METHODS FOR THE REVISION OF THE NCHS/CDC GROWTH CHARTS: BIRTH TO 36 MONTHS

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1. Introduction

Charts showing percentile levels of variables, such as stature and weight, in relation to childhood ages are used widely by physicians and other health-care professionals. Growth charts of status-at-an-age have been available in the U.S. for at least 70 years, but all the early charts were derived from small unrepresentative samples and many were based on unwarranted assumptions that the distributions were normal. Many different growth charts were used in the U.S. until 1977 when this situation changed rapidly after the publication of growth charts by the National Center for Health Statistics (NCHS; Hamill et al., 1977).

The NCHS charts presented reference percentiles for two overlapping age ranges: 0 to 3 years and 2 to 18 years. National data were not available for the younger age range. Consequently, data from the Fels Research Institute (Fels) were used because the sample was large at each age and the measurement errors were small. These mixed-longitudinal data for the age range 0-3 years were chosen because they were considered the best set of U.S. data for infant growth, although the Fels population is a sample of convenience and the subjects were born between 1929 and 1975 during which time secular changes may have occurred.

Data from two national surveys conducted by NCHS between 1963 and 1974 were used for the age range 2-18 years. Each of these surveys employed a multi-stage sampling design and they included all races unlike the Fels Study, which was effectively restricted to whites. These data were weighted to obtain separate national estimates from each survey. The sample sizes for weight in boys at some selected ages are shown in Table 1. In all the data sets, the sexes were about equally represented.

Table 1. Sample sizes for weight in boys at selected ages and the sources of the data.

Ages	n	Sources
1 year	374	Fels Research Institute
6 years	575	Health Examination Survey
6 years	179	First Health and Nutrition Examination Survey
12 years	643	Health Examination Survey
12 years	200	First Health and Nutrition Examination Survey

Separate empirical percentiles were obtained for the Fels data and for the data from each of the NCHS surveys. These percentiles were obtained at birth, 1, 3, 6, 9 and 12 months and then each 6 months to 18 years using cumulative percentages. Interpolations were not made to units smaller than those of the original measurements. For example, the 90th percentile was set at the lowest *recorded* value for which the cumulative percentage of the smaller values exceeded 90.The selected percentiles were the 5th, 10th, 25th, 50th, 75th, 90th and 95th. The empirical percentiles for weight in girls for the NCHS surveys at ages older than 6.5 years are shown in Figure 1 where they are plotted opposite the last completed half years of age. The Health Examination Survey (HES) was conducted in three cycles: the first was of adults, the second included children aged 6.00 through 11.99 years, and the third included youth from 12.00 through 17.99 years. The First Health and Nutrition Examination Survey (HANES I) included children aged 1-18 years. While the levels and general trends of the percentiles are similar for the two surveys, the match is far from exact. Additionally, the marked irregularity of the *empirical* percentiles from these surveys makes them unsuitable as reference data.

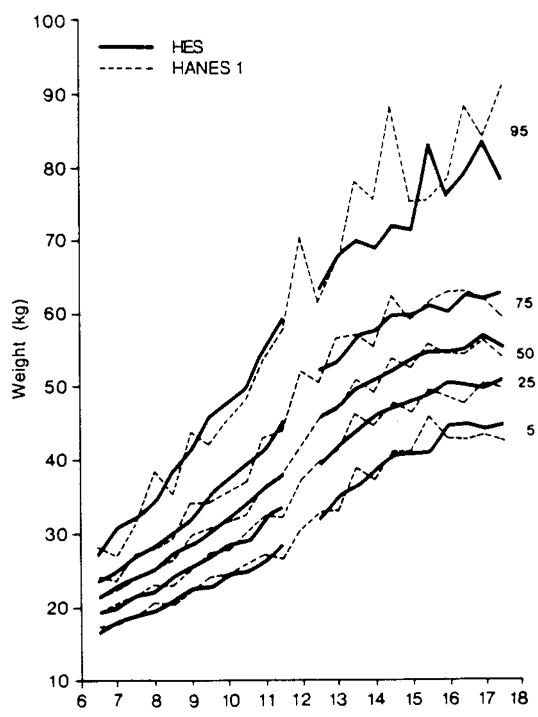

Figure 1. Selected empirical percentiles for weight (kg) at ages 6-18 years from the Health Examination Surveys (HES) and The First Health and Nutrition Examination Survey (HANES I).

These percentiles were smoothed using cubic splines. It was not recognized at the time that this procedure over-smoothed the data particularly during pubescence, probably because too few knots were used (Table 2). Indeed, it was considered that an improved set of reference data had been provided that would be generally useful in the U.S. It was believed these reference data would not need modification for about 10 years by which time secular changes in the U.S. may have reduced the applicability of these reference data.

Table 2. The locations of knots for the cubic splines in each sex.*

Variable	Ages
Younger set	
recumbent length	0,9,24, and 36 months
weight	0,6,18, and 36 months
weight-for-recumbent length	49,72, 90, and 103 cm
Older set	
stature and weight	24,138,168,204, and 216 months
weight-for-stature	55, 80,115, and 145 cm

*There were some minor variations from these summarizing ages; details are provided by Dibley et al. (1987).

