention

MR ROBERT MURPHY
National Center for Health Statistics, Centers for Disease Control and Prevention

DR MARY OVERPECK
National Institute for Child Health and Human Development, National Institutes of Health

APPENDIX B

SECULAR TRENDS IN BIRTHWEIGHTS

Year	Median (g)	Weights ≥ 4,000 g (%)
1970	3,330	8 4
1975	3,320	9 4
1980	3,360	10 7
1985	3,370	11 1
1990	3,370	10 9
1993	3,360	10 5

Data from Natıonal Natalıty Surveys Courtesy of Joyce A Martın

APPENDIX C

NUMBER OF SUBJECTS FOR EACH NCHS SURVEY BY AGE AND SEX GROUPS

Age (Yr)	NHES (1963–70)	NHANES I (1971–74)	NHANES II (1976–80)	NHANES III* (1988–94)	Totals
0 25–0 49	-	-	-	414	414
0 50–0 99	-	-	179	638	817
1	-	286	370	626	942
2	-	298	350	618	1,266
3	-	308	421	526	1,255
4	-	304	105	548	1,257
5	-	273	393	534	1,200
6	575	179	146	324	1,224
7	632	164	150	2,701	1,216
8	618	152	145	298	1,213
9	603	169	141	300	1,213
10	576	184	165	338	1,263
11	595	178	153	308	1,234
12	643	200	147	194	1,184
13	626	1,274	165	188	1,153
14	618	174	188	138	1,118
15	613	171	180	184	1,148
16	556	169	180	188	1,093
17	458	176	183	214	1,031

*Estimates for Phase 1 plus Phase 2
Dashes represent data not applicable

NUMBER OF SUBJECTS FOR EACH NCHS SURVEY BY AGE AND SEX GROUPS

Age (Yr)	NHES (1963–70)	NHANES I (1971–74)	NHANES II (1976–80)	NHANES III* (1988–94)	Totals
0-25–0 49	-	-	-	468	468
0-50–0 99	-	-	177	580	757
1	-	267	336	732	1,094
3	-	292	367	626	1,285
4	-	281	388	564	1,233
5	-	314	369	580	1,263
6	536	176	150	300	1,162
7	609	169	154	302	1,234
8	613	152	125	302	1,192
9	581	171	154	336	1,242
10	584	197	128	294	1,203
11	525	166	143	296	1,130
12	547	177	146	168	1,038
13	582	198	155	196	1,131
14	586	184	181	232	1,183
15	503	167	144	182	996
16	536	171	167	188	1,062
17	442	150	134	186	912

*Estimates for Phase 1 plus Phase 2
Dashes represent data not applicable

APPENDIX D

DESCRIPTIONS OF THE DATA BASES FROM THE IOWA STUDIES AND THE FELS LONGITUDINAL STUDY

Iowa Studies These studies included 1,142 normal, term, white infants (200 breast-fed males, 214 breast-fed females, 380 formula-fed males, 348 formula-fed females) with birth weights of 2,500 grams or more who were born from March 1965 through March 1987 Many of these infants were born to members of the faculty of the University of Iowa Hospital records of birthweights are available Measurements of weight, length, and head circumference were made by trained investigators within 2 days of ages 8, 14, 28, 42, and 56 days, and within 4 days of ages 84 and 112 days Each measurement was made in duplicate and the mean of the two values was used in the analyses Because reliable data on length at birth were not obtained, the values for length at age 8 days were used

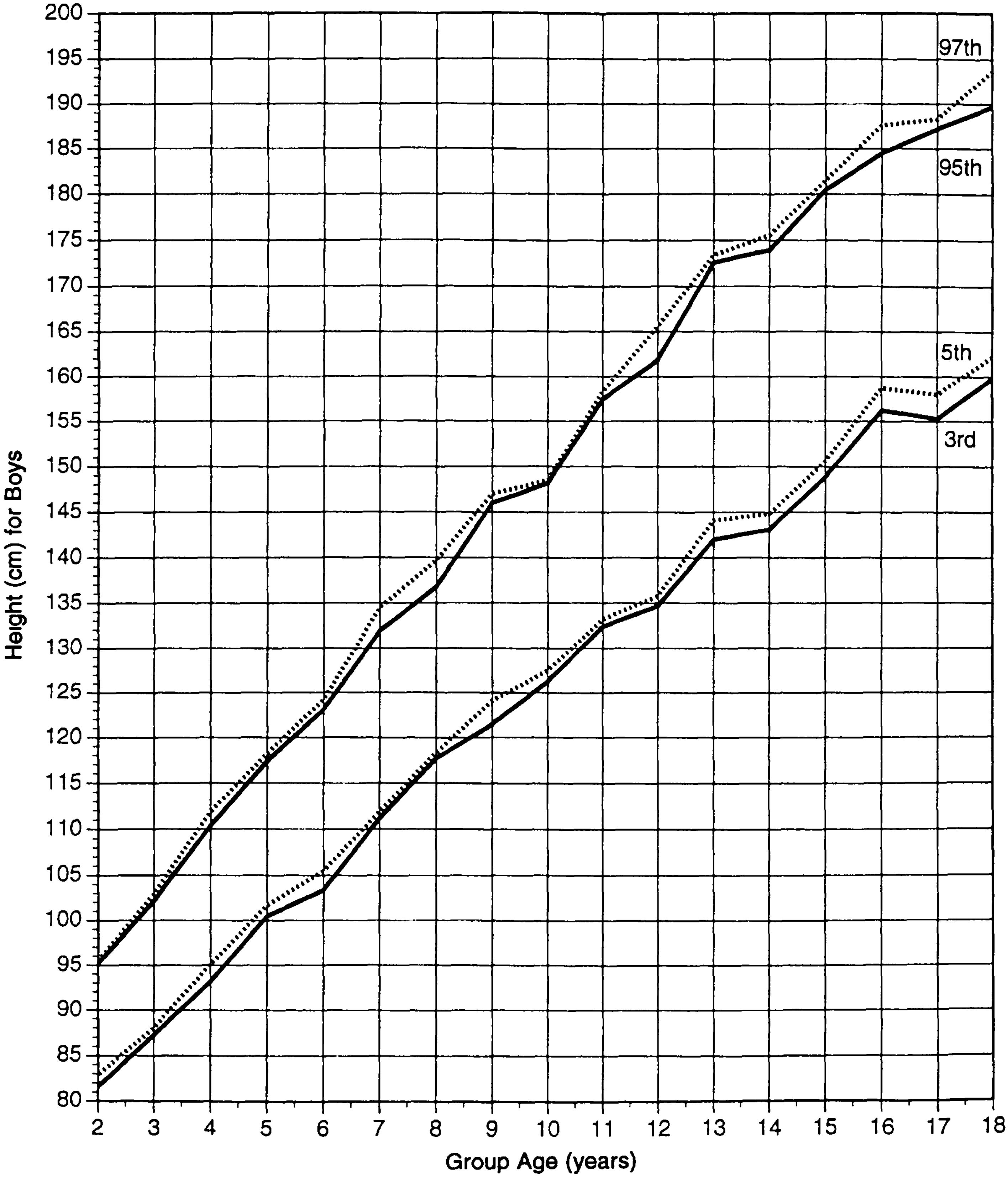
With few exceptions the subjects are the same as those described by Nelson et al (1989) A subset of this cohort (65 formula-fed males, 74 formula-fed females) continued to be studied after 112 days of age and were fed formulas providing approximately 67 kilocalories per deciliter They were measured within 4 days of ages 140, 168, and 196 days Data concerning some of the infants studied from 112 to 196 days of age have been reported (Fomon et al , 1971, 1977, 1981, Fomon, 1993)

