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Long-term adequacy of exclusive breast-feeding: how scientific research has led to revised opinions

R. G. Whitehead* and A. A. Paul
MRC Human Nutrition Research, Downhams Lane, Milton Rd, Cambridge CB4 1XJ, UK

The present paper reviews the research of the authors and their colleagues over the past 20 years to provide improved nutritional and anthropometric guidelines for the assessment of lactational adequacy and for when the weaning process might be initiated. The nutritional guidelines are based on revised dietary energy requirements. The basic assumption is that since breast milk is a well-balanced food, if energy needs are satisfied so will those for essential nutrients. Energy requirements for young babies have been derived from the application of the doubly-labelled-water technique. This approach indicated that 460 kJ (110 kcal)/kg per d at 1 month and 397 and 355 kJ (95 and 85 kcal)/kg per d at 3 and 6 months respectively would be satisfactory for a nutrient content of high bioavailability. Translated into a breast-milk intake of 850 ml/d the latter would cover the dietary energy needs of the average child growing along the 50th centile until at least 4 months, but the typical child from many developing countries following the 25th centile until 6 months. The importance of revised growth reference values for infancy, equally crucial for assessing lactational adequacy, is also reviewed. In contrast with the shapes of earlier reference patterns, growth trajectories are different when babies are fed in accordance with modern paediatric advice. Mothers and health professionals using the older growth charts to assess the progress of a baby can be misled into assuming that the weaning process needs to be introduced sooner than necessary. Examples of this situation within the context of a developing country are provided.

Lactation: Infants: Growth

How long the average mother can breast-feed exclusively before there is a nutritional need to introduce additional foods is a question of prime public health importance, especially in developing countries. Here not only are traditional weaning foods often of poor nutritional quality, but prevailing hygienic standards make them microbiologically hazardous for the young infant (Rowland *et al*. 1978). The answer given in the present paper is based on the adequacy of the dietary energy supplies from human milk to satisfy the babies' needs for this pivotal component. The tacit assumption is that as long as these supplies are sufficient, the rest of the nutritional needs will be satisfied too. Human milk contains all the essential macro- and micronutrients, balanced in the proportions required for healthy growth and infant well-being. The proportions of casein and whey proteins, the latter predominating, and their amino acid composition match exactly those needed for the baby's rapid anabolic metabolism. The vitamin and mineral contents are also in a highly bioavailable form. Of equal importance for the survival of the infant, especially those living in areas where disease is highly endemic, the milk also contains a range of immunoglobulins and other protective factors against infection. Specific antibodies in response to locally prevailing infections are produced by the maternal gastrointestinal and respiratory mucosa, which stimulate the mammary glands to synthesize similar compounds, thus protecting not only the mother but also the breast-fed baby (Whitehead, 1983).

Abbreviations: NCHS, National Center for Health Statistics; WHO/FAO, World Health Organization/Food and Agriculture Organization; WHO/FAO/UNU, WHO/FAO/United Nations University.

***Corresponding author:** Dr R. G. Whitehead, fax +44 (0)1223 291934, email rgwhitehead@compuserve.com

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These are just a few of the compositional benefits of human milk. Clearly the longer exclusive breast-feeding can be quantitatively justified the better it is for the infant. Paediatric opinion, as expressed for example in the official UK advice on the subject, *Present Day Practice in Infant Feeding*, the latest edition of which is Department of Health and Social Security (1988), has long held this period to be until 4–6 months. Some authorities, especially those dealing with the complex health problems of developing countries, have recommended exclusive breast-feeding for even longer. During the early 1980s, however, we came to realize that there were both troublesome nutritional and anthropometric inconsistencies.

