Growth Charts Compared

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Abstract

Growth assessment of children requires comparison of growth measurements with normative references, usually in the form of growth charts. Traditionally growth charts (growth references) have described the growth of children who were considered normal and were living in a defined geographic area. The new WHO growth charts, on the other hand, are growth standards that aim to represent growth as it occurs worldwide. Moreover, they represent growth as it occurs under optimal circumstances and is thought to be conducive to optimal long-term health. Most growth references are single-country references, exemplified here by charts from the UK, the Netherlands and the USA. By contrast, the Euro-Growth reference and the WHO standard are based on multinational samples. Comparison of these five charts reveals surprisingly large differences that are for the most part unexplained. Differences between the WHO charts and other charts are only partially explained by the use of a prescriptive approach and by the data truncation employed. The large differences between charts probably are of merely trivial consequence when charts are used in monitoring individual children. When charts are used in health assessment of groups of children, the impact of the differences, however, is substantial.

Growth is a sensitive indicator of the health of infants and children. The assessment of growth therefore plays a central role in child health monitoring. Growth assessment involves comparison of an individual child’s growth performance with norms in the form of growth charts. Growth charts are also used to assess the growth of groups of children in epidemiological studies [1]. Many countries have created their own national growth charts. Countries that do not have their own charts must rely on charts created elsewhere.

The claim of growth charts to represent the norm usually derives from the fact that they represent the observed growth of normal children living in a defined geographic area, such as country or a continent (e.g. Europe). Since
they aim to represent the growth of normal children, they exclude data for children with chronic illnesses, especially illnesses that affect growth, and data for children on medications that potentially affect growth. Also, children born prematurely or with low birthweight may or may not be included, with considerable variation in the birthweight cutoff when they are included. Some national growth charts exclude children from racial/ethnic minorities. Growth charts that represent all children deemed to be normal are referred to as descriptive growth charts or growth references. The national growth charts for the UK [2], the Netherlands [3] and the USA [4] as well as the multinational Euro-Growth chart [5] are examples of growth references.

The WHO 2006 [6] multinational growth charts depart from the growth reference model in several ways. To be globally representative, children living in six countries provided the measurements for the WHO charts. But the children were not representative of their country of residence. Rather, they were selected on the basis of sociodemographic characteristics and other criteria, including whether or not the child’s nutrition adhered to WHO guidelines. Although the selection criteria were the same in all six countries and were applied uniformly, their application led to the exclusion of a variable proportion of children, so that in some countries the great majority of children were excluded whereas in others only a small proportion was excluded. Also, in constructing the charts for 2- to 5-year-old children, data for children with the highest weight for height were deemed unhealthy and were excluded. The growth charts generated by this ‘prescriptive’ approach are referred to as growth standards.

The great majority of growth charts have been constructed from cross-sectional data where each child is measured once. One key advantage of this approach is that it makes possible the measurement of relatively large numbers of subjects. The alternative approach has been to measure children longitudinally. Both of the multinational charts discussed here used the longitudinal approach (WHO only for birth to 2 years, not for 2–5 years). They were based on relatively small numbers of subjects, which is the main disadvantage of the longitudinal approach. The possibility to create norms of incremental growth, the main advantage offered by the longitudinal approach, has only been realized by Euro-Growth [7].

**Methods**

We compare three national growth charts, i.e. charts for the UK [2], the Netherlands [3] and the USA [4], and two multinational charts, Euro-Growth [5] and WHO [6]. The three national charts as well as the WHO charts for 2–5 years are based on cross-sectional data from relatively large numbers of subjects. The multinational charts are based on longitudinal measurements either entirely (Euro-Growth) or for the first 2 years (WHO). The number of subjects in the longitudinal samples was relatively small (birth to 2 years 1,205 in Euro-Growth and 882 in WHO). Although there were
considerable differences with regard to the extent to which low birthweight/prema-
ture infants were included, these differences are unlikely to affect the character of
the charts except at the extreme outlying percentiles. For purposes of comparison,
we also include growth data for breastfed infants collected in various localities (see
below).

The charts for the UK (UK90) [2] are based on data from 37,700 children (boys
and girls) from 17 separate surveys and are deemed representative of the popula-
tion of England, Scotland and Wales. The children ranged in age from birth to 23 years
and included all prematurely born and low birthweight infants. Most ethnic non-white
children were excluded.

The Dutch charts (NL97) [3] are based on 14,500 boys and girls who were con-
sidered representative of the Netherlands. Infants with birthweight <2,500 g were
included. Children of non-Dutch parents were excluded with the exception of children
with one Dutch and one West European parent.