Fels Longitudinal Study These data were collected from infants who were members of families in southwestern Ohio that were from a wide range of socioeconomic levels Most of the infants were formula fed with birth dates from 1930 through 1995 (Guo et al , 1991, Roche, 1992, Roche et al , 1989) All except six of these infants were white, and their birth weights are known The statures and weights of their parents were in close agreement with national data (Abraham et al , 1979, Najjar & Rowland, 1987) Examinations were scheduled at 1, 3, 6, 9, and 12 months and then 6-monthly Nearly all the participants were examined within a few weeks of these target ages and also at some intermediate ages All measurements were made independently by two trained observers from the Fels staff The means of pairs of measurements were used in the analyses

The sample sizes for the Iowa Studies and the Fels Longitudinal Study combined are

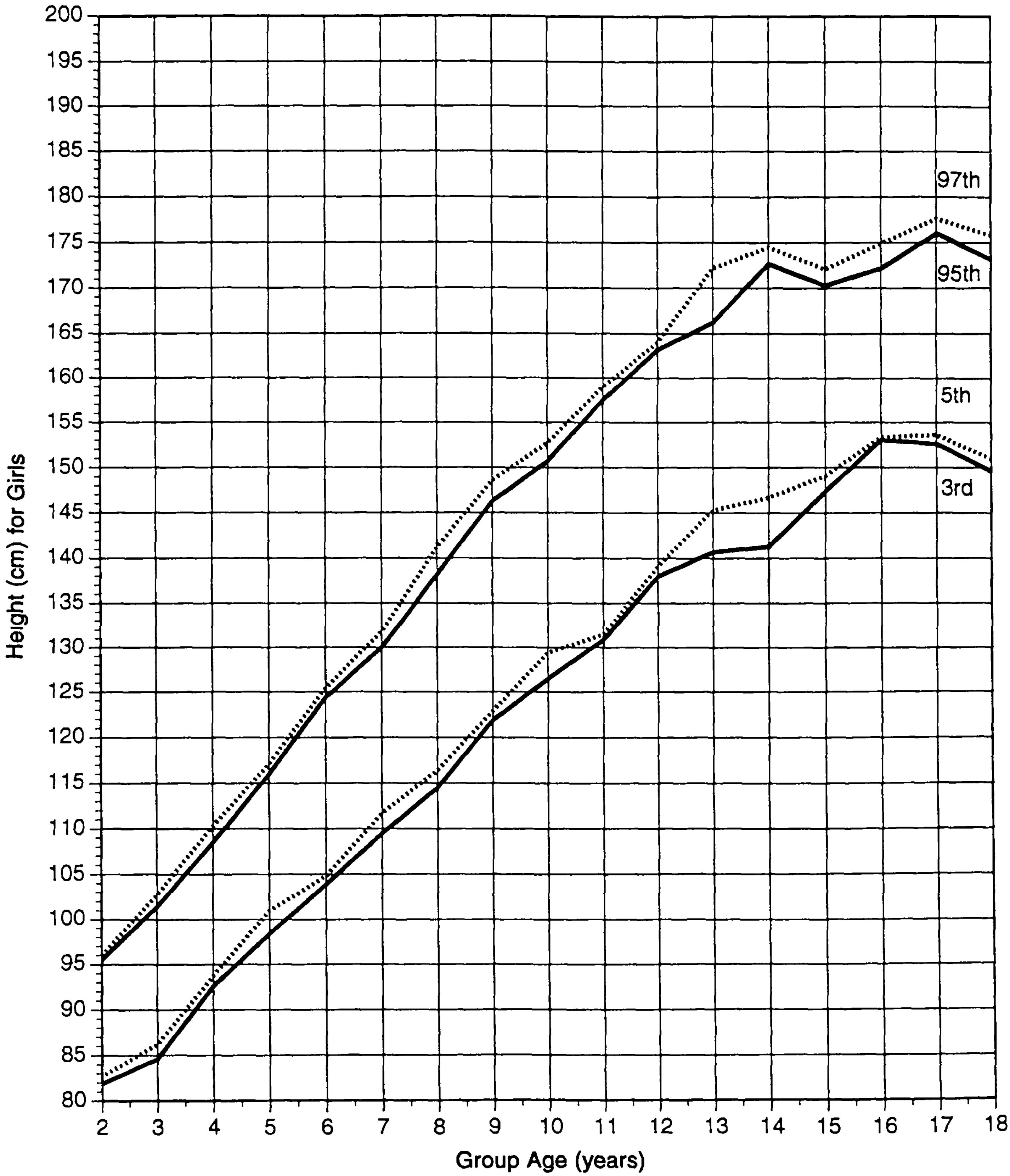
Age (mo)	Males	Females
Birth	580	562
1	580	562
3	580	562
3	813	786
4	298	298
5	298	298
6	298	298
7	233	224
8	233	224
9	233	224
10	233	224
11	233	224
12	233	224
13	233	224
14	233	224