Dietary energy requirements of infants

All national and international expert nutritional committees at this time (early 1980s) recommended that for the first 3 months of life average energy needs were 502 kJ (120 kcal)/kg per d. This requirement reduced only slowly from then onwards to 480 kJ (115 kcal)/kg per d from 4–6 months, 460 kJ (110 kcal)/kg per d at 6–9 months and 440 kJ (105 kcal)/kg per d towards the end of infancy (World Health Organization/Food and Agriculture Organization (WHO/FAO), 1973). If it is accepted that the average peak quantity of milk produced by a mother is 850 ml/d and that this milk provides about 2900 kJ (700 kcal)/l, the total energy supplied to the baby would be rather less than 2510 kJ (600 kcal)/d. Using the accepted WHO/FAO (1973) energy recommendations and assuming average rates of growth tracked the average of the 50th National Center for Health Statistics (NCHS) centile for boys and girls (Hamill *et al*. 1977), the total energy needs of the baby would be 2468 kJ (590 kcal)/d at 2 months, 2845 kJ (680 kcal/d at 3 months and 3070 kJ (734 kcal)/d at 4 months. In other words, dietary energy needs would only be satisfied up to 2 months, not 4–6 months as suggested by the paediatricians.

There were a number of possible explanations for this enigma. Perhaps the paediatricians were wrong after all. There were those who wished to believe that this was so. Alternatively, it was possible that the time-honoured energy requirement values were erroneously high. Considering the inherent errors involved in measuring breast-milk intake by test weighing, it seemed more likely that the assumed volume of milk intake might be an underestimate. The development of stable-isotope methods for this measurement subsequently established, however, that the latter assumption based on test-weighing data had in fact resulted in remarkably accurate estimates (Coward *et al*. 1982). Thus, we were left with the need to question the energy requirement values.

Estimation of dietary energy needs from food intake data

The first hint that current dietary energy recommendations covering infancy might indeed be overestimates came from an analysis of published intake data for healthy babies (Whitehead *et al*. 1981). This analysis was carried out as part of the preparation for the WHO/FAO/United Nations University (WHO/FAO/UNU; 1985) report *Energy and Protein Requirements*. The analysis showed that mean dietary energy consumption levels for infants of different ages in most of the populations covered in the analysis were well below WHO/FAO (1973) recommendations. The data also indicated that during the first 6 months of life energy intakes on a per kg body weight basis, and presumably therefore requirements, fell much more steeply than had previously been assumed. Quadratic regression analysis produced the relationship shown in Fig. 1. This relationship was in marked contrast with the essentially linear previously-accepted association between infant energy needs and age. These data did result in the lowering of the recommended energy allowances for infancy by WHO/FAO/UNU (1985) to a small extent, but not to the levels indicated by the regression analysis. This variance was reasonable because of the inevitable uncertainties that surround dietary intake data, especially with such young children. WHO/FAO/UNU (1985) made a plea, however, for objective studies of actual energy expenditure. It was reasoned that such studies would provide a much more secure basis for requirement calculations. The need to provide such information, and particularly to solve the lactation enigma, was one of the reasons for the emphasis of the Medical Research Council Dunn Nutrition Centre (Cambridge, UK) during the next decade on stable-isotope research. The refinement of the doubly-labelled-water technique for use in young infants and children represented quite a challenge.

