Assessment of growth: variations according to references and growth parameters used1–3

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ABSTRACT
Numerous studies have investigated associations between early growth and future risk of obesity, but the methods used varied considerably. Different growth references or parameters can be considered. Growth references from France, the United States (the Centers for Disease Control and Prevention), the Netherlands, Belgium, and the United Kingdom were compared with World Health Organization (WHO) standards. For the first 3 mo of life, all references showed markedly lower values for weight, length, and body mass index (BMI) compared with WHO standards, but after the age of 6 mo references were generally higher than WHO standards. Compared with nonbreastfed infants, the growth of breastfed infants was generally closer to that of WHO standards. Because data in the WHO standards were collected on infants who were breastfed, the difference between references and WHO standards might be mainly attributable to feeding practices. Epidemiologic and clinical studies evaluated the consequences of using either WHO standards or national references and showed differences according to the reference used. Analyses of children’s weight curves by physicians showed significant differences in the interpretation of child growth and therefore in the advice given to parents. Finally, the effect of using different growth parameters to predict future risk of obesity was examined and showed that weight and length gains may be good candidates to study future risks. In conclusion, because the reference or parameters used to assess growth have an important effect on the interpretation of growth, it is crucial to be aware of the consequences of the methods used in clinical or epidemiologic contexts. Am J Clin Nutr 2011;94(suppl):1794S–8S.

INTRODUCTION
Many early life factors play a role in the development of later overweight and obesity (1). Growth, in particular, is an important marker of later health and depends primarily on nutrition. Both infant body size during the early years of life and infant growth velocity have been shown to be associated with risk of later overweight and obesity in childhood and adulthood (2–4). Weight gain is a particularly accurate predictive indicator of obesity compared with changes in length (5–7) or body mass index (BMI) (6).

Given the importance of growth in early life and childhood in relation to future disease, it is crucial to precisely monitor childhood growth and determine whether it is adequate. Growth charts are essential for evaluating growth and development. However, the evaluation of childhood growth trajectories is highly dependent on the growth charts used. Much growth data are available. Longitudinal growth studies have been conducted since the early 20th century in North America (8): The University of Iowa Child Welfare Research Station study was conducted in 1917–1970 by Baldwin and Meredith, the Harvard growth study was carried out in 1922–1934 by Dearborn and Shuttleworth, the Fels longitudinal study by Roche and Falkner was started in 1929, and the Philadelphia Center for Research in growth study by Krogman and Johnston began in 1948. In Europe, longitudinal growth studies have been conducted since the middle of the 20th century and include the Oxford Child Health Survey dating from 1944 by Ryle et al and the Harpenden Growth Study in 1948 by Tanner et al. Finally, the International Children’s Center study coordinated by Masse and Falkner was conducted in London, Paris, Zurich, Stockholm, Brussels, Louisville (KY), and Dakar from 1953 on (9). These data are still being used as references in countries such as France (10). Other countries throughout the world later developed their own references.

More recently, the World Health Organization (WHO) released new standards for assessing the growth and development of children from birth to 5 y of age (11). WHO standards were developed to replace the National Center for Health Statistics/WHO international growth reference (12), the limitations of which have been described in detail elsewhere (13).

In the literature, studies that assessed children’s growth used various references and growth parameters. Therefore, we were interested in reporting comparisons between available references and investigating potential differences between the new WHO standards and national references in France, the Netherlands, Belgium, the United States, and the United Kingdom. We also discuss implications of using these various references and stand-
ards in epidemiologic and clinical contexts. Finally, we examine the predictive value for later overweight by using different growth parameters.

METHODS AND RESULTS

Differences according to the reference used

WHO standards

In 2006, new WHO standards were released (11). The WHO Multicenter Growth Reference Study aimed at describing the growth of healthy breastfed infants (14). In this study, mothers followed health practices that included not smoking during or after pregnancy and ensuring adequate health care for children. The study was conducted in 6 countries (Brazil, Ghana, India, Norway, Oman, and the United States) and combined longitudinal follow-up (birth to 24 mo of age) with a cross-sectional component (18–71 mo of age). Eligibility criteria for the cross-sectional component were the same as those for the longitudinal component, with the exception of feeding practices. The longitudinal component included exclusive or predominant breastfeeding at  ≥24 mo of age, the introduction of complementary foods by 6 mo of age, and continued breastfeeding to ≥12 mo of age. The criterion for the cross-sectional component was a minimum of 3 mo of breastfeeding. Growth curves were generated for boys and girls aged 0–60 mo, and software was developed by the WHO (15). The software converts measurements into z scores that enable comparisons of various anthropometric characteristics such as weight-for-age, height- and length-for-age, BMI-for-age and, more recently, growth velocities. WHO standards demonstrated that children worldwide who are raised in healthy environments and benefit from healthy feeding practices have strikingly similar growth patterns (16). The standards depict normal human growth under optimal environmental conditions and, therefore, can be used to assess children everywhere, regardless of ethnicity or socioeconomic status. In contrast, references are often established on the basis of a representative population without selection criteria for feeding practices.

