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 National Center for Health Statistics (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, the WHO Multicentre Growth Reference Study (MGRS) was implemented between 1997 and 2003 to develop international growth standards for children below 5 years of age. The MGRS is unique in that it was purposely designed to produce a standard by selecting healthy children from diverse ethnic backgrounds 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. The first set of the WHO Child Growth Standards for attained growth based on length/height, weight and age was released in April 2006. The second complementary set, based on head and arm circumference and subscapular and triceps skinfolds, followed a year later.

A key component in the MGRS design was a longitudinal cohort of children who were examined in a sequence of 21 visits starting at birth and ending at 24 months of age. Such frequently collected and well-controlled data are highly unusual. A principal rationale for the MGRS longitudinal component was to allow for the development of growth velocity standards. The increments on which the velocity standards are based were calculated using the longitudinal sample of 882 children (428 boys and 454 girls) whose mothers complied fully with the MGRS infant-feeding and no-smoking criteria and completed the follow-up period of 24 months. The children were measured at birth; at weeks 1, 2, 4 and 6; monthly from 2–12 months; and bimonthly in the second year.

On the recommendation of a consultative expert group it was decided to develop velocity standards for the following anthropometric variables: weight (the most commonly used measurement and the most responsive to short-term influences), head circumference (the next most-used measurement in clinical settings), and length (potentially useful since stunting originates in the first two years of life, and early detection of changes in velocity may be beneficial for prevention). It was hypothesized that body mass index (BMI) velocity might be useful in predicting changes leading to extremes of adiposity. However, unreliability in BMI increments is a composite of measurement error from various sources. Moreover, BMI peaks during infancy and then drops through the second year. These characteristics make BMI velocity difficult to interpret, and there is little knowledge of its prognostic utility. Therefore, BMI velocity standards were not developed.

Another recommendation by the consultative expert group on the construction of the velocity curves was to explore other distributions in addition to the one used to construct the attained growth standards (the Box-Cox-power-exponential — BCPE). This investigation was carried out in an effort to identify the most appropriate methodology for handling anticipated negative increments specifically in relation to weight. The findings favoured the application of the BCPE distribution with some methodological adjustments only in the case of weight conditional on age. The steps followed to select the best models to fit the data for each indicator were comparable to those used to construct the attained growth standards.

Before the BCPE could be applied to the weight increments conditional on age, it was necessary to add a constant value, delta, to all weight increments to shift their distribution above zero. Afterwards, the predicted centiles were shifted down by the pre-added delta. By the MGRS design, the latest 3-month increment that could be calculated based on observed measurements was from age 11 to 14 months. The 3-month velocities were constructed for the full age range (birth to 24 months) using the parameter curves estimated for the 2-month (birth to 24 months), the 3-month (birth to 14 months) and the 4-month (birth to 24 months) intervals jointly in a cubic spline surface. All velocity standards required the modelling of skewness. In the interest of keeping the z-score calculation formula simple and considering the fact that adjustment for kurtosis had negligible impact on the final predicted
centiles, it was decided not to fit kurtosis (i.e. models were restricted to the LMS class). The diagnostic tools used iteratively to detect possible model misfits and biases in the fitted curves included tests of local and global goodness of fit, such as Q-tests and worm plots. Patterns of differences between empirical and fitted centiles were also examined.

Following wide consultation with different potential users of these standards (e.g. paediatric endocrinologists, neonatologists, lactation counsellors, managers of child health programmes, and researchers), the increments presented in this report are those considered to be most useful clinically. The WHO velocity standards for weight are presented as 1-mo increments from birth to 12 months, and as 2- to 6-month increments from birth to 24 months. In addition, weight increments are presented from birth to 60 days in 1-week and 2-week intervals that coincide with the measurement schedule in the MGRS. The velocity standards for length are presented in 2- to 6-month increments from birth to 24 months. For head circumference, 2- and 3-month increments are presented from birth to 12 months, and 4- and 6-month increments from birth to 24 months. One-month increments for length and head circumference were not considered clinically useful as the measurement error over such a short period exceeds the 5th centile as early as 6 months of age. For similar reasons, the 2- and 3-month increments for head circumference go up to 12 months of age only. The overall choice of intervals is in line with those proposed by other authors. Electronic copies of the full set of velocity standards are available on the Web: www.who.int/childgrowth/en.

The intrinsic biological complexity of the dynamics of human growth makes the use and interpretation of the standards presented in this report more challenging than that of the attained growth standards. Growth progresses at a rapidly decelerating rate from birth, reaching a near-plateau by the end of the first year, and continues to taper off gently through the second year. This is the expected overall pattern of growth under conditions of adequate nutrition and psychosocial care. However, growth velocities of individual children are characterized by very high variability in consecutive growth intervals. It is not unusual for a child to grow at the 95th velocity centile one month and at the 20th the next while continuing to track on the attained weight-for-age chart. Correlations between subsequent increments are typically low; this reflects both a natural pattern of saltatory growth and possible catch-up or catch-down growth that contributes to overall narrowly canalized patterns in the attained growth trajectories of individual children.