APPENDIX E



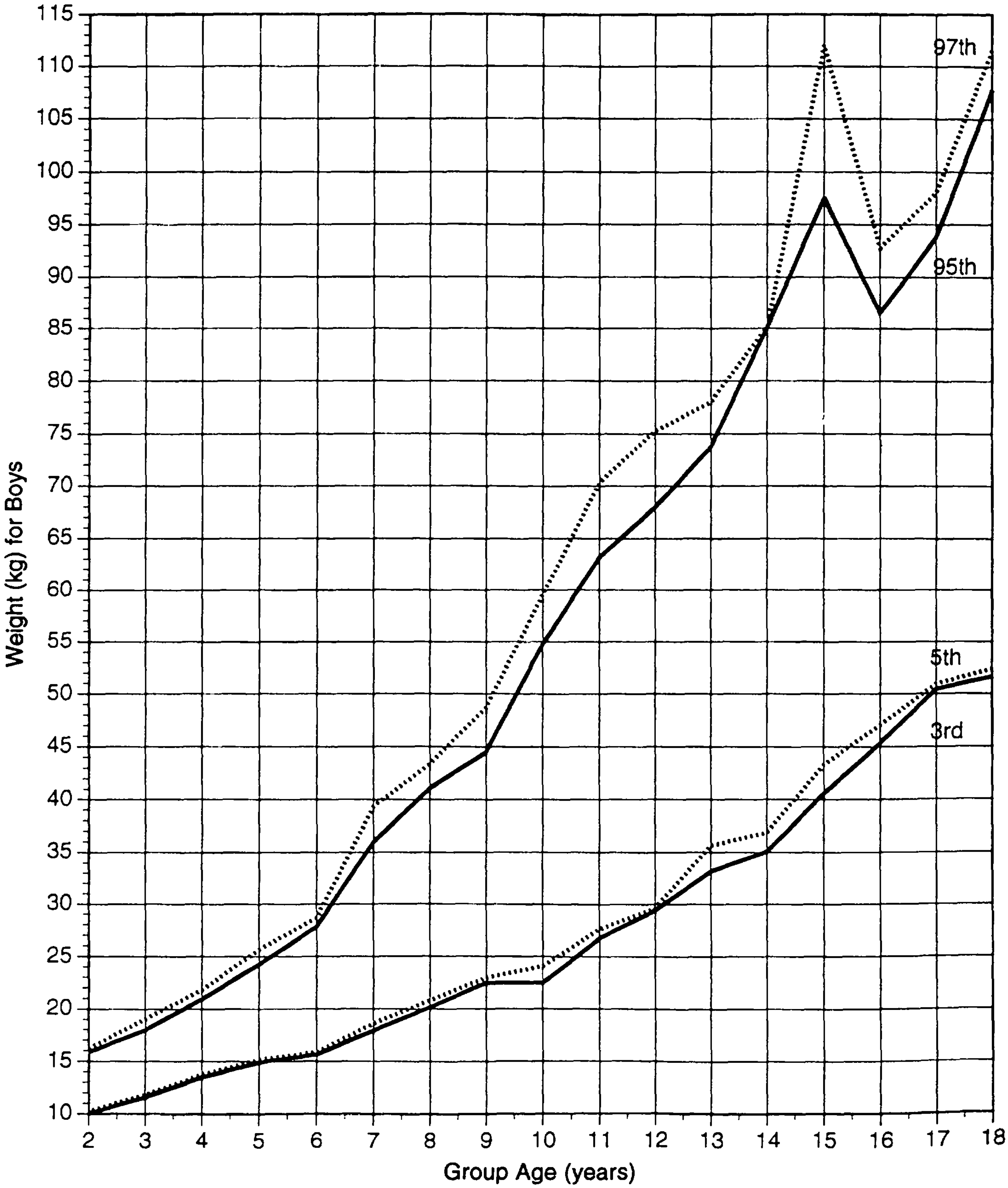
NHANES III Phase 1 unsmoothed
(courtesy of Shumei S Guo)

APPENDIX E (continued)