Comparison between French values and WHO standards

In France, reference curves (10) were established by using data from the International Growth Study (9). The same subjects were followed from birth (in 1953–1955) to adulthood (in 1979). Anthropometric measurements were performed by using a protocol similar to that used in the Multicenter Growth Reference Study (17), which enabled valid comparisons between the 2 studies. For comparative purposes, weight, length and height, and BMI measurements of French children were transformed into z scores with WHO Anthro software (15). Comparisons between French measurements and WHO standards (18) are shown in Figure 1, A and B. French birth measurements were close to those of WHO standards. Length was 50.0 ± 2.2 cm in French studies and 49.9 ± 1.9 cm in WHO studies for boys and 49.4 ± 1.8 cm in French studies and 49.2 ± 1.9 cm in WHO studies for girls. Weight was 3.39 ± 0.44 kg in French studies and 3.35 ± 0.49 kg in WHO studies for boys and 3.28 ± 0.47 kg in the French studies and 3.23 ± 0.46 kg in WHO studies for girls. Thereafter, substantial differences appeared during the first months of life. After birth and until 6 mo, all French values (ie, length, weight, and BMI) were lower than WHO values, with differences attaining a −0.9 z score at the age of 1–3 mo. Subsequently, length remained lower until 5 y of age. For weight, French and WHO values were similar at around 6 mo; thereafter, French values were higher than WHO values until the age of 2 y. After 2 y of age, French values were lower than the age of 5 y (−0.3 z score). For the BMI, French values attained WHO values at 6 mo. Then, French values exceeded WHO values, with a maximum difference of a +0.8 z score at 18 mo and finally came close to WHO values again at the age of 5 y. These observations were similar in both sexes.

Another study aimed at evaluating the prevalence of overweight and obesity in 7–9-y-old children born in 1991–1993 and living in France was carried out in 2000 (19). Data on growth were collected retrospectively in the child’s health booklet and were compared with those of WHO standards (Figure 1B). The same trends as those when French references were compared to WHO standards were observed. Until 6 mo, all French values were lower than WHO values. After 9 mo, French children had shorter lengths but higher weights and BMI than WHO values. Compared with differences recorded between children born in 1953 (10) and WHO standards (−0.8 to +0.8 z score), these observations indicated that differences between children born in 1991–1993 (19) and WHO standards were smaller (−0.4 to +0.4 z score). These results suggested a trend toward decreasing differences between French and WHO populations over time.

Comparison between references from various countries and WHO standards

In the United States, the 2000 Centers for Disease Control and Prevention (CDC) growth charts (20) were developed on the basis of national data collected via a series of 5 surveys between 1963 and 1994 (21). The most recent survey was the National Center for Health Statistics/CDC Third National Health and Nutrition Examination Survey (1988–1994). There was no criterion for feeding practices.
In the Netherlands, cross-sectional growth reference data were obtained in 1955, 1965, 1980, and 1997. In the biometric survey of 1997, length, height, and weight were measured in 14,500 healthy 0–20-y-old individuals of Dutch origin (22). This sample was nationwide and representative of the demographic, geographic, and socioeconomic distribution of the population. There was no criterion for feeding practices.

In Belgium, cross-sectional growth reference data were obtained in 2002–2004. Length, height, and weight were measured in a sample of 15,989 healthy subjects of Belgian origin of 0–25 y of age (23). There was no criterion for feeding practices.

In the United Kingdom, the Royal College of Pediatrics and Child Health recommended the use of UK 1990 growth reference charts (24), which included weight, height, BMI, head circumference, and stages of puberty from birth to 20 y of age. There was no criterion for feeding practices.

