

WHO Child Growth Standards

**Length/height-for-age, weight-for-age, weight-for-length, weight-for-height
and body mass index-for-age**

Methods and development



**World Health
Organization**

**Department of Nutrition for
Health and Development**

Executive summary

In 1993 the World Health Organization (WHO) undertook a comprehensive review of the uses and interpretation of anthropometric references. The review concluded that the NCHS/WHO growth reference, which had been recommended for international use since the late 1970s, did not adequately represent early childhood growth and that new growth curves were necessary. The World Health Assembly endorsed this recommendation in 1994. In response WHO undertook the Multicentre Growth Reference Study (MGRS) between 1997 and 2003 to generate new curves for assessing the growth and development of children the world over.

The MGRS combined a longitudinal follow-up from birth to 24 months and a cross-sectional survey of children aged 18 to 71 months. Primary growth data and related information were gathered from 8440 healthy breastfed infants and young children from widely diverse ethnic backgrounds and cultural settings (Brazil, Ghana, India, Norway, Oman and USA). The MGRS is unique in that it was purposely designed to produce a standard by selecting healthy children living under conditions likely to favour the achievement of their full genetic growth potential. Furthermore, the mothers of the children selected for the construction of the standards engaged in fundamental health-promoting practices, namely breastfeeding and not smoking.

This report presents the first set of WHO Child Growth Standards (i.e. length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index (BMI)-for-age) and describes the methodical process followed in their development. The first step in this process was a consultative expert review of some 30 growth curve construction methods, including types of distributions and smoothing techniques to identify the best approach to constructing the standards. Next was the selection of a software package flexible enough to allow the comparative testing of the alternative methods used to generate the growth curves. Then the selected approach was applied systematically to search for the best models to fit the data for each indicator.

The Box-Cox-power-exponential (BCPE) method, with curve smoothing by cubic splines was selected for constructing the WHO child growth curves. The BCPE accommodates various kinds of distributions, from normal to skewed or kurtotic. The age-based indicators originating at birth required a power-transformation to stretch the age scale (x-axis) as a preliminary step to fitting the curves. For each set of curves, the search for the best model specification began by examining various combinations of degrees of freedom to fit the median and variance estimator curves. When data had a non-normal distribution, degrees of freedom for parameters to model skewness and kurtosis were added to the initial model and adequacy of fit evaluated. Apart from length/height-for-age, which followed a normal distribution, the other standards required the modelling of skewness, but not kurtosis. The diagnostic tools used iteratively to detect possible model misfits and biases in the fitted curves included various tests of local and global goodness of fit, worm plots and residual plots. Patterns of differences between empirical and fitted percentiles were also examined, as were proportions of observed versus expected percentages of children with measurements below selected percentiles.

The methodology described above was followed to generate — for boys and girls aged 0 to 60 months — percentile and z-score curves for length/height-for-age, weight-for-age, weight-for-length, weight-for-height and BMI-for-age. The last standard is an addition to the set of indicators previously available as part of the NCHS/WHO reference. In-depth descriptions are presented of how each sex-specific standard was constructed. Also presented are comparisons of the new WHO standards with the NCHS/WHO growth reference and the CDC 2000 growth charts.

To interpret differences between the WHO standards and the NCHS/WHO reference it is important to understand that they reflect differences not only in the populations used, but also in the methodologies applied to construct the two sets of growth curves. To address the significant skewness of the NCHS/WHO sample's weight-for-age and weight-for-height, separate standard deviations were calculated for distributions below and above the median for each of the two indicators. This approach is limited in fitting skewed data, especially at the extreme tails of the distribution, since it only partially adjusts for the skewness inherent in the weight-based indicators. The WHO standards, on the other hand, employed LMS-based methods that fit

skewed data adequately and generate fitted curves that follow closely the empirical data. Like the WHO standards, construction of the CDC 2000 growth charts was also based on the LMS method and, therefore, differences between this reference and the WHO standards are largely a reflection of differences in the populations on which the two sets of curves were based.

Length/height-for-age. The standard for linear growth has a part based on length (length-for-age, 0 to 24 months) and another on height (height-for-age, 2 to 5 years). The two parts were constructed using the same model but the final curves reflect the average difference between recumbent length and standing height. By design, children between 18 and 30 months in the cross-sectional component of the MGRS had both length and height measurements taken. The average difference between the two measurements in this set of 1625 children was 0.73 cm. To fit a single model for the whole age range, 0.7 cm was therefore added to the cross-sectional height values before merging them with the longitudinal sample's length data. After the model was fitted, the median curve was shifted back downwards by 0.7 cm for ages above two years, and the coefficient of variation curve adjusted to the new median values to construct the height-for-age growth curves. The same power transformation of age was applied to stretch the age scale for each of the sexes before fitting cubic splines to generate their respective growth curves. The boys' curves required a model with higher degrees of freedom to fit both the median and coefficient of variation curves. The data for both sexes followed the normal distribution.

Weight-for-age. The weights of the longitudinal and cross-sectional samples were merged without any adjustments and a single model was fitted to generate one continuous set of curves constituting each sex-specific weight-for-age standard. The same power transformation was applied to both boys' and girls' age before fitting the curve construction model. The weight data for both sexes were skewed, so in specifying the model, the parameter related to skewness was fitted in addition to the median and the approximate coefficient of variation. In modelling skewness the girls' curves required more degrees of freedom to fit a curve for this parameter.