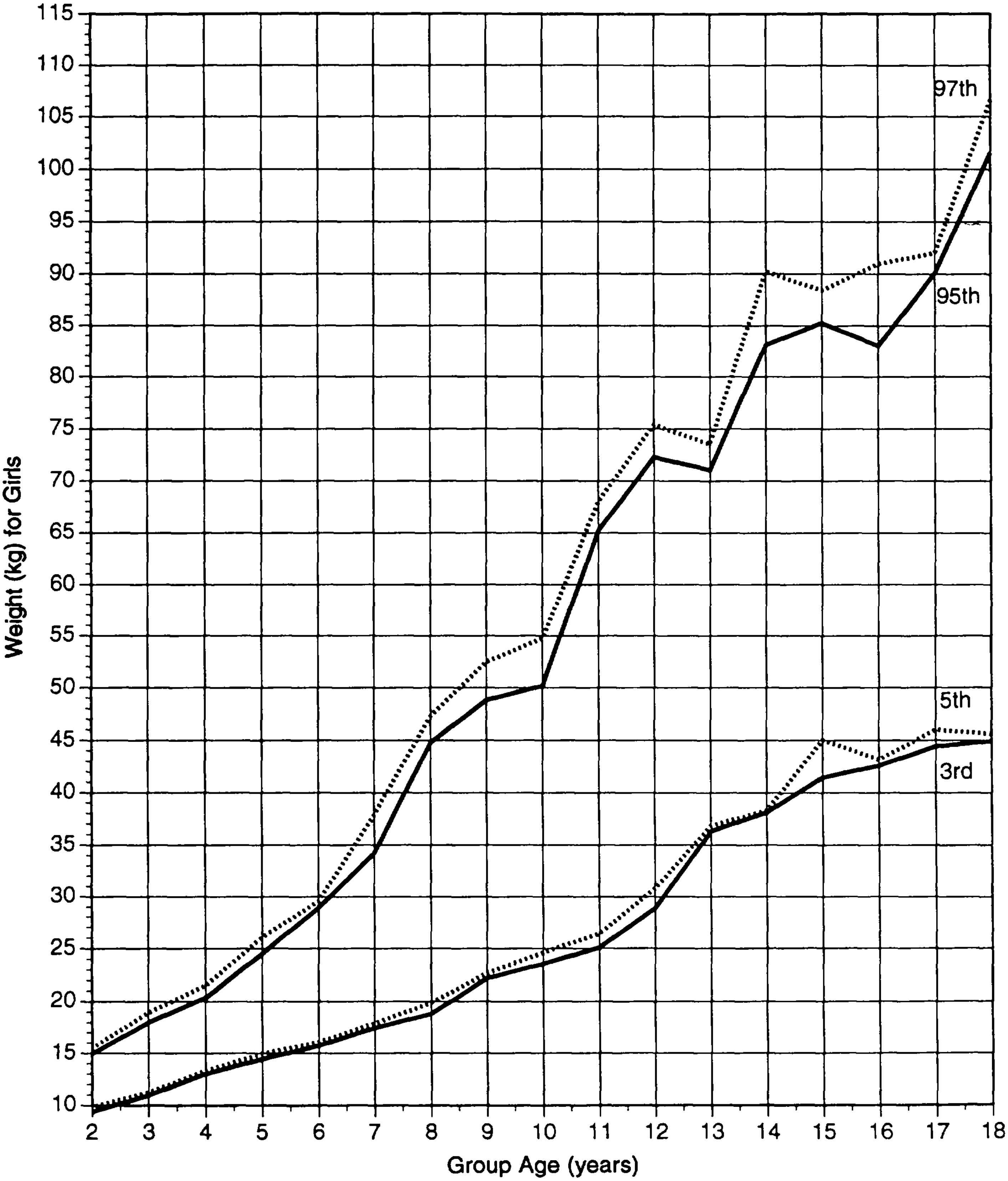
NHANES III Phase 1 unsmoothed
(courtesy of Shumei S Guo)

APPENDIX E (continued)



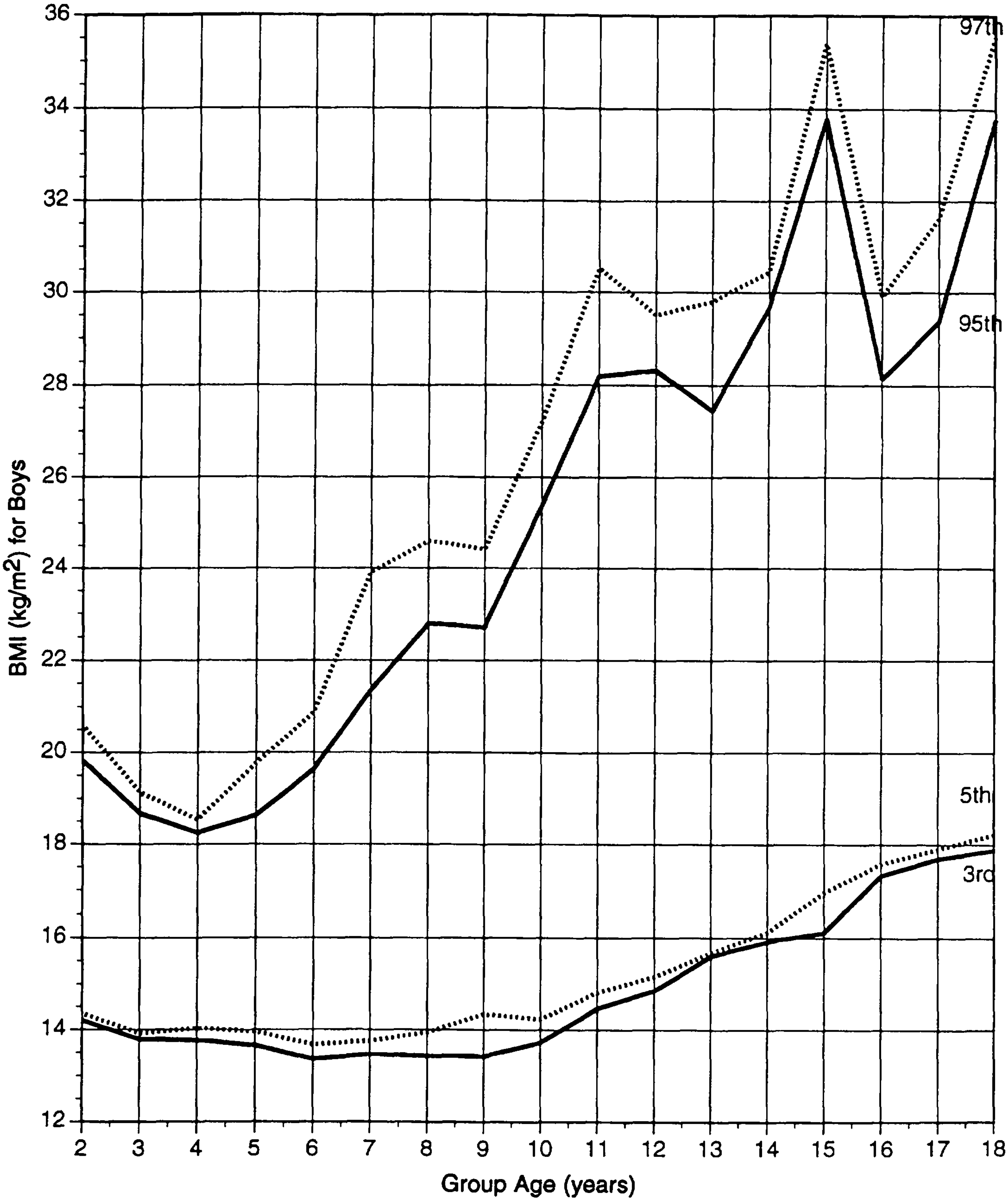
NHANES III Phase 1 unsmoothed
(courtesy of Shumei S Guo)