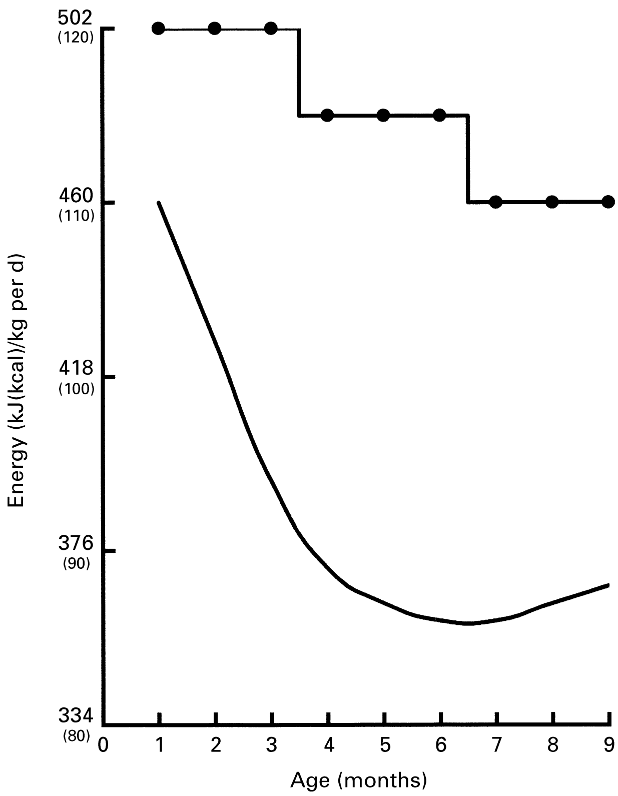

Fig. 1. Quadratic regression relationship (Whitehead *et al.* 1981) obtained between the energy intake of boys and girls and age during the first 9 months of life (—) compared with the World Health Organization/Food and Agriculture Organization (1973) recommendation (●—●).

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The estimation of infant energy expenditure using doubly-labelled water

One of the main features of the doubly-labelled-water method especially relevant to energy studies on breast- and mixed-fed infants is that the technique does not interfere with the close bonding between mother and child, as does test weighing or placing the child in a cot calorimeter. The baby is merely given a small oral dose of water enriched with ^{2}H- and ^{18}O-labelled water. Subsequently, small quantities of saliva are sampled five or six times during the next 10–14 d for analysis in a mass spectrometer. The measured ^{2}H enrichment gradually falls with time, reflecting water losses from the body. The ^{18}O enrichment reduces more quickly because it is lost not only as water but also during the production of CO_2 through the influence of carbonic anhydrase. The greater the energy expenditure the more CO_2 is produced and the larger the difference between rates of ^{2}H and ^{18}O enrichment reduction. This difference enables CO_2 production rate to be measured and hence energy expenditure derived (Ritz *et al*. 1994).

The method measures basal metabolism and energy expenditure associated with activity plus the energy consumed during the actual processes of growth. It cannot, of course, account for the intrinsic energy contents of the newly-deposited tissues. However, these latter data can be obtained from body composition data for reference infants (Fomon *et al*. 1982). Fig. 2 shows the results of such an analysis on the energy expenditure of 355 healthy infants and young children from different parts of the world carried out by Prentice *et al*. (1988). As predicted by the earlier quadratic regression analysis of infant dietary intake data (Whitehead *et al*. 1981), the new approach confirmed that energy expenditure, hence requirements on a per kg body weight per d basis, did indeed fall steeply between 1 and 6 months of age. Expenditure values at 1, 3, 6 and 9 months averaged 460 (110), 397 (95), 355 (85) and 347 (83) kJ (kcal)/kg per d respectively.

Comparison of infant energy intake and expenditure data

Fig. 3 compares these two sets of data together with the conclusions of an additional food-intake study (Whitehead *et al*. 1982) on Cambridge (UK) babies who were known to be fed in accordance with the recommendations contained in *Present Day Practice in Infant Feeding* (Department of Health and Social Security, 1974). All were breast-fed or given an approved infant formula (correctly reconstituted) to at least 4 months, and none received additional solids before that time. At all stages during the first 6 months of life there was a close similarity between all three data sets. The dietary energy values obtained were all markedly lower than the WHO/FAO (1973) recommendations for dietary energy intake, and even those ultimately adopted by WHO/FAO/UNU (1985) and Department of Health (1991). This situation is as it should be, because the latter national and international authorities could not assume that all infants would be breast-fed, and some infants would be fed

