European Journal of Clinical Nutrition (2011) 65, 3–9
 0954-3007/11
www.nature.com/ejcn

INVITED REVIEW

How did babies grow 100 years ago?

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The rates and patterns of growth in weight of European and North American infants have changed over the last 100 years. Since the development and first use of growth charts for postnatal health surveillance a century ago, there appears to have been an increase in the weight of 1-year olds of about 1 kg. Taking into account the higher past rates of infant morbidity and mortality, and poorer quality of artificial feeds, this change is likely to be another expression of the secular increase in physical stature consequent on improved hygiene and nutrition. Using the new WHO (World Health Organisation) standards of infant weight growth, this secular change can be observed for both breast-fed and formula-fed babies. The slower weight growth of the former, both now and in the past compared with modern formula-fed babies, may have implications of our understanding of the risk factors for obesity and cardiovascular disease. The variability of infant growth in time and space, and the plasticity of developmental processes during the life course (fetal life, infancy, puberty and reproduction), means that the WHO infant growth standard should not alone be regarded as an ideal growth trajectory for all babies.
European Journal of Clinical Nutrition (2011) **65,** 3–9; doi:10.1038/ejcn.2010.257; published online 1 December 2010

Keywords: infant; weight; growth-chart; obesity; health

Introduction

How babies grow can have immediate and long-term effects on their health. Babies that 'fail to thrive' are at risk of poor cognitive development (Corbett and Drewett, 2004); babies that become overweight in childhood are likely to be obese in later life (Baird *et al.*, 2005); babies born early or small can 'catch-up' but this may have later health penalties (Weaver, 2006a).

More than 25 years ago, David Barker proposed that fetal and infant size were determinants of adult health. 'Barker's hypothesis' was based on the correlation of measurements of the weights of babies at birth (an index of fetal health and intrauterine growth) and at 1 year (an index of their growth in infancy) and their morbidity (incidence of cardiovascular disease, hypertension, stroke, diabetes and hyperlipidaemia) and mortality in later life (Barker, 1992, 1994). An enormous amount of further research has been undertaken since then into the developmental origins of health and disease (DOHAD) using animal models, natural experiments (twin studies) and longitudinal cohorts of human populations (Gluckman and Hanson, 2006). The DOHAD hypothesis is underpinned by plausible mechanisms, which can be observed and tested in animals (Bateson *et al.*, 2004) and in short-term human studies (Singhal, 2006). Such is the influence of Barker's hypothesis on our thinking about the genesis of adult disease that it now informs public health policy (Marmot and Wilkinson, 2006).

There has recently been a shift of focus from birth weight and other measures of intrauterine (fetal) health, to dynamic measures of growth and development of the newborn, leading to a view that *rate of growth* in infancy may be a more powerful determinant of later health than birth weight or weight at 1 year of age (Weaver, 2006a). Growth acceleration in infancy appears to increase the risk of later obesity and cardiovascular disease (Singhal and Lucas, 2004; Singhal *et al.*, 2010). The association of faster weight gain (upward centile crossing for weight) in infancy and greater risk of long-term obesity (Baird *et al.*, 2005) has been observed in children and adults, in high- and low-income countries (Monteiro and Victora, 2005).

The longitudinal cohorts on which Barker's hypothesis was based were composed of children born early in the twentieth century (Barker, 1992, 1994). The measurements of their body weights, lengths and growth rates lack reference data against which to judge how they grew compared with healthy babies a 100 years ago. Modern infant growth charts are inappropriate because they are derived from populations of babies with very different health, welfare and feeding histories. Nevertheless, growth standards now inform public health programmes and regular infant weighing is the