Weight-for-age values of the United States (CDC) (20), Netherlands (22), Belgium (23), United Kingdom (24, 25), and France (10) compared with those of WHO standards are shown in Figure 2. At birth and during the first weeks of life, weight-for-age values of these references were greater than those of WHO standards. Thereafter, as was the case for French references, weight-for-age values were lower until 6 mo of age and subsequently overtook WHO-standard values.

In those 4 studies, birth weight was higher than that of WHO standards (Figure 2). Therefore, a regression to the mean could be suggested to explain the early deviation between references and WHO standards. However, this explanation does not apply to French references because birth weight was close to that of WHO standards (Figure 1). Therefore, in addition to other explanations (26), differences between growth charts might be partly because of the different growth patterns of breastfed compared with nonbreastfed infants.

**Comparison of breastfed and nonbreastfed samples with WHO standards**

Length and height, weight, and BMI z scores according to WHO standards were calculated in a 2002–2004 reference population from Belgium and in a subset of exclusively breastfed children from the reference population (27). Children were considered exclusively breastfed if they had been breastfed for ≥6 mo, and no formula milk was introduced before that age. As was the case for the entire Belgium population, weight-for-age values of breastfed infants were greater at birth and until 2 mo of age, lower between 2 and 6 mo of age, and subsequently overtook WHO-standard values; however, length and weight growth patterns in the breastfed population were closer to those of WHO standards than measurements of the entire population.

A multicenter European study was performed to compare the growth of children who were randomly assigned to receive formula that contained either a higher or lower protein content (28). An observational group of exclusively breastfed children was included for additional comparisons. Birth weight was identical in the 3 groups (boys: 3.34 kg; girls: 3.25 kg) and was similar to the birth weight of WHO standards (boys: 3.35 kg; girls: 3.23 kg) (Figure 3). Subsequently, the weight in the 3 groups was lower than the weight in WHO standards, but finally exceeded the weight in WHO standards from the ages of 4–9 mo. From 0 to 2 y of age, the weight growth pattern of breastfed infants tended to be closer that of WHO standards than the weight pattern of formula-fed infants. The weight growth pattern of the lower-protein group was closer to those of the breastfed group and WHO standards than to that of the higher-protein group. Again, because birth weight was close to that of WHO standards, the regression to the mean could not explain the differences observed in the first months of life.

**Implications for the use of WHO standards**

Clinical implications: A recent study was conducted in France to determine whether the use of different references could influence growth interpretation and subsequent advice given to parents (29). Twenty-two physicians retrospectively interpreted individual growth curves of 20 exclusively breastfed infants according to either French references or WHO standards. All curves were interpreted twice. A statistically significant difference in the interpretation of French and WHO curves was recorded at the age of 2 mo. In one-third of infants, weight gain during the first weeks of life was overestimated by using French references than when WHO standards were used. In those subjects, either restrictive feeding was advised or a weight deficit was not taken into account.

Epidemiologic implications: The prevalence of overweight in 0–59-mo-old children from the United States (National Health and Nutrition Examination Survey 1999–2004) was assessed on the basis of either CDC references or WHO standards...
When the 95th percentile of weight-for-length was used, the prevalence of overweight was lower by using CDC references (9.6%) than WHO standards (12.8%). However, the prevalence was comparable when using the 95th percentile for the CDC references (9.6%) and the WHO-recommended cutoffs of +2 z score (97.7th percentiles) (8.5%). In a study conducted in 2001 in 24–60 mo-old girls from the Czech Republic (31), the prevalence of overweight was 15.3% by using the International Obesity Task Force definition, whereas by using WHO standards, 3.4% and 19% of subjects had a BMI above +2 and +1 z scores, respectively. Therefore, the prevalence of overweight in children varied according to the chart used and the cutoffs applied.

Differences according to the growth parameter used

On the basis of a longitudinal study (32), we examined the predictive value of adult body composition by using weight, length, or BMI changes (33). As in previous studies, we showed that fat body mass (assessed by bioimpedance analysis) at an adult age was associated with weight gain between birth and 2 y of age \( (r = 0.42, P < 0.01) \) and also with length gain \( (r = 0.28, \; P < 0.05) \) and BMI changes \( (r = 0.33, \; P < 0.01) \). After adjustment for length gain, the predictive value of weight gain for later fat body mass was decreased \( (r = 0.32, \; P < 0.05) \) and reached a similar level as for length and BMI.