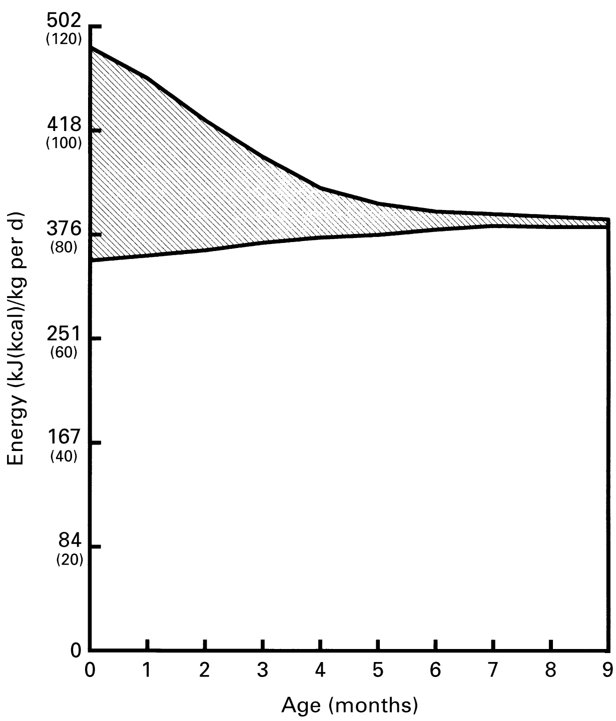

Fig. 2. Estimate of energy requirements derived by adding the energy deposited during growth (Fomon *et al.* 1982; ▧) to measures of total energy expenditure derived using the doubly-labelled-water method (Prentice *et al.* 1988).

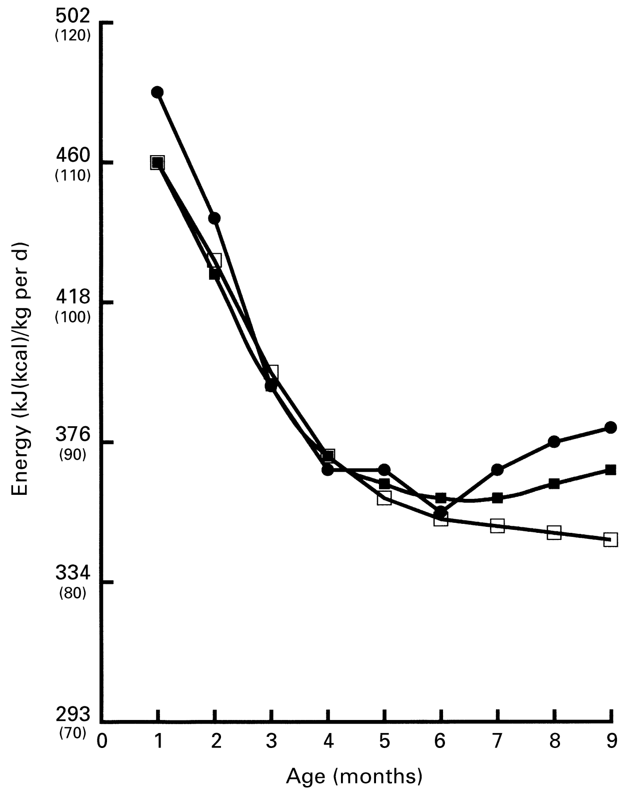

Fig. 3. Energy needs of young babies, on a per kg body weight per d basis, predicted from: (●), the doubly-labelled-water method calculated as in Fig. 2; (■), the intake regression relationship shown in Fig. 1; (□), a group of Cambridge (UK) children (Paul *et al.* 1988).

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diets in which the bioavailability of the dietary energy would not be anything like as good.

Quantifying the adequacy of breast-milk energy intakes from doubly-labelled-water data

For reassessing the dietary energy adequacy of different levels of breast-milk intake at progressive stages during infancy rather than making recommendations for energy requirements, it was considered not unreasonable to use the straightforward energy expenditure data obtained from the stable-isotope studies (Whitehead, 1995). If a rate of weight gain which tracks the mean of the 50th NCHS centiles for boys and girls is assumed, the average daily amount of dietary energy (kJ (kcal)) required at 2, 3 and 4 months of age would now be only 2125 (508), 2259 (540) and 2376 (568) respectively. Thus, using this approach we now have a guideline that is much more compatible with the energy content of 850 ml breast milk and the pragmatic advice that has been given by paediatricians for decades.

Although breast-feeding is the ideal for all young babies wherever they live, it is absolutely essential for the health and survival of the majority of children in the developing countries. Since the average baby tends to be a little smaller than its European or American counterpart, being born weighing approximately 3·0 kg and then, if healthy, growing along the 25th centile rather than the 50th centile, it is meaningful to redo the earlier calculation for such a child. The energy requirement at 2 months now becomes 1895 kJ (453 kcal)/d, the 3-month estimate 2029 kJ (485 kcal)/d, the 4-month estimate 2121 kJ (507 kcal)/d and even the 6-month estimate is only 2452 kJ (586 kcal)/d. In other words, the often-quoted advice that mothers in the developing countries should persist with exclusive breast-feeding until up to 6 months of age can be justified on nutritional grounds (Fig. 4).