Weight-for-length/height. The construction of the weight-for-length (45 to 110 cm) and weight-for-height (65 to 120 cm) standards followed a procedure similar to that applied to construct the length/height-for-age standards. That is, to fit a single model, 0.7 cm was added to the cross-sectional height values, and after the model was fitted, the weight-for-length centile curves in the length interval 65.7 to 120.7 cm were shifted back by 0.7 cm to derive the weight-for-height standards corresponding to the height range 65 cm to 120 cm. The lower limit of the weight-for-length standards (45 cm) was chosen to cover up to approximately -2 SD girls' length at birth. The upper limit for the weight-for-height standards was influenced by the need to accommodate the tallest children at age 60 months, that is, 120 cm is approximately +2 SD boys' height-for-age at 60 months. The overlap between the upper end of the weight-for-length standards and the lower end of the weight-for-height standards is intended to facilitate their application in severely undernourished populations and emergency settings.

There was no evidence that a length/height transformation similar to that described for age was required for constructing the weight-for-length/height standards. The modelling of the median and variance curves followed the procedure described for the first two standards. Results from the final model for girls' weight-for-length/height suggested the need to investigate potential improvements in the curves by modelling kurtosis. Adjustment for kurtosis, however had a negligible impact on the final centiles. Therefore, considering that modelling the fourth parameter would increase complexity in application of the standards and create inconsistency between the sexes, the final curves were generated without adjusting for kurtosis. The degrees of freedom for the median and variance curves varied between the boys' and girls' standards. The fact that the weight-for-length/height indicator combines different velocities for the two measurements involved (weight and length/height) at overlapping ages likely explains the slight wiggle in the final WHO standards (for both boys and girls) as also observed in other references.

Body mass index-for-age. Body mass index is the ratio *weight (in kg)/recumbent length or standing height (in m²)*. To address the difference between length and height, the approach used for constructing the BMI-for-age standards was different from that described for length/height-for-age. Because BMI is a ratio with squared length or height in the denominator, adding 0.7 cm to the height values and back-transforming

them after fitting was not feasible. The solution adopted was to construct the standards for the younger and the older children separately based on two sets of data with an overlapping range of ages below and above 24 months. To construct the BMI-for-age standard based on length (0 to 2 years), the longitudinal sample's length data and the cross-sectional sample's height data (18 to 30 months) were combined after adding 0.7 cm to the height values. Analogously, to construct the standard from 2 to 5 years, the cross-sectional sample's height plus the longitudinal sample's length data (18 to 24 months) were combined after subtracting 0.7 cm from the length values. Thus, a common set of data from 18 to 30 months was used to generate the BMI standards for the younger and the older children. The resulting disjunction between the two standards thus in essence reflects the 0.7 cm difference between length and height. This does not mean, however, that a child at a specific age will have the same length- and height-based BMI-for-age z-score as this is mathematically impossible given the nature of the BMI ratio.

An age power transformation as described for the other age-based standards was required before constructing the length-based BMI-for-age curves. No such transformation was necessary for the height-based BMI-for-age. The WHO length- and height-based BMI-for-age standards do not overlap, i.e. the length-based interval ends at 730 days and the height-based interval starts at 731 days. Cubic spline fitting was achieved with variable degrees of freedom for the length- versus height-based standards, and also for the boys' versus girls' final curves.

Technical aspects of the standards. The method used to construct the WHO standards generally relied on the Box-Cox power exponential distribution and the final selected models simplified to the LMS model. As a result, the computation of percentiles and z-scores for these standards uses formulae based on the LMS method. However, a restriction was imposed on all indicators to enable the derivation of percentiles only within the interval corresponding to z-scores between -3 and 3. The underlying reasoning is that percentiles beyond ± 3 SD are invariant to changes in equivalent z-scores. The loss accruing to this restriction is small since the inclusion range corresponds to the 0.135th to 99.865th percentiles.

The weight-based indicators presented right-skewed distributions. When modelled correctly, right skewness has the effect of making distances between positive z-scores increase progressively the farther away they are from the median, while distances between negative z-scores decrease progressively. The LMS method fits skewed data adequately by using a Box-Cox normal distribution, which follows the empirical data closely. The drawback, however, is that the outer tails of the distribution are highly affected by extreme data points even if only very few. A restricted application of the LMS method was thus used for the construction of the WHO weight-based indicators, limiting the Box-Cox normal distribution to the interval corresponding to z-scores where empirical data were available (i.e. between -3 SD and 3 SD). Beyond these limits, the standard deviation at each age (or length/height) was fixed to the distance between ± 2 SD and ± 3 SD, respectively. This approach avoids making assumptions about the distribution of data beyond the limits of the observed values.

Epidemiological aspects of the standards. As expected, there are notable differences with the NCHS/WHO reference that vary by age, sex, anthropometric measure and specific percentile or z-score curve. Differences are particularly important in infancy. Stunting will be greater throughout childhood when assessed using the new WHO standards compared to the NCHS/WHO reference. The growth pattern of breastfed infants will result in a substantial increase in rates of underweight during the first half of infancy and a decrease thereafter. For wasting, the main difference is during infancy when wasting rates will be substantially higher using the new WHO standards. With respect to overweight, use of the new WHO standards will result in a greater prevalence that will vary by age, sex and nutritional status of the index population.

The growth standards presented in this report provide a technically robust tool that represents the best description of physiological growth for children under five years of age. The standards depict normal early childhood growth under optimal environmental conditions and can be used to assess children everywhere, regardless of ethnicity, socioeconomic status and type of feeding.