DISCUSSION

Differences according to the reference used

Marked differences appeared between growth measurements in WHO standards and national references [French, the United States (CDC), Netherlands, Belgium, and the United Kingdom]. In all comparisons, the same pattern of differences was observed (ie lower values compared with those of WHO standards in the first 6 mo of life, higher values compared with those of WHO standards from 6 mo to 18 mo of age, and closer values to those of WHO standards thereafter. These differences must be taken into account, as they affect the interpretation of results at clinical (29) and epidemiologic (30, 31) levels. From a clinical point of view, the use of WHO standards increases the number of children considered having a low rate of growth. The choice of a specific chart might indicate that a child had an adequate growth, whereas other charts showed that the same child may deviate from the mean curve, which could lead pediatricians to propose changes in feeding practices or other health measures.

Differences between national references and WHO standards may have various explanations. WHO standards were recent compared with most national references (eg, French references were established 40 y before WHO standards), and changes in growth over time may have occurred. Indeed, differences between the most recent French study and WHO standards were smaller than differences between the French study conducted 40 y earlier and WHO standards (Figure 1). Geographic characteristics might also play a role in the observed differences. However, this is unlikely to have occurred because all references from different countries [France, the United States (CDC), the Netherlands, Belgium, and the United Kingdom] showed a similar pattern of differences from WHO standards, and because WHO standards are based on a study conducted in several countries rather than just one.

Another potential factor that explained differences between WHO standards and other references is the type of feeding. The longitudinal component included exclusive or predominant breastfeeding for \( \geq 4 \) mo, the introduction of complementary foods by 6 mo of age, and continued breastfeeding until \( \geq 12 \) mo of age. On the other hand, the feeding type was not a selection criterion in the other reference studies. At the time of the French reference study (10), breastfeeding was particularly low [ie, only one child out of 2 (34)]. Weight differences between WHO standards and national references during the first months of life were comparable with differences observed between breastfed and nonbreastfed infants, respectively. In the first 6 mo, breastfed infants were generally heavier than nonbreastfed infants; thereafter, breastfed infants were leaner (35). Studies that evaluated weights of breastfed infants compared with those of nonbreastfed infants showed that the former were closer to those of WHO standards than to those of US (CDC) (36) or French (29) references. In the multicenter European study and Belgium study, the weight and length growth patterns of breastfed infants were closer to those of WHO standards (with less fluctuation when compared with that of WHO standards) than was the growth patterns of nonbreastfed infants (27, 28). Therefore, it appears that WHO standards are better adapted for assessing the growth of breastfed children than are traditional references.

In the multicenter European study (28) that compared the growth of infants who received either a higher- or lower-protein formula, growth in the lower-protein group was closer to that of the breastfed group than that of the higher protein group. Therefore, it can be hypothesized that the lower protein proportion in the milk of breastfed babies contributes to the growth pattern described in WHO standards. Interestingly, no effect of the intervention on length growth was observed at any time point over the first 24 mo of life (28).

Differences according to the growth parameter used

It has been shown that infant body size and growth velocity during the early years of life were associated with risk of developing later overweight and obesity in childhood and adulthood (2–4). However, rate of growth is generally investigated on the basis of an increase in weight, whereas the effect of other anthropometric indicators on later overweight and obesity has received less attention. A study that examined the association between early growth and later body composition in Brazilian boys showed similar predictive values for weight and BMI changes (7). Results in the literature concerning length are inconsistent. Some studies showed no or only a limited association (6, 7, 37, 38), whereas other studies showed an association in boys only (5), and still other studies showed an association in both sexes (39).

In our study, as in previous studies, weight gain had the best predictive value for later overweight, but after adjustment for length gain, the predictive value of weight gain was no greater than that of length gain or BMI change. Despite their similar predictive values, it must be investigated whether these different growth parameters are associated with different metabolic risks at adult age.

Conclusions

Growth parameters of various references were compared with those of WHO standards. A similar pattern of differences emerged...
for all references with, as a rule, lower values compared with those of WHO standards in the first months of life and followed by subsequent higher values. Breastfeeding practices seemed to play an important role in growth. Therefore, WHO standards should be used to assess growth, particularly in breastfed children.

The data presented here show that the growth reference or parameters used have an important effect on the results obtained in studies that assess childhood growth. Therefore, it is crucial to be aware of the consequences of the methods used when interpreting growth data in clinical and epidemiologic contexts.

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