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Received 17 July 2010; revised 19 October 2010; accepted 28 October 2010; published online 1 December 2010

foundation of child health surveillance (Weaver, 2010). World Health Organisation (WHO) growth standards (WHO, 2006) based on healthy, breast-fed, thriving babies, compiled from the sequential measurement of infants born and reared in a number of different countries around the world, suggest that environmental factors (infection and feeding) rather than genetic endowment, are the principal determinants of rate of growth in infancy (de Onis *et al.*, 2007). WHO argues that its infant growth charts are potentially universally applicable to all children worldwide and should be used as a 'standard in all populations' (WHO, 2009) 'referable to all children everywhere' (International Pediatric Association, 2006). It is fair to assume that the growth of healthy babies a 100 years ago was also largely determined by rates of infection, mode and quality of feeding, given that changes in population genetics that might theoretically account for changes in growth patterns are not possible within two or three generations. Examination of published data on how babies grew a 100 years ago reveals different rates and patterns of infant growth compared with now. These differences raise important and intriguing questions about the compilation of growth charts as much as what they may tell us about health in early life and subsequently. This review describes the origins and development of infant growth charts, exploring the conceptions and sources of measurements that informed their construction and use then and now.

Origin and development of growth charts

In the nineteenth century concern about infant mortality, informed by the collection and analysis of infant mortality rates, focused attention on the causes and consequences of death early in life (Armstrong, 1986). A preoccupation with 'infant viability' prompted the collection of birth weights (as an index of viability) in the late-eighteenth and early-nineteenth centuries (Clarke, 1786; Friedlander, 1815; Quetelet, 1831), and the strong association between 'improper feeding' and poor growth became apparent (Routh, 1860). Systematic attempts to weigh and measure large populations of infants were given impetus by the rise of the 'numeric method' (Matthews, 1995), and the invention and application of statistics to social, medical and public health questions (Villermé, 1828). The mid-nineteenth century saw the start of a debate about the use and interpretation of statistics to clinical and physiological problems (Matthews, 1995), which made use of population data and their graphical representation.

Thermometry was an influential example of the clinical value of charting sequential quantitative numerical data. Pioneered by Carl Wunderlich (1871), who undertook thousands of measurements of body temperature from patients with all sorts of different diseases, clinical thermometry came to find a place in medical care. The analysis and presentation of sequential data raised two problems: how to display them and how to make them generalisable. The chart gave an answer to the former. An answer to the latter lay in obtaining many measurements (observing the 'law of large numbers') before seeking mean values (Matthews, 1995).

Adolphe Quetelet was a pioneer of the development of statistical methods for the analysis of complex biological and social data. He aimed to define 'l'homme moyen', based on his belief that the average of all human attributes in a given country serves to define the 'type' of the nation analogous to the 'centre of gravity' in physics (Quetelet, 1830). He was one of the first to attempt to define the 'normal' growth of infants, collecting the weights of an unknown number of children in the foundling hospital in Brussels (Quetelet, 1831). These measurements, which established that girls and boys grew at different rates, remained the only source of data on infant growth for several decades.

The graphical representation of infant growth was a product of this debate, and simple growth charts started to be published in journals (Russow, 1880; Schmid-Monnard, 1892) and then in textbooks of paediatrics (Camerer, 1908) and infant care (Pritchard, 1904). By the 1890s, growth charts found a useful place in the postnatal wards of Paris hospitals, particularly within those for the care of 'weaklings', and then became the mainstay and justification for the *consultations de nourrissons* (postnatal infant welfare clinics) designed to monitor the growth of babies at home (Budin, 1907). Comparable growth charts were also used in the *gouttes de lait* (pioneered by Léon Dufour in Normandy), and these were adopted in some London infant milk depots (Newman, 1906), and more widely in other parts of the British Isles (Weaver, 2010). The importance of breast feeding for infant health was stressed and efforts were made to ensure that alternative feeds were clean and constituted according to contemporary nutritional knowledge and principles (Weaver, 2006b). By the turn of the nineteenth century, anxieties about the health of mothers and their babies prompted international political as well as public health concerns, with the spectre of 'physical deterioration', 'degeneration' and 'national inefficiency' leading to surveys and reports on maternal and child health (Parliamentary papers, 1904; Mackenzie and Foster, 1907). Infant mortality, feeding and growth became the subjects of public health debate in England (Newman, 1906), France (Rollet, 1997), Germany (Kintner, 1987) and the United States (Meckel, 1990).