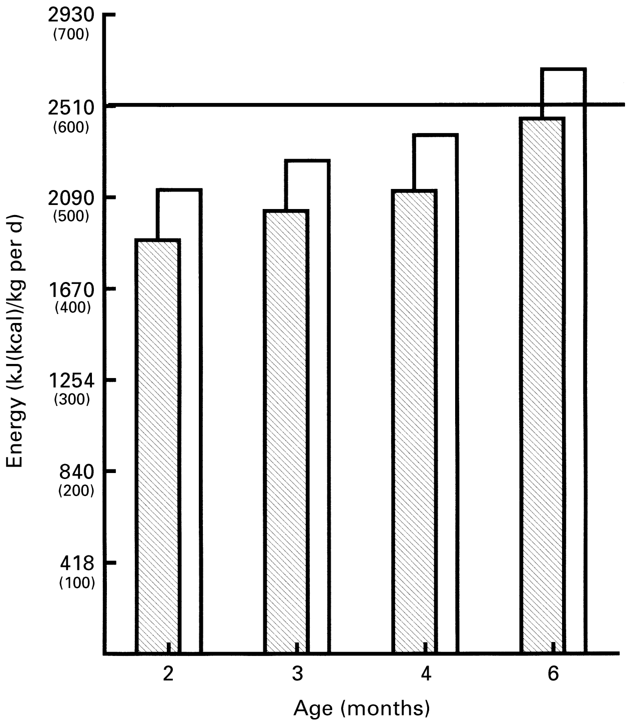

Fig. 4. Daily energy needs of babies growing along the National Center for Health Statistics (Hamill *et al.* 1977) 25th (▨) and 50th centile (▭), calculated using doubly-labelled-water data (850 ml breast-milk contain, up to 2150 kJ (600 kcal)).

Individual variation

Some researchers might criticise this work as merely proving something that was known intuitively all along. However, it has rationalized some of the nutritional controversies surrounding this aspect of human lactation, as well as helping to provide a more objective definition of when the weaning process might need to be initiated. An issue that has not been taken into account is that the lactational-adequacy calculations have all been based on an average maximal milk intake of 850 ml. Individual variation has not been considered. Whitehead & Paul (1981) studied this variation in a group of healthy successfully breast-fed Cambridge babies, all of whom were wholly or partly breast-fed at least up to 6 months. During each month total energy intake from breast milk plus the relatively small contribution from solids was significantly correlated with the babies' body weights. Until 6 months there was also a significant correlation with growth velocity. However, the highest correlation was obtained using multiple regression analysis with both anthropometric measurements as independent variables. This study implied that the amount of milk provided by the mother was possibly linked with the child's potential for growth, the higher milk volumes at any age being consumed by the larger faster-growing babies. Such a conclusion would be compatible with the fact that mothers with twins routinely produce much more breast-milk in total than those with single babies.

Reference values for healthy infant growth

Paediatric health professionals rely mainly on the assessment of growth to determine whether or not a child is being adequately fed. This assessment involves the regular weighing of the baby, either at a clinic or during home visits, and the recording of the results on a growth chart. It is common practice in countries such as the UK that if a child's progress is such that his/her weight begins to 'cross centile lines', usually two or more, the case is referred to a doctor for further investigation.