2. The Variables

The reference data provided in the NCHS growth charts were for weight at all ages, and stature from 2 to 18 years. Recumbent length data were provided from 0 to 3 years. Weight-for-recumbent length and weight-for-stature were included for prepubescent children because they allow judgments of weight "adjusted for body length" and these bivariate relationships are, for all practical purposes, independent of age before pubescence.

3. The Problems

The problems that arose were directly related to the success of the NCHS charts. Before long, they were used generally in the U.S. and some other countries and they were recommended for international use by The World Health Organization (WHO) and other multinational organizations (World Health Organization, 1978). Soon it became clear that what had seemed to be a satisfactory match between the Fels data and the NCHS data at 2-3 years, when these sets overlapped, caused problems in some analytical situations, although the irregularities were not of sufficient magnitude to be problematic when the charts were used clinically in the assessment of individual children. The problems that were recognized particularly affected the analysis of survey data from developing countries (Dibley et al., 1987). Some of these data showed marked changes in the prevalence of children with values < 5th percentile when a transition was made from judgments using the Fels part of the charts (0-3 years) to those made using the NCHS part of the charts (2-18 years). Additionally, research workers in developing countries needed more extreme lower reference levels than the 5th percentiles, and they needed weight-for-stature reference data for statures that are shorter than those at which U.S. children are first able to stand appropriately (Dibley et al., 1987).

4. The Solutions

a. Outlying percentiles

Outlying percentiles (3rd, 97th) and ±2 and 3 standard deviation (s.d.) levels can be calculated easily for recumbent length and stature because these variables are normally distributed. The other variables (weight, weight-for-recumbent length, weight-for-stature) are positively skewed to an extent that increases with age. To provide outlying reference values for these variables, WHO (1983), split each distribution at the median and treated each half as part of a normal distribution, although they were not distributed normally (Dibley et al., 1987). Separate s.d. values were calculated for each half from the smoothed empirical percentiles, not the raw data, using the mean of the s.d. values calculated from each percentile level. The outlying levels they obtained were presented in a tabular format. This approach met the need for outlying reference values but at these outlying levels the discrepancies between the Fels-based and NCHS-based percentiles were amplified.

b. Weight-for-stature

WHO (1983) met the need of many in developing countries to have weight-for-stature reference data that extend to statures less than 90 cm. The procedures applied took account of the almost exact correlation between recumbent length and stature although recumbent length systematically exceeds stature by amounts that differ between studies. The steps taken were to (i) compute the weights corresponding to stature for values near the lower end of the range of the NCHS reference data, (ii) locate corresponding weights on the weight-for-recumbent length curves, (iii) use conversion factors to adjust recumbent length to stature in the upper end of the range of the weight-for-recumbent length reference data, (iv) add the results of this conversion to the lower end of the weight-for-stature reference data, and (v) use cubic splines to smooth the combined data set. This approach has been used in a further revision based on new data for the differences between paired recumbent length and stature measurements of the same children in NCHS surveys. As a result, the weight-for-stature reference data now extend down to 75 cm.

c. Junction between Fels and NCHS parts of the reference data

As noted previously, there were differences in the percentile levels for the two data sets at ages when paired estimates were available, e.g., 5th percentile for weight at 3 years. Recently, these junctions have been smoothed utilizing data that are now available from NCHS surveys at ages 6 months and older (Hamill et al., 1977; Johnson et al., 1981; Najjar and Rowland, 1987). National reference data for birth weight and data early in infancy for weight and recumbent length from the Fels Study, that were adjusted for birth weight, were used to generate the revised curves for ages younger than 18 months. National data are not available in sufficient quantities for ages from soon after birth to 18 months.

Reference percentile curves for this period were constructed by applying a model that described the individual patterns of growth of Fels children from birth to 36 months. The model for weight and recumbent length has the form:

$$f(t) = a + b \log(t+1) + c(t+1)^{0.5} + \varepsilon$$

where f(t) is the value of the variable at age t, and a,b and c are parameters to be estimated, and ε is an error term.

The following model was fitted to serial weight-for-recumbent length data:

$$f(x) = ax + bx^2 + cx^3 + \varepsilon,$$

where f(x) is the weight (kg) for recumbent length (cm, x), a, b, and c are the parameters to be estimated and ε is an error term.

These models were fitted to the serial data for each Fels child with only small RMSE . Subsequently, these models were fitted to the NCHS empirical percentiles at each month of age from 18 through 36 months and to the points at or near birth for the same percentile level. As a result, the final curves represent national values for birth weights, Fels data near birth and national data for 18-36 months. and their shapes are based, in part, on serial data from individual children in the Fels Study.

The Final Solution

The procedures described form a useful approach to the revision of the present NCHS/CDC Growth Charts that may constitute an adequate response to the serious data limitations that exist. Alternative approaches are still being considered.

It is hoped that further evolution of these or other methods will provide a satisfactory interim reference until NHANES III survey data are available as the basis for a more complete revision or the replacement of the current reference. It is expected that this major revision or replacement on the basis of cross-sectional data will be compared with sets of serial data from healthy children to assure biological accuracy.

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