APPENDIX E (continued)



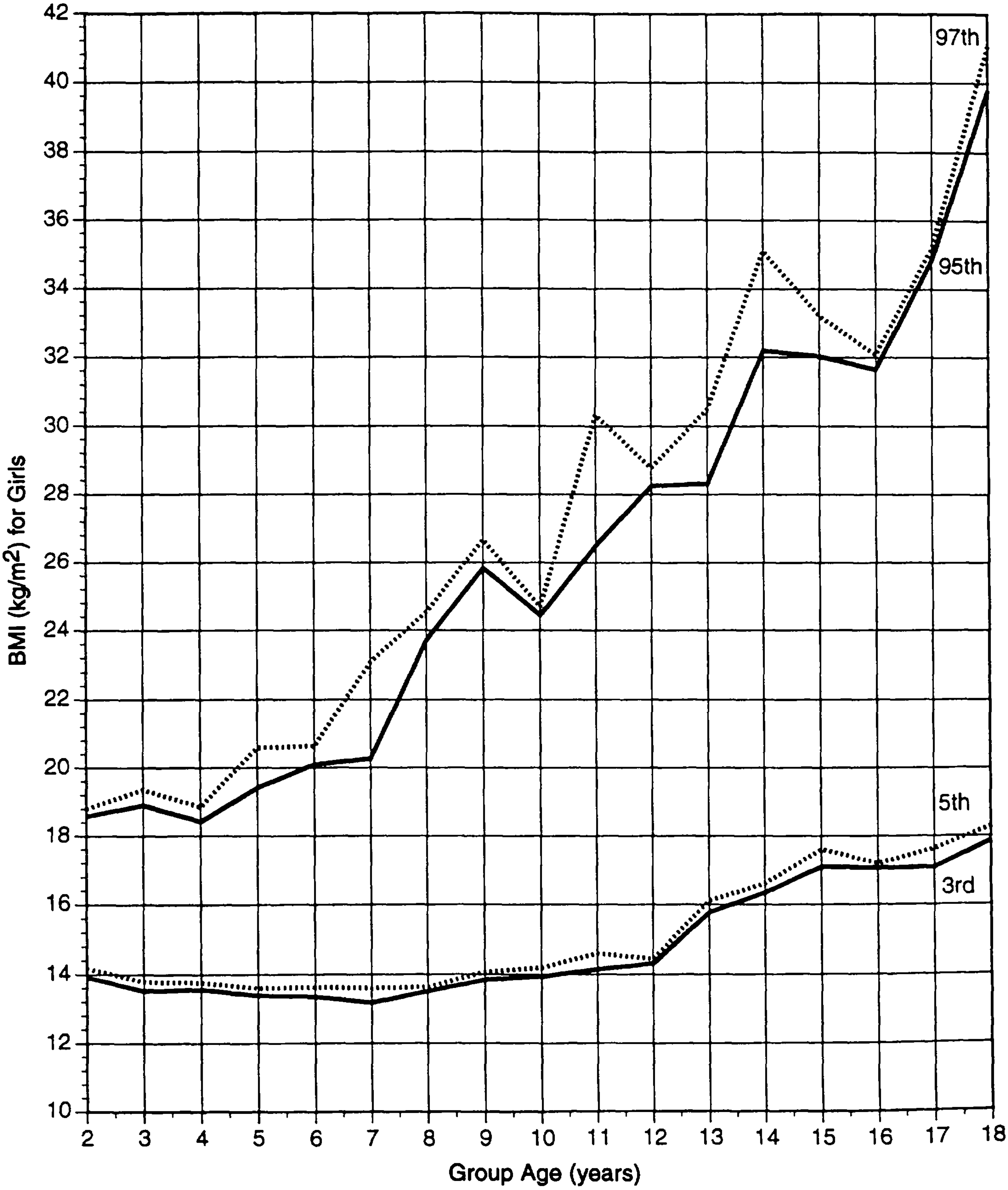
NHANES III Phase 1 unsmoothed
(courtesy of Shumei S Guo)

APPENDIX E (continued)



NHANES III Phase 1 unsmoothed
(courtesy of Shumei S Guo)

APPENDIX E (continued)



NHANES III Phase 1 unsmoothed
(courtesy of Shumei S Guo)