It was during a comparative analysis of growth data from breast-fed children in The Gambia and Cambridge, UK, that a second enigma linked with human lactation became apparent. Fig. 5 illustrates the mean weights of the two sets of children expressed as percentages of the 50th NCHS reference centile (Hamill *et al.* 1977). This calculation is commonly used in child clinics in developing countries. The Gambian data demonstrated that although the children were born small, there was some early recovery relative to the reference, but this ceased at approximately 2 months. From then onwards the community growth data deteriorated markedly. All the children were exclusively breast-fed until at least the 4th month, but the analysis indicated that the limit for this single source of food to sustain good growth

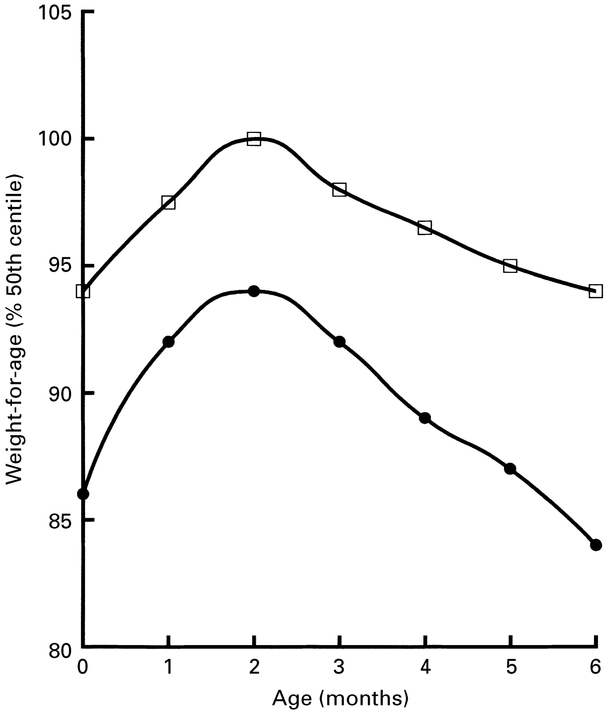

Fig. 5. Weight progress of two groups of Gambian (●) and British babies (□). The weight-for-age data is expressed as a percentage of the National Center for Health Statistics (Hamill *et al.* 1977) 50th centile reference values.

might be no longer than 2 months. Initially this situation did not seem too improbable, as many of the mothers were only marginally nourished, and at times of heavy manual labour in the fields were decidedly undernourished. As a result their measured breast-milk output might well have suffered. The issue became more complicated when, for comparison, data we had collected on Cambridge children was subjected to the same type of analysis. This analysis also indicated that 2 months might be the limit of breast-feeding to sustain reference rates of growth. Indeed, apart from the differences in initial size, the shape of the growth trajectories of the two data sets was essentially the same. Since the Cambridge babies were all very healthy throughout the study, this conclusion was improbable, and led us to question the validity of the growth reference charts insofar as their use for assessing very early infant growth was concerned.

Growth reference charts

There were a number of reasons why the NCHS reference data (Hamill *et al*. 1977) might not provide a particularly relevant target for infancy. Although the final data were not published until 1977, they had been based on information collected much earlier, between 1929 and 1975. All other commonly-used growth reference charts had a similar data vintage. For example, the UK Tanner growth charts (Tanner *et al*. 1966) used data collected from 1952–4 (Whitehead & Paul, 1984). At the times when these sets of data were collected the diets on which the babies were fed often differed markedly from those recommended by paediatricians. Breast-feeding was becoming uncommon, and there were also significant shortcomings in the design of commercially-available infant formula milks that have now, more or less, been corrected. Furthermore, the milk powders were often reconstituted incorrectly by the mother and made too concentrated. Most relevant of all, solids were often introduced as early as 1 week and almost invariably sooner than the recommended 4 months.

From a philosophical as well as a practical standpoint, it was debatable whether the adequacy of breast-feeding and when additional weaning foods ought to be introduced should be judged on the growth of children so inappropriately fed. There was an additional technical issue. The anthropometric data for infancy had been collected at intervals that were too infrequent to characterize in detail the complex changes in growth trajectory that occur during the 1st year of life. This problem is discussed by Whitehead & Paul (1984). It was decided, therefore, to set up a new growth study on healthy British babies who were being fed in accordance with the recommendations of Department of Health and Social Security (1974), reconfirmed by Department of Health and Social Security (1988).