Infant welfare clinics

In France this concern was embodied in the word and concept of 'puericulture', which described a movement that brought together obstetricians, paediatricians and political activists with a common interest in maternal and infant welfare. It was dedicated to the preservation of child health during the critical months of early life, by maintaining

regular, medically supervised contact with post-parturient mothers and their babies. Characteristic features of the movement were 'scientific feeding', weighing (and other forms of quantitation), and the medicalisation of well-baby care (La Berge, 1991). The *consulations* and *gouttes de lait* were significant products of the puericulture movement, and were adopted widely throughout France and further afield (McCleary, 1933).

The *consultations* offered obvious opportunities to define growth standards and these were exploited by Variot and Fliniaux (1914), who questioned the prevailing opinion that the growth and development of artificially fed babies was generally inferior to that of breast fed. The artificially fed did almost as well as the breast fed, particularly in the second half of the year, but the mixed fed did the best. They showed that the *gouttes de lait* and *consultations de nourrissons* could promote growth comparable to that of the breast fed, using artificial feeds. The numbers of infants weighed may have been small (around 50 per month), but this study defined a range of normality within which babies thrived, and was particularly significant as one of the first to report not only the separate weight growth of boys and girls but also according to how they were fed (Figure 1).

Following the same thinking as Variot and Fliniaux (1914) and searching for British infant growth data, Brailsford Robertson sought to define the normal growth of English babies (Robertson, 1916). He questioned the appropriateness of using French babies as a standard against which to measure English infants, also noting that the 'Newman Standard' (Newman, 1906) did not distinguish boys from girls. In carefully selected infant welfare clinics in London and Leeds, he collected the weights of healthy babies with which he composed charts of the growth of boys and girls who were all apparently healthy and well nourished (Robertson, 1916). Using these and other data, Robertson (1923) brought together and reviewed all the issues concerning normality and growth standards in infancy, drawing attention to the importance of selecting healthy, thriving babies when attempting to define 'normal' infant growth.

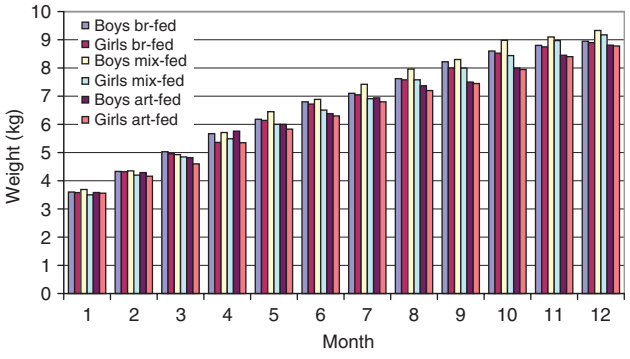

Figure 1 Monthly body weights of infants fed on the breast, bottle or with mixed feeds, taken from Variot and Fliniaux (1914). See text for further details.

Interwar debate about maternal and child health focussed on the relative influences on poor infant growth, health and mortality of poor mothering, ignorance and fecklessness, as opposed to poverty and insufficient budget to purchase food (Pearson, 1912; Paton and Findlay, 1926). Was it heredity or nutrition that was responsible, was personal behaviour more important than food deficiency (McKeown, 1988), was death in early life a necessary selective process, and might measures to reduce it lead to 'physical degeneration'? A shift in public health thinking between the world wars, from health in general to particular medical problems, such as, ischaemic heart disease and lung cancer in adults, eclipsed the prevalent concern for infant and child health (Davey Smith and Kuh, 1997). Nevertheless, infant welfare services proliferated and health surveillance became routine, with weighing, measuring, vitamin, milk and food supplementation (COMA, 2002). However, the steady decline of infant mortality rates throughout the twentieth century eased anxiety about health in early life. Immunisation programmes, school meals and a focus on particular childhood diseases (rickets and tuberculosis for instance) eclipsed the preoccupation with the health of the newborn, as artificial infant feeding (formula milks) became safe, popular, socially convenient and acceptable (Weaver, 2006b).