APPENDIX F

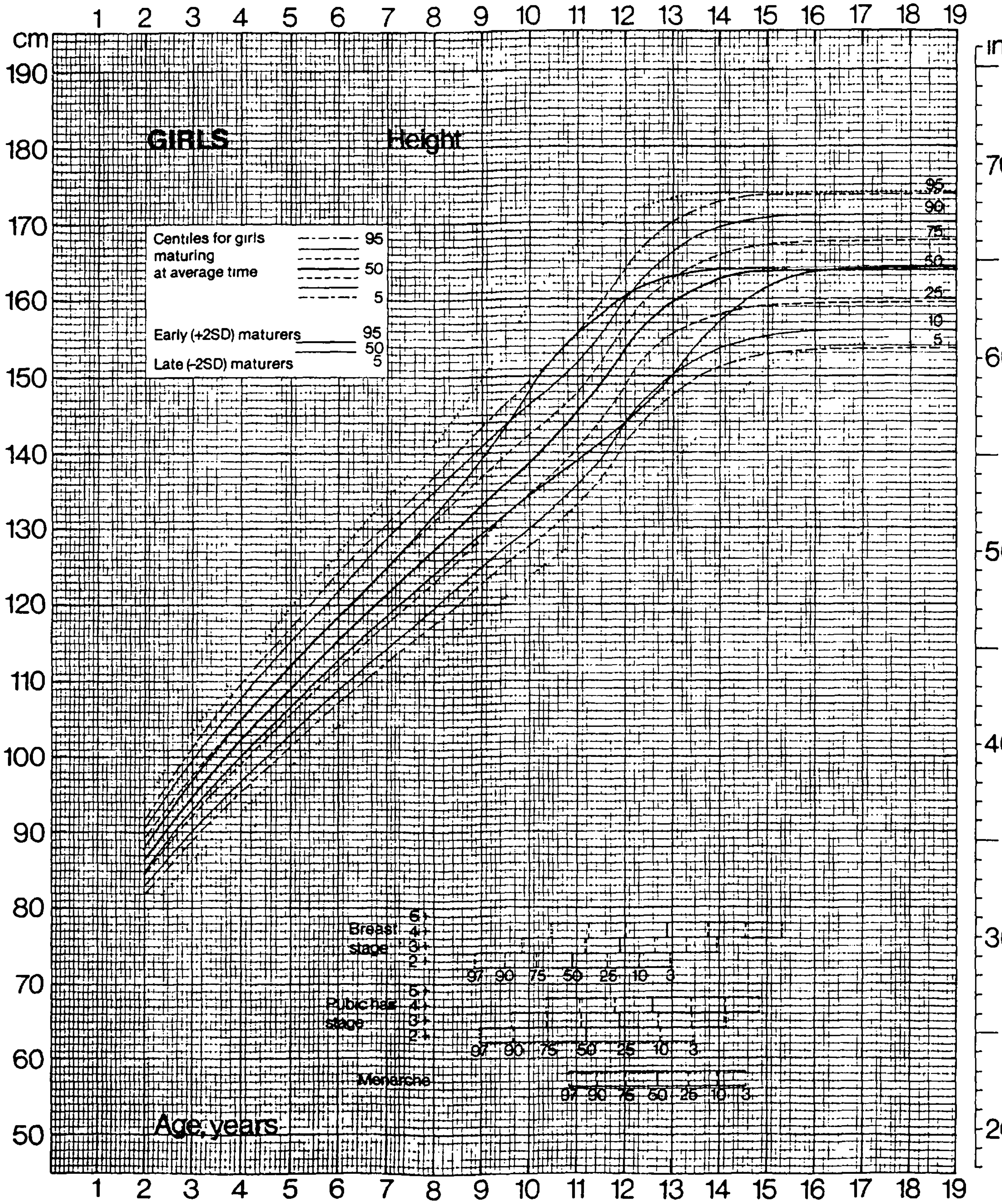


Fig 5. Height attained for American girls *Red lines* 50th centile *(solid)* and 95th centile *(dashed)* for girls 2 SD of tempo early, *green lines*, 50th centile *(solid)* and 5th centile *(dashed)* for girls 2 SD of tempo late