The Cambridge infant growth study

Parallel dietary investigations carried out during the course of the new Cambridge growth study confirmed that almost certainly the babies had lower dietary energy intakes than those used in the earlier growth studies. The biggest anthropometric differences were found in the triceps and subscapular skinfold thickness measurements that are much influenced by subcutaneous fat stores (Paul *et al.* 1998). In the case of the triceps measurements, for example, the 50th centile values of Tanner & Whitehouse (1975) rose quickly after birth and by 4 months they were close to 12 mm. The new Cambridge data showed much less fat storage and at 4 months the 50th centile triceps skinfold values were only about 8 mm. Inevitably such changes in body composition had a significant effect on growth in weight and the shape of the weight centile charts (Paul *et al*. 1988; Whitehead *et al*. 1989). Fig. 6 shows the growth centile curves derived from the Cambridge data compared with the NCHS reference values of Hamill *et al*. (1977). The essential analytical differences are an initial higher velocity of growth generated by the Cambridge values compared with the reference ones, but then a relative deceleration from about 8 weeks, ultimately bringing the weight centiles well below the corresponding reference values. In other words, the Cambridge data produced centile curves with a greater degree of curvature during the first 6 months, a mathematical finding only revealed by the more frequent body-weight measurements.

The mother of a healthy breast-fed baby following this growth pattern, but using the older centile charts to plot progress would initially believe her baby was doing especially well, and she would be particularly happy. The subsequent apparent worsening of this rate of development, however, might cause the mother to believe that her milk supplies were starting to become inadequate to support this ‘super’ rate of growth that could represent the child’s genetic potential. Understandably, this apparent inadequacy might lead to a rapid complete switch to artificial feeding, or