The US charts (CDC) [4] represent a modification of the 1977 NCHS charts [8],
which had been adopted for global use as NCHS/WHO charts. The CDC charts are
based on data from 5 nationally representative surveys (NHANES) conducted in the
US between 1963 and 1994. Because the surveys included only small numbers of sub-
jects less than 1 year old (fewer than 330 per month), additional length data (but not
weight data) were obtained from government-sponsored health clinics for months 1–5.
Thus, for the age bracket 3–12 months the charts are based on weight data from fewer
than 300 subjects per month and for months 1 and 2 no weight data. Length data for
6–12 months were similarly limited, but for 1–5 months data from several thousand
subjects were used. No information about the nutritional management of infants is
available. Weight data for children >6 years obtained between 1988 and 1994 were
excluded because of the high prevalence in that cohort of children with ‘unhealthy’
(i.e. high) weights.

The Euro-Growth charts (Euro) [5] are based on data gathered at 22 sites in 11
European countries. Subjects born between 1990 and 1993 were followed longitudi-
nally from birth to 5 years. Of 2,245 subjects enrolled, 1,746 completed the study to
age 12 months, 1,205 to age 24 months and 1,071 to age 3 years. Subjects were born
after 37 or more weeks of gestation with a birthweight greater than 2,500 g. A substan-
tial minority of subjects were fed according to WHO recommendations, i.e. breast for
1 year with complementary foods only after 6 months, and data for these subjects are
presented separately [9].

The WHO 2006 charts (WHO) [6] are based on data obtained in a ‘Multicentre
Growth Reference Study’ carried out between 1997 and 2003 that involved children
living under conditions that posed no constraints on growth. For the charts to be glob-
ally representative, data were gathered at 6 sites in 6 countries (Brazil, Ghana, India,
Norway, Oman, USA). The study consisted of a longitudinal study from birth to 3 years
of age and a cross-sectional study of children aged 1.5–5 years. In the longitudinal
study, 1,737 subjects were enrolled, of whom 882 completed the study; only their data
were used. Infants born at term were included regardless of birthweight, so that the
sample included 2.3% of infants with birthweight <2,500 g. Subjects were required to
be fed according to WHO recommendations, meaning that they were breastfed for the
first 12 months of life with complementary foods introduced after 6 months of age.
Their mothers did not smoke cigarettes. The strict eligibility criteria led to the inclu-
sion in some countries of only a small minority of subjects, who came predominantly
from the more privileged strata of societies. The cross-sectional study involved 6,669
subjects aged 18–71 months of age from the same demographic strata as the longitudi-
nal study. Data for subjects with weight for height >+2 standard deviations (SD; 1.4%
of boys and 1.1% of girls) were not used in the creation of charts for 2–5 years.
Three sets of growth data for breastfed infants living in North America and Europe were used for comparative purposes. They included (a) data from six European and North American countries [10], referred to as Working-Group Breast or WGBreast; (b) data from Iowa combining previously published [11, 12] and unpublished data, referred to as IABF, and (c) data for the breastfed subset of the Euro-Growth sample [9], referred to as Euro-BF. Each of these sets comprised infants who were breastfed for all or most of the first 12 months of life and did not receive complementary foods until after 4 months. In the WGBreast set, only a minority of infants received supplemental formula after 6 months of age. In the Iowa set, some of the infants did not receive supplemental formula until after 9 months, whereas others received some formula beginning at 4 months or 6 months. In the Euro-BF subset, information regarding formula feeding after 4–6 months is not available. WGBreast included 226 infants, IABF 586 infants birth to 4 months and 167 to 12 months) and Euro-BF included 319 infants. The WGBreast and Euro-BF data are smoothed, whereas the IABF data are not.

All growth charts are gender specific, although only one gender (male or female) is presented here. We present select percentiles (5th, 50th and 95th). To facilitate comparison of charts, we express charts also as SD scores based on WHO. When we show SD scores, both genders are combined.

Results

Birth to 2 Years

In a comparison of growth charts, the 1st year of life is of the greatest interest for several reasons. For one, due to the rapidly changing growth velocity, the shape of the growth curves is difficult to capture faithfully in smooth percentile curves. Also, in the first year of life differences in feeding practice (e.g. breast vs. formula) affect growth velocity and hence the shape of the curves. We therefore concentrate our comparisons on the 1st year of life. As will be shown, from a growth charts perspective, the 2nd year of life represents largely a continuation of events and trends that began in the second 6 months of life.

