8. CONCLUSION

The goal of the MGRS was to describe the growth of healthy children. Well-defined criteria were applied in the study design to achieve this aim. Screening at enrolment using site-specific socioeconomic criteria and maternal non-smoking status excluded children likely to experience constrained growth. Morbidities that affect growth (e.g. repeated bouts of infectious diarrhoea and Crohn disease) were identified and affected children were excluded from the sample. Application of these criteria resulted in the exclusion of all detectable undernutrition from both the longitudinal and cross-sectional samples.

In the longitudinal sample, the criterion of breastfeeding through 12 months and its close monitoring throughout data collection yielded a sample of children with no evidence of overnutrition (i.e. no excessive right skewness). In the cross-sectional sample, however, despite the criterion of at least 3 months of any breastfeeding, the sample was exceedingly skewed to the right, indicating the need to identify and exclude excessively high weights for height if the goal of constructing a standard was to be achieved. A similar prescriptive approach was taken by the developers of the CDC 2000 growth charts for the USA when, for the weight and BMI growth charts, they excluded data from the last national survey (i.e. NHANES III) for children aged ≥6 years. Without this exclusion, the 95th and 85th percentile curves of the CDC charts would have been higher, and fewer children would have been classified as overweight or at risk of overweight (Kuczmarski et al., 2002).

The construction of the child growth curves followed a careful, methodical process. Rigorous methods of data collection, standardized across sites, were followed during the entire study. Sound procedures for data management and cleaning were applied (Onyango et al., 2004). As a result, the anthropometric data available for analysis were of the highest possible quality. The selection of the best statistical approach to construct the standards followed a broad consultative process that included a thorough review of 30 available methods. State-of-the-art statistical methodologies were then employed to generate the standards (Borghi et al., 2006).

The Box-Cox-power-exponential (BCPE) method (Rigby and Stasinopoulos, 2004a), with curve smoothing by cubic splines, was selected as the approach for constructing the growth curves. The BCPE accommodates various kinds of distributions, from normal to skewed or kurtotic, as necessary. There was wide variability in the degrees of freedom required for the cubic splines to achieve the best models. Except for length/height-for-age, which followed a normal distribution, all other standards required the modelling of skewness but not kurtosis. A set of diagnostic tools was used to detect possible biases in estimated percentile or z-score curves. These included examining patterns of differences between empirical and fitted centiles, and comparing observed and expected proportions of children with measurements below selected percentile curves. Percentile and z-score curves for boys and girls aged 0–60 months were generated for length/height-for-age, weight-for-age, weight-for-length (45 to 110 cm), weight-for-height (65 to 120 cm) and body mass index-for-age. The last indicator is an addition to the previously available set of indicators in the NCHS/WHO reference. Appendix A summarizes the specifications of the BCPE models for each of the standards.

It was possible to construct both length-for-age (birth to 2 years) and height-for-age (2 to 5 years) standards fitting a unique model, yet still reflect the average difference between recumbent length and standing height. The cross-sectional component included the measurement of both length and height in 1625 children aged 18 to 30 months, and from these data it was estimated that length was larger by 0.7 cm on average. To fit a single model for the whole age range, 0.7 cm was therefore added to the cross-sectional height values. After the model was fitted, the final curves were shifted downwards by 0.7 cm for ages 2 years and above to create the height-for-age standards. Coefficient of variation values were adjusted to reflect this back-transformation using the shifted medians and standard deviations. The length-for-age standard was derived directly from the fitted model. A similar approach was followed in generating the weight-for-length (45 to 110 cm) and weight-for-height (65 to 120 cm) standards.

The difference between length and height was handled differently in constructing the BMI-for-age standards. 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 (birth 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 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.

Overall, concordance between smoothed curves and empirical centiles was excellent and free of bias in both the median range and the tails, indicating that the resulting curves are an adequate description of the true growth of healthy children. The length- and height-for-age standards had the best fit, and the performance was almost as good for the standards based on combinations of weight and length. For example, the average absolute difference between smoothed and empirical centiles was 0.13 cm for boys' length-for-age (Figure 7) and 0.16 kg for girls' weight-for-height (Figure 84). Taking the sign into account, the average differences are close to zero: -0.03 cm and -0.02 kg, respectively, which indicates lack of bias in the fit between smoothed and empirical percentiles.

Differences between the previously recommended NCHS/WHO international reference and the new WHO standards have been illustrated in this report. As expected, there are notable differences that vary by age, sex, anthropometric measure and specific percentile or z-score curve. Differences are particularly important in infancy. Impact on population estimates of child malnutrition will depend on age, sex, anthropometric indicator considered, and population-specific anthropometric characteristics. Thus, it is impossible to construct an algorithm that can derive prevalence estimates based on the WHO standards directly from estimates obtained from the NCHS/WHO reference. A noteworthy effect is that estimates of stunting will be higher throughout childhood when assessed using the new WHO standards compared to the previous international reference. The growth pattern of breastfed infants compared to the NCHS/WHO reference will result in a substantial increase in underweight rates during the first half of infancy (i.e. 0–6 months) and a decrease thereafter. For wasting, the main difference between the new standards and the old reference is during infancy (i.e. up to about 70 cm length) 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.

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 samples' weight-for-age and weight-for-height, the developers of the reference calculated separate standard deviations for distributions below and above the median for each of the two indicators (Dibley et al., 1987). 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. When modelled correctly, the right skewness in data 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. To fit the skewed data adequately, the LMS method (Cole and Green, 1992) fits a Box-Cox normal distribution, which follows the empirical data closely. The drawback of this method is that the outer tails of the distribution are highly affected by extreme data points even if very few (e.g. less than 1%). 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 was fixed to the distance between ±2 SD and ±3 SD, respectively. This approach avoids making assumptions about the distribution of the data beyond the limits of the actual data (e.g. the 3 SD corresponds to the 99.9th percentile). The construction of the CDC 2000 growth charts (Kuczmarski, 2002) was also based on the LMS method and, therefore, differences seen in the comparisons between this reference and the WHO standards are largely a reflection of differences in the populations on which the two sets of curves are based.

The WHO Child Growth Standards provide a technically robust tool for assessing the well-being of infants and young children. They were derived from children who were raised in environments that minimized constraints to growth such as poor diets and infection. In addition, their mothers followed healthy practices such as breastfeeding their children and not smoking during and after pregnancy. 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. Replacing the NCHS/WHO growth reference, which is based on children from a single country, with one based on an international group of children recognizes the fact that children the world over grow similarly when their health and care needs are met. In the same way, linking physical growth to motor development underscores the importance of looking at child development comprehensively. Together, three new elements — a *prescriptive* approach that moves beyond the development of growth references towards a standard, inclusion of children from around the world, and links between physical growth and motor development — provide a solid instrument for helping to meet the health and nutritional needs of the world's children.