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A method of presenting longitudinal growth data

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1. Longitudinal growth profiles contain much information but are difficult to incorporate into mathematical and statistical analyses.

2. A growth function, which is a weighted average of growth achievement at different ages, is proposed.

3. This function is a non-dimensional number with defined statistical properties, and emphasizes growth achievement in early life. It can be used to compare the growth of individuals and populations.

Physical growth continues at varying rates from conception to adulthood, but both rate and the final attainment are affected by many genetic and environmental factors, including nutrition (Jelliffe, 1966). Serial measurements of the growth of an individual give a growth profile, but it is very difficult to condense the information contained in the profile into a simple function. Such a function is necessary if growth is to be used as a factor in mathematical and statistical analyses. All reductions in the volume of data entail some loss of information and if a simple growth function is to be clinically meaningful it must have the following properties: (1) it should be applicable to different measurements for example, weight, height, weight-for-height, etc. Ideally it should be non-dimensional so as to accommodate different units and measurements; (2) it should reflect the paramount importance of growth early in the life of the individual, that is in the antenatal and infant periods; (3) it should not be invalidated by irregular timing of the measurements. Regular timing is exceptional, particularly in retrospective studies; (4) it should have defined numerical and statistical properties, so that analyses of individuals, groups and populations can be undertaken; (5) although there will inevitably be a loss of information, the growth function should retain enough to be clinically useful, while being simple enough for analyses; (6) it should be simple to calculate.

MATERIALS AND METHODS

A growth function

A growth function based on the weighted average value of growth-for-age meets all these criteria to some extent. The proposed growth function is:

$$\text{growth function (\%)} = \frac{\Sigma(V_{OA}/V_{EA} \times \Delta A/A)}{\Sigma(\Delta A/A)} \times 100,$$

where A is the age of the child from time of conception; V_{OA} is the observed level of growth at age A; V_{EA} is the expected level of growth at age A; ΔA is the interval since the last observation.

The term V_{OA}/V_{EA} in the formula gives the relationship between the observed value and the expected value of the measurement. The expected value for age must be taken from a national, or preferably international standard. For some of the anthropometric measurements in children the Boston standard (Stuart, 1969) is widely used and readily available. Other growth standards cover a wider range of measurements and would be equally valid (Tanner *et al.* 1966; Diem & Lentner, 1970).

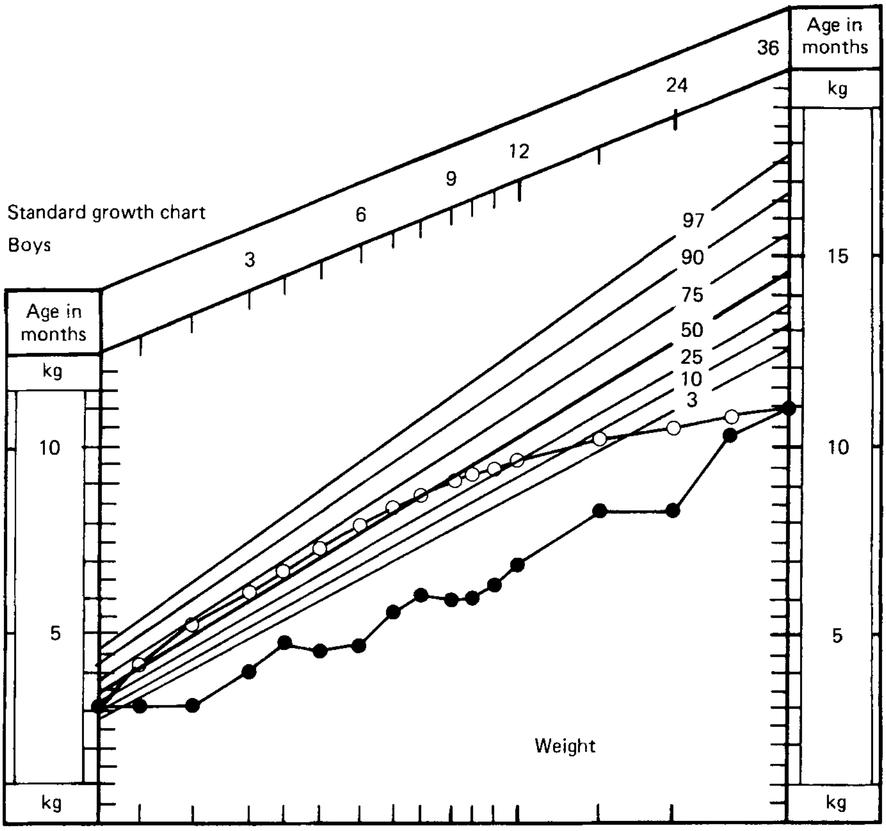

Fig. 1. The growth pattern of an Australian Aboriginal child (●——●) and an alternative growth pattern (○——○). (——) Values for children on 97th, 90th, 75th, 50th, 25th, 10th and 3rd percentiles, as indicated.

The weighting term is $\Delta A/A$. Each of the two variables has a role. ΔA is the interval since the last observation, and allows for variation in the frequency of the observations. A, the age of the child. Its position in the denominator of the weighting term means that, as the age increases, the numerical value of each observation in the summation is reduced.

The age is reckoned from the time of conception so that measurements made at birth can be used. For an observation made on a full-term infant at birth, the age should be taken as 9 months (or its equivalent in other units) and ΔA should also be 9 months. In developing countries the period of gestation is often not known accurately. There is no completely satisfactory solution to this problem, but it is probably best to consider gestation to be 9 months unless there is good evidence to the contrary.