Figure 1 shows weight for age of three national growth charts from the UK, the Netherlands and the USA, and the two multinational curves. The curves appear fairly similar in both shape and position. To facilitate comparison of charts, in figure 2 the 50th percentiles of the national curves and the Euro-Growth curve are expressed in SD units of the WHO curve. It is evident that weight during the first 4–6 months is higher with WHO than with any other chart. After 6 months the opposite is true, with WHO weight lower than in the four other charts. The differences are substantial, reaching 0.4 SD units in the first 6 months and 0.5 SD units, in the opposite direction, by 12 months. Differences for other than the 50th percentiles (not shown) are generally of a similar magnitude.

It appears possible that the difference in weight between the WHO chart and the other charts might be due to the fact that all WHO infants were breastfed and followed WHO recommendations for use of complementary
Fig. 1. Weight for age, males, 1–12 months of UK90, NL97, CDC, Euro and WHO. Shown are the 5th, 50th and 95th percentiles.

Fig. 2. Weight for age 1–12 months of UK90, NL97, CDC and Euro. 50th percentiles expressed as WHO SD scores.
foods. Figure 3 presents weight data for three sets of breastfed infants, all expressed as SD units of WHO. Weight of breastfed infants generally deviates less from WHO weight than weight of the four other charts, suggesting that breastfeeding is at least part of the explanation for the differences between WHO and the other charts. However, the pattern of the differences from WHO is similar to the pattern shown in figure 2, suggesting that other factors, perhaps including differences in curve fitting techniques, may explain most of the differences between curves.

Length for age percentiles are shown in figure 4 for all five charts. Closer agreement than among weight charts is suggested, especially during the first 6 months. Comparison of SD units (fig. 5) confirms this impression. Differences do not exceed 0.3 SD units at any time. During the second 6 months, both Euro and NL97 exceed WHO, whereas UK90 and CDC agree closely with WHO. CDC length shows a peculiar pattern, being lower during the first 6 months than all other curves. An explanation is not available, but the suspicion is that the quality of the length data used by CDC for birth to 5 months may hold the explanation.

During the 2nd year of life, differences and trends in weight that were established between 6 and 12 months continue essentially unchanged, with WHO weight being lower than weight of all other charts (fig. 6). The differences between WHO and the other charts range from 0.3 to 0.6 SD units and

Fig. 3. Weight for age 1–12 months of breastfed infants. 50th percentiles expressed as WHO SD scores.
Fig. 4. Length for age, females, 1–12 months of UK90, NL97, CDC, Euro and WHO. Shown are the 5th, 50th and 95th percentiles.

Fig. 5. Length for age 1–12 months of UK90, NL97, CDC and Euro. 50th percentiles expressed as WHO SD scores.
are thus not trivial. Although the nutritional regimen employed by WHO, which included breastfeeding well into the 2nd year of life, explains at least part of these differences, whether other factors also play a role is not known. For length during the 2nd year of life (data not shown), the pattern established by 12 months continues as it does for weight. CDC length remains somewhat below WHO length, whereas length of other charts either is close to WHO length or somewhat above, with differences not exceeding 0.2 SD units.

Two to 5 Years

Weight percentiles are shown in figure 7 and 50th percentile values expressed as WHO SD units are shown in figure 8. The Dutch charts show the highest weight for all percentiles and at all ages, closely followed by Euro-Growth. WHO weight, on the other hand, is the lowest or among the lowest at all ages. Given that WHO excluded data for children with the highest weight for height, it might be expected that the 95th percentile and perhaps the 50th percentiles would be somewhat low. But weight truncation at the upper end does not explain why the lower WHO percentiles should be low (fig. 7). Overall, the differences between charts are surprisingly large. As figure 8 shows, the 50th percentiles for weight can differ by as much as 0.6 SD units.

The differences between height curves (fig. 9) are larger still than the differences between weight curves, as is best appreciated when 50th percen-
**Fig. 7.** Weight for age, males, 2–5 years of UK90, NL97, CDC, Euro and WHO. Shown are the 5th, 50th and 95th percentiles.

**Fig. 8.** Weight for age 2–5 years of UK90, NL97, CDC and Euro. 50th percentiles expressed as WHO SD scores.
tiles are expressed as SD units (fig. 10). The largest difference between 50th percentile curves is 0.8 SD units. A difference of 0.8 SD units, for example, is equal to 3.36 cm for boys at 4 years. The Dutch are the tallest and again are followed by Euro, although the advantage of the Dutch for height is larger than for weight. Surprisingly and unexplained, CDC height is lowest and as much as 0.3 SD units below WHO.

Body mass index percentiles shown in figure 11 indicate that WHO is lowest at each of the percentiles shown, which is not too surprising given the truncation of weight at the upper end of the distribution. What is perhaps surprising is that the spread among 50th percentile curves (fig. 12) is less than with either weight or height. An explanation for this seeming paradox is not evident.