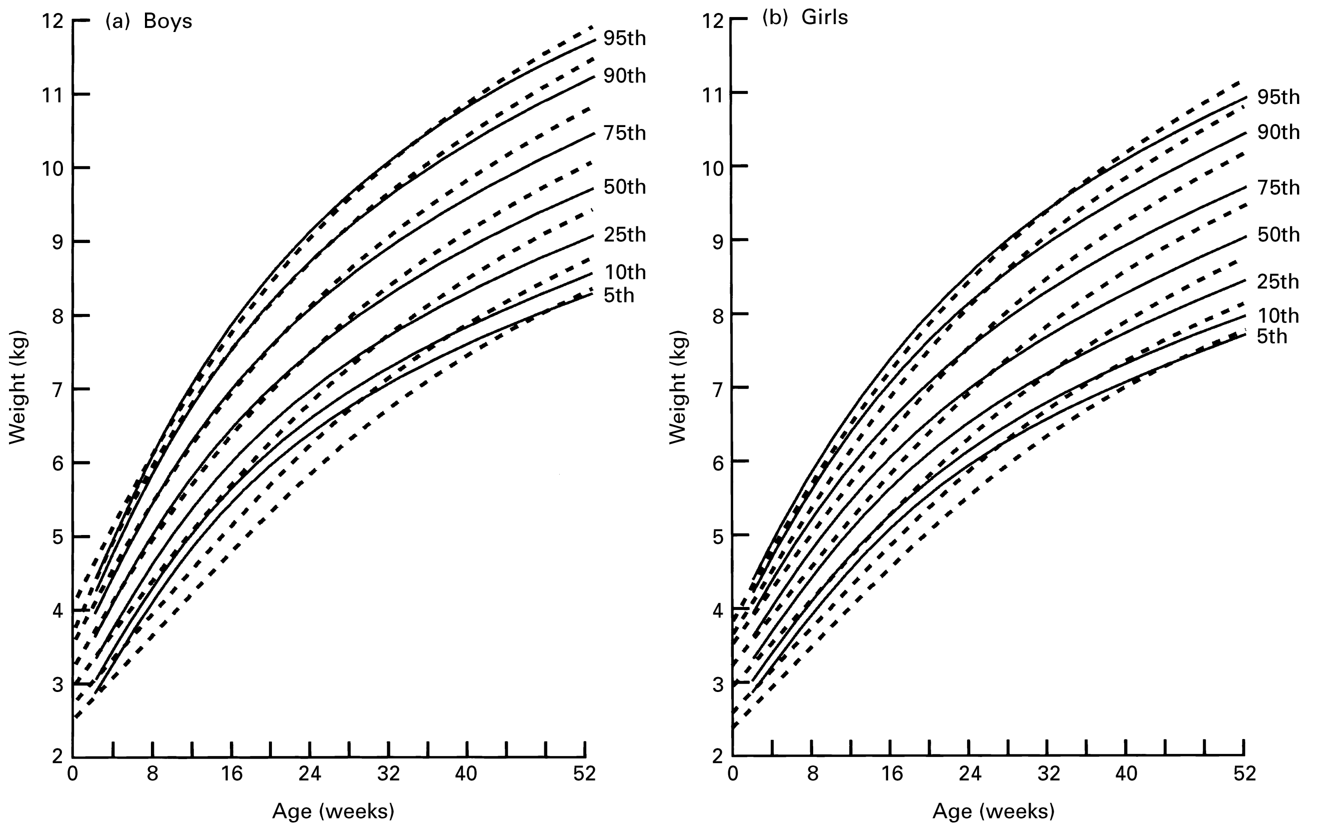

Fig. 6. The 5th–95th centiles of weight for Cambridge (a) boys and (b) girls (—) compared with National Center for Health Statistics (- - -) centiles (Hamill *et al.* 1977).

an unnecessarily early introduction of solids. The new UK growth reference charts (Freeman *et al.* 1995) for infancy, which are largely based on the Cambridge growth data (Whitehead & Paul, 1994), now help to avoid such hasty decisions.

The importance of revised infant growth charts for developing countries

WHO has also initiated internationally-based growth studies with a view to a revision of their growth reference tables and charts, for infancy as well as other ages (Anderson *et al.* 1995). It is in the context of a developing country that such a revision is of particular public health importance. Fig. 7 provides one example from a clinic in The Gambia serving mostly healthy urbanized children (Rowland, 1985). The overall interpretation of the data would be very different depending on which set of references was used. With NCHS (Hamill *et al.* 1977) the growth 'watershed' would be at 2 months, but if compared with the growth of Cambridge children no adverse effect would be discernible until 4–5 months, and even then it could not be deemed serious. This consideration could be important in the planning of subsequent public health programmes for these children.

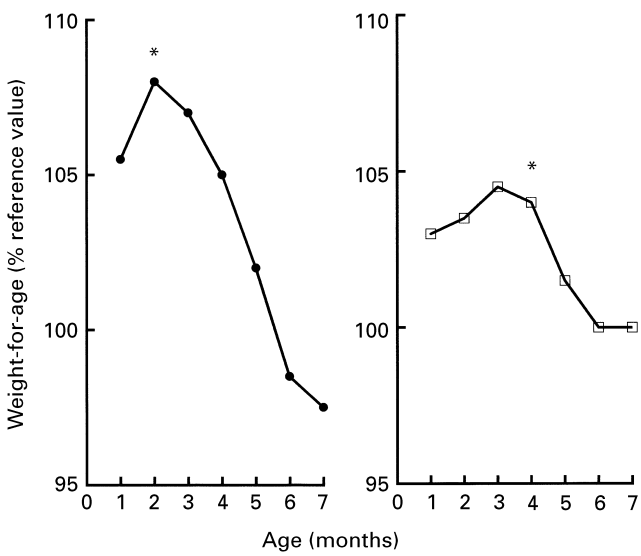

Fig. 7. Weight-for-age of breast- and mixed-fed infants from the peri-urban area of Bakau, The Gambia (Rowland, 1985) expressed as a percentage of: (●), National Center for Health Statistics reference 50th centile (Hamill *et al.* 1977); (□), the mean weights of Cambridge infants (Whitehead & Paul, 1984). Pooled data for boys and girls. *The age at which the downward deviation in growth velocity begins compared with the reference.

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Summary

The present paper has reviewed some of the work of our colleagues and ourselves over a number of years to place both nutritional and anthropometric guidelines for infancy on a firmer quantitative footing. Human lactation is too important for both the short- and long-term well-being of babies for it to be undermined by contrary advice based on incorrect reference values.

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