The 1-, 2-, 3-, 4- and 6-month increment tables are independent of each other and the clinician should use the one that most closely approximates the interval over which the child is seen. For example, the centile corresponding to an increment between age 2 and 3 months is not associated with the centile corresponding to half of the increment in the 2-month interval between ages 1 and 3 months. This is because one cannot expect the growth rate in a given 2-month period, except perhaps at the median, to be the sum of the two corresponding 1-month intervals. With specific reference to weight, negative increments, which generally occur after 6 months of age, are captured in the lowest centiles. They coincide with the weaning period, when children are more exposed to food contamination, and when they become more active and start to explore their environment.

The tables of weight velocity from birth to 60 days present physiological weight losses that occur in the early postnatal period but are not usually included in available reference data. It was not possible to estimate from these data precisely when infants should recover their birth weight following weight loss that is common in the first few postnatal days. Net increments at the median (0 to 7 days) are positive for both boys and girls, suggesting that recovery of birth weight could be achieved in less than one week. Considering the 25th centile (0 g increment from birth to 7 days), the data suggest that 75% of newborns recover their birth weight by day 7. It is understood that recovery depends on what percentage of birth weight was lost and the successful initiation of lactation. However, rather than focus only on weight gain, it is important to adopt a holistic approach that looks at the child's overall health status and clinical signs, which are key to maintaining successful infant nutrition. This includes also assessing mother-child interaction, indicators of successful breastfeeding such as infant breastfeeding behaviour and the timing of stage II lactogenesis, and breastfeeding technique. Centiles are presented for both net increments and velocity in g/d. When mother-child dyads experience
breastfeeding difficulties in the early postpartum period, lactation performance and weight gain are monitored every few days, hence increments per day are likely to be handier to use than weekly or fortnightly increments. However, even in the absence of such difficulties, visits to the clinic take place at random ages, and these daily increments offer a flexible option for evaluating growth over fractions of the tabulated time blocks.

Measurements of growth are subject to error from multiple sources. Faulty measurements can lead to grossly erroneous judgements regarding a child's growth. The accuracy of growth assessment is improved greatly if measurements are replicated independently and the values averaged. Although the high level of reliability achieved in the MGRS is unlikely to be reached in routine clinical measurement in primary health care settings, measurements need to be taken with reasonable care and accuracy as the calculation of increments involves two measurement errors.

Ideally, velocity assessment should be done at scheduled visits that coincide with the ages and intervals (1, 2, 3, 4 and 6 months) for which the centiles are presented. In practice, however, the timing of clinic visits is dictated by uncontrollable factors, and ingenuity will be called for in applying the standards. The discussion section of the report provides overall guidance on interpreting increments that are beyond the allowable range of variation around the intervals, or observed intervals that are on target (say exactly 2 months) but with starting and ending ages that do not coincide with those tabulated in the standards.

There are some fundamental differences between velocity and attained (distance) growth that affect how the increment standards should be used and interpreted. Chief among them is the lack of correlation between successive increments in healthy, normally growing children. For individual attained growth curves, the variability in successive z-scores tends to be minimal over short periods (there are high correlations between successive attained values). This "tracking" is not usually seen for successive individual growth velocities. In the WHO standards, the probability of two consecutive 1-month or 2-month weight increments falling below the 5th centile is 0.3%. If the 15th centile is chosen, this probability increases to only 2% and 1.8%, respectively. Normally growing children can have a very high z-score one month and a very low one the following month, or vice versa, without any underlying reason for concern. Thus, a single low value is not informative; only when velocities are repeatedly low should they cause concern. Nevertheless, very low z-score values, even if observed only once, should raise the question of whether there is underlying morbidity within the holistic clinical assessment of the child.

During periods of severe illness (e.g. prolonged diarrhoea) one would expect very low velocity followed by compensatory high velocity (catch-up). During catch-up growth, one would expect successive increments to be repeatedly in the higher ranges. An important difference with attained growth is that single extreme values of increments are comparatively less worrisome. Ultimately, growth velocity must always be interpreted in conjunction with attained growth, since the position on the attained growth chart is essential to interpreting the growth rate.

The velocity standards presented in this report provide a set of tools for monitoring the rapid and changing rate of growth in early childhood. Future research will need to determine what patterns of successive velocity thresholds over which specified intervals have the best diagnostic and prognostic validity for specific diseases.