Discussion

The notion that growth charts should describe an idealized population and thereby provide a description of growth as it should be is of recent origin. The ‘prescriptive’ approach utilized by WHO has yielded charts that represent growth as it occurs when circumstances are optimal. But even under optimal circumstances, there are some children whose weight is higher than is considered compatible with good health. Hence, WHO elected to exclude data for children with the highest weight for height. Therefore, the WHO charts
**Fig. 10.** Height for age 2–5 years of UK90, NL97, CDC and Euro. 50th percentiles expressed as WHO SD scores.

**Fig. 11.** BMI for age, males, 2–5 years of UK90, NL97, CDC, Euro and WHO. Shown are the 5th, 50th and 95th percentiles.
describe the growth of children as it could or should be, not as it actually occurs even under privileged conditions.

As one would expect, the WHO charts differ in several ways and to a substantial extent from existing growth charts, both national and multinational. Not all differences, however, seem to be explained by the prescriptive approach. In the first 6 months of life when WHO weight exceeds that of any other chart, we have provided evidence that the feeding mode (exclusive breastfeeding) does not explain all the difference. Selective dropout [13] and possibly differences in curve fitting methods may be as important, if not more important, than feeding mode in explaining the differences in weight percentiles. After age 6 months and through 24 months, however, when WHO weight is lower than weight of any other chart, the differences seem to be entirely the result of the prescriptive approach. If there are other explanations for the sizable difference, they have not been identified.

A number of reports have discussed and described the implications of the use of the WHO standards in nutrition research. Fenn and Penny [14] found in three countries that using the WHO standards led to a higher proportion of children classified as stunted and fewer classified as underweight compared to when the NCHS/WHO charts were used. Others [15–17] have found similar discrepancies, as would be expected. There is no question that the implications for epidemiological research are quite far-reaching.

Fig. 12. BMI for age 2–5 years of UK90, NL97, CDC and Euro. 50th percentiles expressed as WHO SD scores.
The implications for monitoring of individual children’s health may be less serious. After all, in monitoring an individual child’s growth, most commonly periodic growth measurements are performed and are plotted on a growth chart. Growth performance is judged on the basis of how closely the child’s weight and length curves parallel percentile lines (channels) of the growth chart. For this judgment, the position of the percentile line is of less importance than its inclination and shape. When the question must be answered whether an individual child’s size is normal, however, the position of the percentile line is the all important variable rather than its inclination or shape. This is also true when only a single measurement of a child is available and a judgment must be rendered as to the normality of the child’s growth. When growth charts are used to determine the adequacy of the growth of groups of children, the position of the percentile lines is the parameter of greatest importance.

References

Discussion

Dr. Elmouzan: I would like to ask whether the samples from China include rural areas or only urban areas because this has an effect on the type of chart comparison.

Dr. Ziegler: There were only nine urban centers; no rural areas were included [1, 2].

Dr. Haschke: You indicated that the truncation of the WHO growth standards eliminated data from children between 2–5 years who were above 2 SDs. If the sample size was 930, this would have a substantial influence on the 95th or the 97th percentile. If the WHO standards are used for comparison, this could result in an overestimation of obese children in a target population.

Dr. Ziegler: Absolutely, you are correct, I don’t think it makes a difference on the 50th percentile, but it makes a big difference on the outlying percentiles, which are lowered. And that was the exact reason why data for the heaviest children were eliminated.

Dr. Hussain: Have you got head circumference data on the WHO charts?

Dr. Ziegler: Yes they have been published but I have not reviewed them, so I have no comment.

Dr. Martorell: I would like to correct a misunderstanding about the exclusion criteria. If we look at the 0- to 2-year data, the longitudinal part, it’s clear that the WHO children are heavier at the beginning but become thinner later. However, they have lengths that are not very different from those of references like the NCHS. Now, in the 0- to 2-year sample, the exclusion criteria for weight-for-length were above +3 and below –3 [3].

Dr. Ziegler: That differs from my perception. +3 SD and −3 SD were eliminated because they represent outliers. But the elimination in the 2- to 5-year cohort was above +2 standard deviations, only above.

Dr. Martorell: Yes, the cutoff point for the cross-sectional 2- to 5-year sample was +2 SD and around 1% were excluded [3]. But clearly the pattern of growth of the WHO children in the longitudinal sample, i.e. heavier weight for length early on followed by lower weight for length later, is clear and is not due to exclusions.