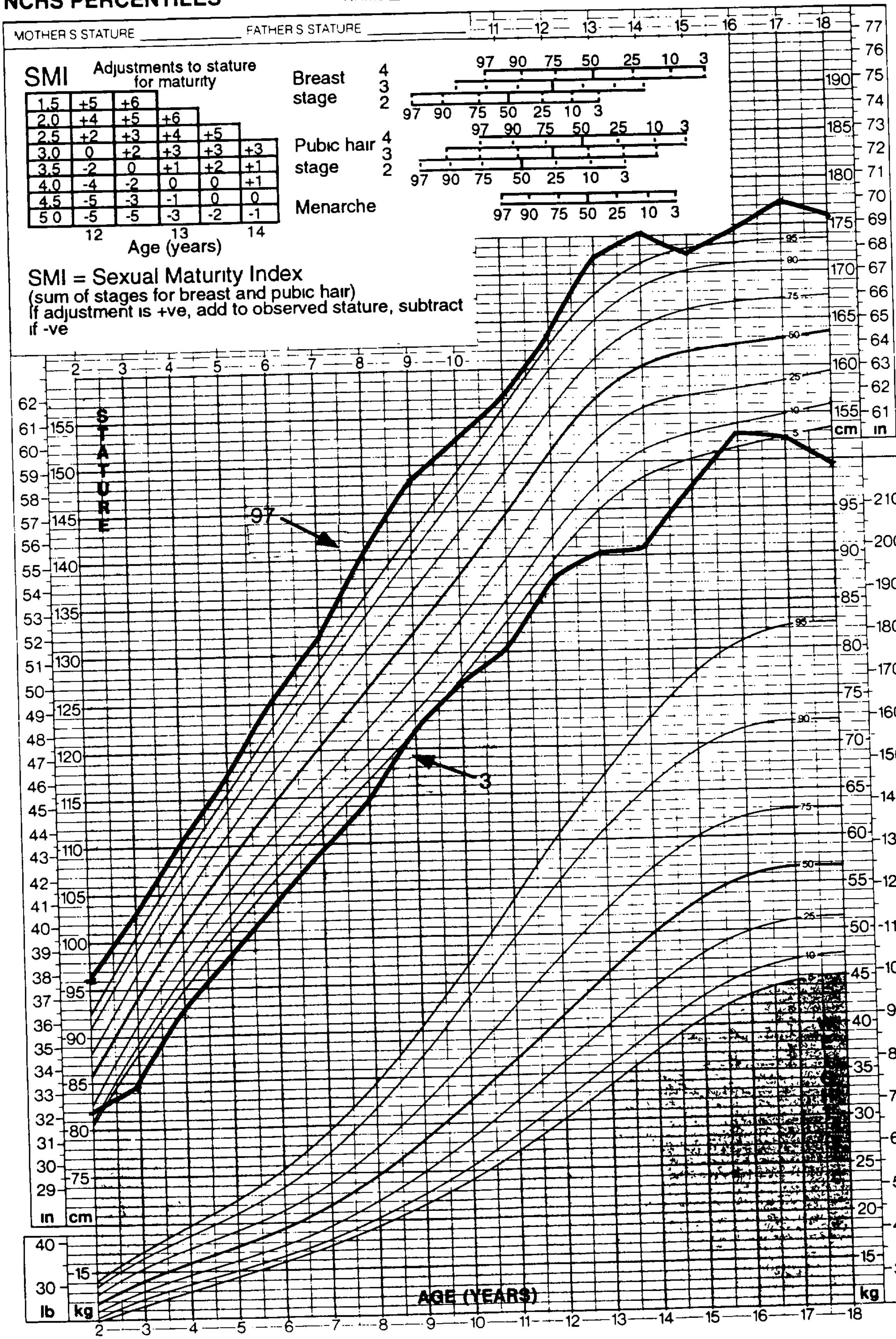
data from Tanner & Davies, 1985

GIRLS. 2 TO 18 YEARS PHYSICAL GROWTH NCHS PERCENTILES*

APPENDIX G

NAME ____________________ RECORD # ____________

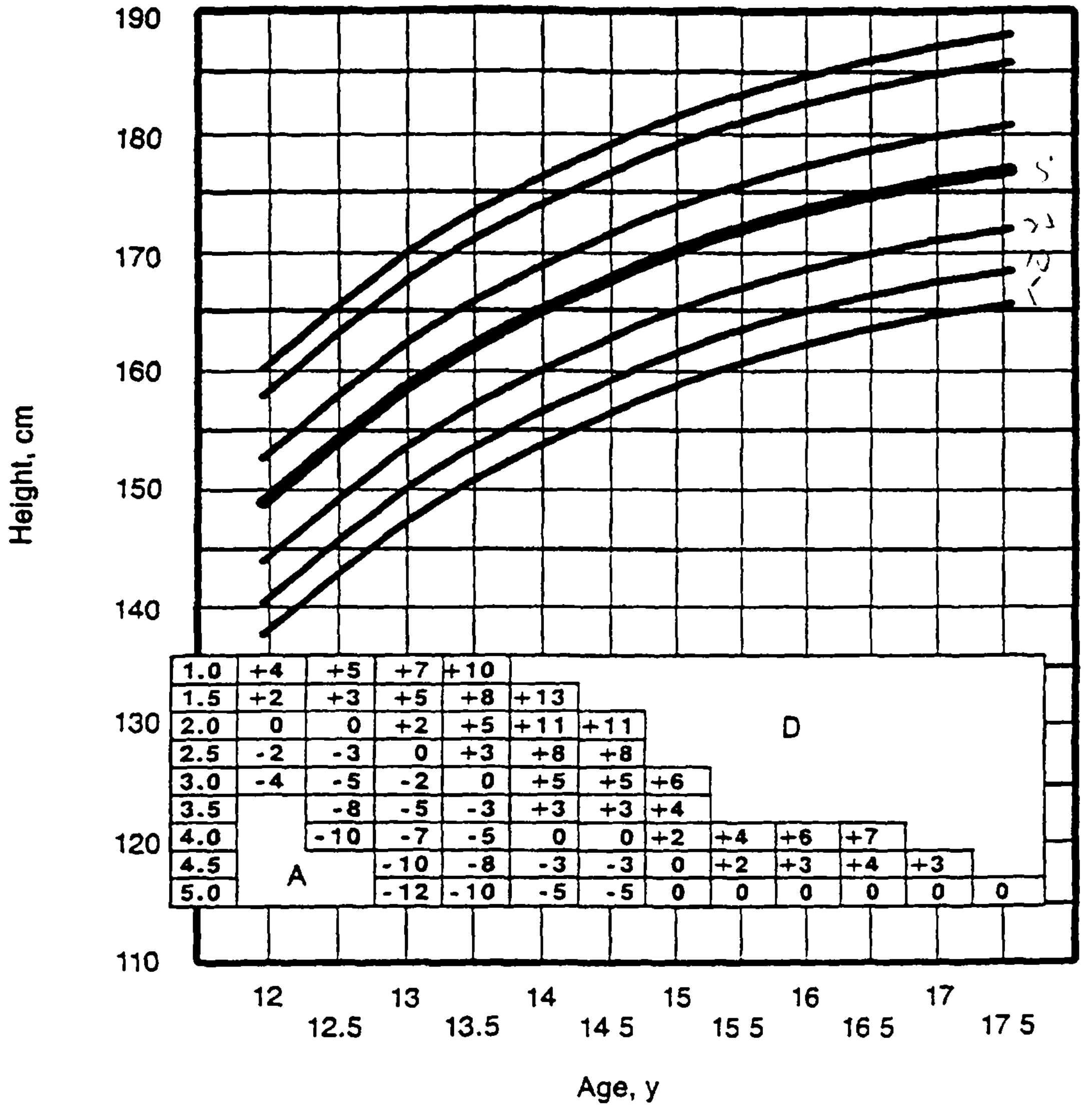
Ross Growth & Development Program



SMI	12		13		14
1.5	+5	+6			
2.0	+4	+5	+6		
2.5	+2	+3	+4	+5	
3.0	0	+2	+3	+3	+3
3.5	-2	0	+1	+2	+1
4.0	-4	-2	0	0	+1
4.5	-5	-3	-1	0	0
5.0	-5	-5	-3	-2	-1

*Adapted from: Hamill PVV, Drizd TA, Johnson CL, Reed RB, Roche AF, Moore WM: Physical growth: National Center for Health Statistics percentiles. AM J CLIN NUTR 32:607-629, 1979. Data from the National Center for Health Statistics (NCHS) Hyattsville, Maryland