RESULTS

The properties of the growth function

The growth function is non-dimensional, so results based on different systems of units can be directly compared, provided the same standard values are used. The use of the reciprocal of the age ensures that early growth status will have a greater influence on the value of the growth function than later observations. Variable intervals between observations are possible and there is no limit to the total number of observations. The function can be applied to any longitudinal data provided standard values-for-age are available.

Table 1. *Values for growth function* calculated from information collected in the first year of life for an Australian Aboriginal child*

Frequency of observation	Growth index (%)
Weekly	81·5
Monthly	81·4
Each 2 months	80·3
Each 3 months	82·1
Each 4 months	82·4
Each 6 months	79·9

(The growth index calculated from the information shown in Fig. 1. Decreasing numbers of observations have been used in the calculations. In calculating each of the indices, the age range was birth to 1 year. With changing frequency of observation there was only slight change in the growth index.)

* For details, see p. 53.

The numerical properties of the function are definable. If all observations equal the standard level, then the numerical value of the function will be 100%. Random errors in the observations produce little change in the function. In a simulated situation, using twenty observations from birth to 5 years, the true observations were all equal to the standard. As expected, the value of the growth function was 100%. When a random error with SD ± 5% was imposed on each of the observations, a series of simulation runs showed that the mean value of the growth function was 99·81% (SE 0·31%). When a random error SD ± 10% was imposed, the mean (± SD) value of the growth function was 99.4 ± 0.43%. The growth function appears very stable in the presence of random error of measurement.

As with all measures of growth, the function has a normal range. When weight information from the Boston standards was used, the growth function of a child following the 3rd percentile had a value of 80–81% from birth to 10 years. The value varied slightly depending on the number of observations used in the calculation. The values for children on the 10th, 90th and 97th percentiles were 85–87%, 115–119% and 128–131% respectively. In a Swiss series (Diem & Lentner, 1970), children on the 10th percentile had a value of 85–86% and on the 90th percentile 112–114%.

The calculation of the growth function is rapid and simple provided a programmable calculator is used and a set of standard values-for-age is available. Calculations can be done by semi-trained staff and take 1–5 min per individual depending on the number of observations. If information is already in a computer file, the programming needed to compute the index is very simple.

A practical example

Fig. 1 shows the weight chart of an Australian aboriginal child who was living on a settlement in Queensland. Observations had been taken each week up to the age of 1 year, and less frequently from 1 year to 3 years. During infancy the child had a number of severe illnesses.

Some of the observations are shown in Fig. 1. Values of the growth function have been calculated using data from the first year of life. In the first calculation all values were used; in later calculations values were selected at longer intervals to find how stable the growth function was under these conditions. The results are shown in Table 1.

With this wide range of frequency, there was a variation of just over 2% in the value of the growth function, suggesting that it is also stable under these conditions. If the child whose actual growth pattern is shown in Fig. 1 had followed a different pattern (alternative growth pattern shown in Fig. 1), then the calculated growth function would have been 92%, compared with 79% for the actual growth values. In spite of the common end-points of the two plots, the growth function has distinguished clearly between continuous growth retardation and the pattern of good early growth followed by a later 'fall-off'. It might under some circumstances be desirable to present information additional to the growth function. A possibility is to give the value of the growth function and the final weight-for-age. The growth history of the child shown in Fig. 1 could be given as growth function 79% or, alternatively, two variables could be given: growth function 70%, 3 year weight-for-age 75%. With the two variables, the final status and the pathway towards that final status are both evaluated, giving considerable information about the growth performance.

DISCUSSION

In all biological work where longitudinal growth data are collected, there is the problem of describing numerically the longitudinal growth profile so that the influence of genetic and environmental factors can be assessed. Some method of summarizing the information in the profile is essential. The choice of method must be a compromise between simplicity of the function and the associated loss of information. The growth function described here tries to capture the important features of the growth profile in a single non-dimensional number. Weighted averages are commonly used in education and other fields. The use of a weighted average as a growth index could simplify the analysis of social, economic and nutritional influences on growth, particularly where existing growth data, which are usually incomplete, must be used.

The non-dimensional growth index proposed in this paper is most sensitive to deviations from normal growth during foetal life and early infancy. Sensitivity decreases with the age of the child. This is a desirable feature, as early under- and over-nutrition can lead to permanent changes in body size and composition. There is good evidence that intra-uterine growth retardation can result in an increased risk of neonatal death (Usher & McLean, 1974), reduced brain growth (Dobbing & Sands, 1973) and in psychomotor functioning (Lasky *et al.* 1975). Malnutrition in infancy can alter brain growth (Dobbing & Sands, 1973) and may have a long-term effect on body composition (Dugdale & Payne, 1975). If the non-dimensional index is based on childhood growth up to 10 years, then the period of growth retardation, which is common among toddlers in developing countries, contributes a reasonable share to the final value of the index. This is appropriate as this period of childhood is socially important, but does not have the critical biological significance of early infancy. Later deviations from normal growth do not affect primary brain development, and some of the other somatic changes are reversible. This lesser biological importance is reflected in the decreased sensitivity of the index in later childhood. Thus the sensitivity of the index, in mathematical terms, parallels the biological significance of aberrations in growth at different stages of childhood. The index should therefore be a useful datum for summarizing growth performance in childhood.

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