Dr. Gillman: I am just going back to something we talked about yesterday, which is that growth in the first 6 months of life, both linear growth and perhaps adiposity, might be determined in part by hormonal factors as well as nutrition. Can you comment on what the implications of that might be for creating and interpreting growth charts?

Dr. Ziegler: The presumption always is that leaner is better for long-term health. In our large samples, we have always had breastfed babies smaller than formula-fed babies. The difference becomes significant after 2 months of age; after that, formula-fed babies are heavier and longer. But the hormonal implications, I don’t know. We measured IGF-I levels. At 1 month, they are the same regardless of whether the babies are fed formula or breast milk, but at 4 months IGF-I levels are much lower in breastfed babies than in formula-fed babies. In formula-fed babies, they essentially don’t change from 1 to 4 months, whereas in breastfed babies they go down.
Dr. van Buuren: I have seen the previous version of your results, and I felt more comfortable when I was doing the analysis of dropout. First of all, you find substantial differences between the countries, and I think this merely reflects how life is. We all know that the Dutch are taller than the Malaysians and that’s simply what we see on the charts, no matter what standard we have. I think that if you are going to include more and more countries, then the WHO line will be somewhere in the middle, with countries varying over this line. A second remark, you said that there aren’t many studies on cutoffs. I would like to mention that a colleague of mine, Paula van Dommelen, has done good work on formulating cutoffs for identifying Turner syndrome from height measurements, for identifying celiac disease, dehydration in early life, cystic fibrosis and overweight. So there is some new work that looks at health outcomes related to growth [4–6]. I think your data are largely consistent with the idea of dropout. The American data that you showed are growing according to the WHO line. Could this be explained by the fact that all groups were breastfed for a very long time? And what about the other breastfeeding studies, how long was the breastfeeding in those studies?

Dr. Ziegler: You are referring to the graph I showed with the three breastfed groups. The WHO Working Group data, those were North European and US infants, they were exclusively breastfed for 6 months and then continued to be breastfed, and that I think explains why they follow the WHO very closely. As for our own data, we enrolled babies at 1 week and we permitted some supplemental formula; that’s why I think the smaller babies where the mother thinks the baby is not growing enough are not dropping out. Regarding the Euro Growth, I don’t know enough.

Dr. Haschke: The ‘breastfed’ infants in the Euro Growth study were exclusively breastfed at least until 4 months of age.

Dr. Ziegler: So there is a little bit of mystery why we have at 1 month this big difference with WHO lower than the other groups, but at 2 and 3 months the other groups are all lower than the WHO. The main point I tried to make is that the WHO being higher at 2, 3 or 4 months, cannot be explained by the fact that the WHO infants were breastfed exclusively and the others not.

Dr. Boey: Can you explain how this sampling was done to ensure that it was nationally representative?

Dr. Ziegler: The CDC sampling is done to be nationally representative, all minorities and geographic areas are represented. There may have been some oversampling of certain minorities which were low in numbers, but the aim is to have a nationally representative sample, which I think makes the CDC unique.

Dr. Ogden: The samples are nationally representative. There is some over sampling, but the sample weights are used to adjust for the oversampling in the analysis. The response rate in the surveys for children is above 80%.

Dr. Ziegler: So urban, rural and all racial groups are represented according to their presence in the US population.

Dr. Ke: Although there is controversy surrounding these WHO charts, they are really encouraging to a clinician like me as they demonstrate that exclusively breastfed babies grow very well. However, after 6 months these babies have some sort of growth faltering. Does it mean that the complementary feeding practices in India, Brazil or Ghana, which are the representative nations, are not as good as in Europe or the US?

Dr. Ziegler: Your speculation is as good as anyone’s. The WHO in the description of the sample do not provide any information about complementary feedings.

Dr. Haschke: A question to Dr. Martorell. You are probably familiar with the analysis of subgroups in the WHO study. The criteria of the WHO were not to exclude infants who have been exclusively or predominantly breastfed until 4 months of age. There might be a subgroup of infants which has been exclusively breastfed until 6
months of age. Was there a difference in growth between the overall cohort and those infants who were exclusively breastfed until 6 months of age?

Dr. Martorell: Yes, those analyses were done, and there were no differences between these two groups.

Dr. Haschke: What was the reason then?

Dr. Martorell: Differences, if real, would be so small that a very large sample size would be required.

Dr. Moelgaard: You said that you have data on IGF-I. Is there a relationship between growth rate and IGF-I in your data?

Dr. Ziegler: The answer is no, there is no relation between IGF-I levels and growth among individual infants. But, if I compare the breastfed group with the formula-fed group, they differ in the rate of growth and they differ in IGF-I, so for the groups the answer is yes, for the individual it’s no.

References