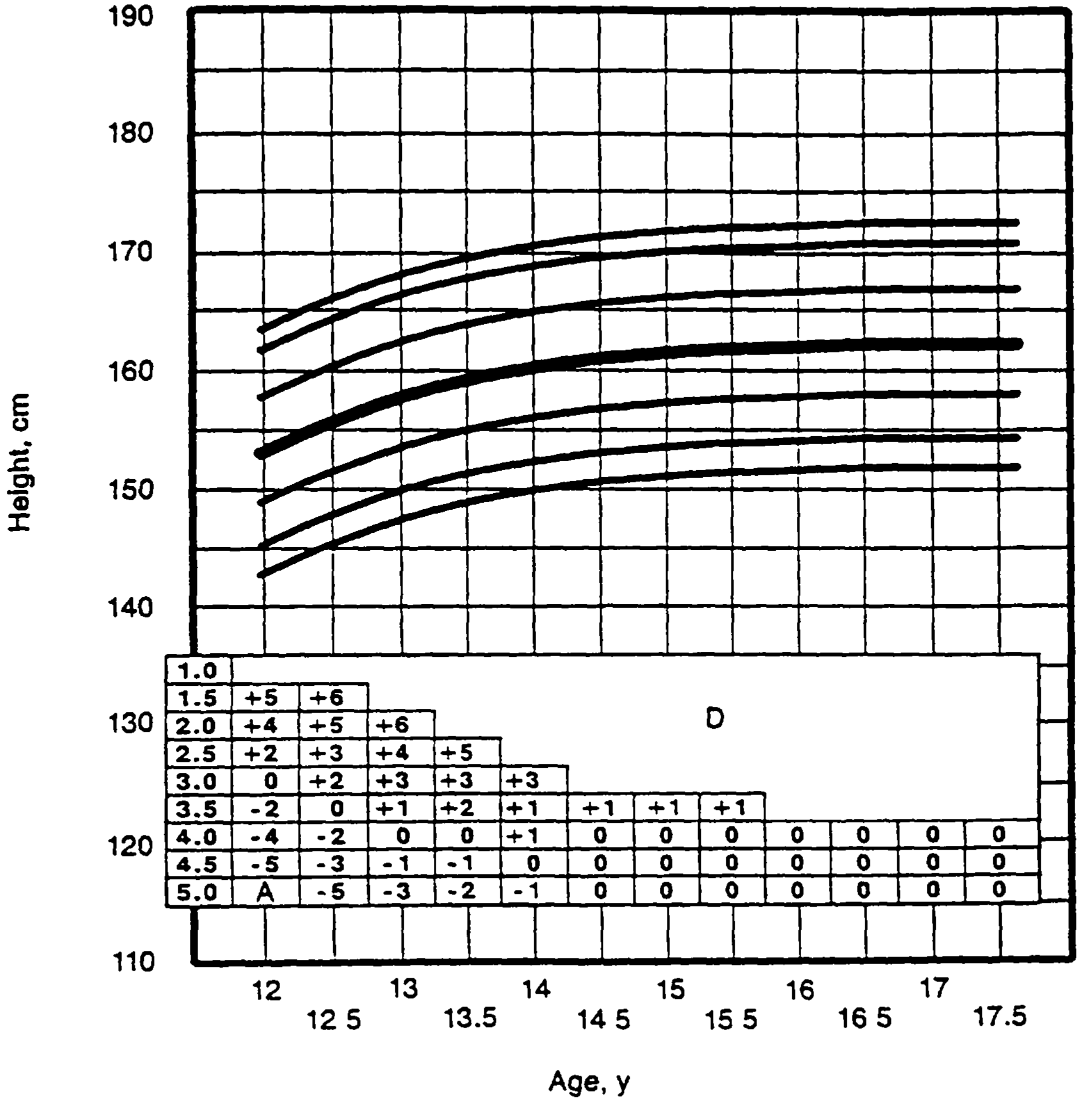
APPENDIX H



	12	12.5	13	13.5	14	14.5	15	15.5	16	16.5	17	17.5
1.0	+4	+5	+7	+10								
1.5	+2	+3	+5	+8	+13							
2.0	0	0	+2	+5	+11	+11						
2.5	-2	-3	0	+3	+8	+8						
3.0	-4	-5	-2	0	+5	+5	+6					
3.5		-8	-5	-3	+3	+3	+4					
4.0		-10	-7	-5	0	0	+2	+4	+6	+7		
4.5			-10	-8	-3	-3	0	+2	+3	+4	+3	
5.0			-12	-10	-5	-5	0	0	0	0	0	0

Fig 1.—Growth curve and correction table for male adolescents. Mean height (bold line) and distribution (95th, 90th, 75th, 25th, 10th, and 5th percentile lines) for adolescents maturing at modal rate (see text) Correction table below curves shows mean difference in height between subjects of same age at different stages of puberty (indicated by left column). To obtain a height percentile adjusted for rate of pubertal maturation, first average Tanner stages for pubic hair and genitalia to form sexual maturity index score and then determine correction factor for patient's age from correction table Add (or, if correction factor is negative, subtract) correction factor to (from) measured height and plot adjusted height onto curves To estimate final adult height, extrapolate adjusted height percentile to adulthood

Data from Wilson et al., 1987



1.0												
1.5	+5	+6										
2.0	+4	+5	+6									
2.5	+2	+3	+4	+5								
3.0	0	+2	+3	+3	+3							
3.5	-2	0	+1	+2	+1	+1	+1	+1				
4.0	-4	-2	0	0	+1	0	0	0	0	0	0	0
4.5	-5	-3	-1	-1	0	0	0	0	0	0	0	0
5.0	A	-5	-3	-2	-1	0	0	0	0	0	0	0

Fig 2.—Growth curve and correction table for female adolescents Mean height (bold line) and distribution (95th, 90th, 75th, 25th, 10th, and 5th percentile lines) for adolescents maturing at modal rate (see text). Correction table below curves shows mean difference in height between subjects of same age at different stages of puberty (indicated by left column). To obtain a height percentile adjusted for rate of pubertal maturation, first average Tanner stages for pubic hair and breasts to form sexual maturity index score and then determine correction factor for patient's age from correction table. Add (or, if correction factor is negative, subtract) correction factor to (from) measured height and plot adjusted height onto curves. To estimate final adult height, extrapolate adjusted height percentile to adulthood

Data from Wilson et al., 1987

☆U.S. GOVERNMENT PRINTING OFFICE 1997 519-306/90012