Nevertheless, growth surveillance remained an important part of child public health programmes in the United Kingdom and the United States (Tanner, 1988; Brosco, 2002). Charts compiled by Tanner and Whitehouse (1973) in London, and by Gairdner and Pearson (1971) in Cambridge became widely adopted in hospitals and clinics. They were replaced by the British Cross-Sectional (Freeman *et al*., 1995) growth charts, and in the United States a succession of growth charts designed to represent 'racial-ethnic diversity and combination of breast and formula-feeding' were used (National Center for Health Statistics, 2000).

How did babies grow 100 years ago?

Babies born in the late-nineteenth and early-twentieth centuries in Germany, France and England appear to have grown at significantly slower rates than did British and American babies born in the mid- to late-twentieth centuries (Figure 2). The data used to construct this figure were taken from the publications listed in the legend. The actual measurements on which some early growth charts were based are elusive, having been collected from unknown populations and did not always distinguish boys from girls, nor how they were fed. Nevertheless, there are striking differences in the patterns of growth of 'early' (lower band of growth curves in Figure 2) and 'recent' (upper band of curves) infants.

Babies born a 100 years ago were generally smaller throughout infancy, and by a year they were about half a kilogram lighter than 'WHO babies', and >1 kg lighter than babies born between 1971 and 2002. Babies born at the end of the twentieth century grew at a faster rate than 'WHO

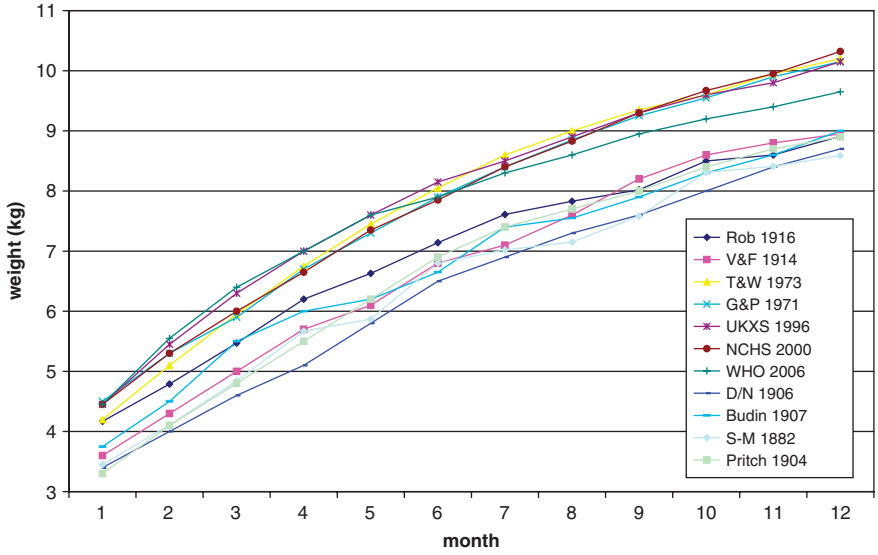

Figure 2 Weight growth of infants taken from measurements published by: Rob, Robertson (1916); V&F, Variot and Fliniaux (1914); T&W, Tanner and Whitehouse (1973); G&P, Gairdner and Pearson (1971); UKXS, Freeman *et al.* (1995); NCHS, National Center for Health Statistics (2000); WHO, World Health Organization (2006); D/N, Newman (1906); Budin, Budin (1907); S-M, Schmid-Monnard (1892); Pritch, Pritchard (1904). For 'early' data (lower band of growth curves), the sex of babies measured was not specified by Pritchard (1904), Newman (1906) or Budin (1907). In all other cases, the weights of boys have been used. For all 'recent' data (upper band of growth curves) male infant growth charts or tables were used. Mode of feeding was not specified by Schmid-Monnard (1892), Pritchard (1904), Newman (1906) or Budin (1907). For Variot and Fliniaux (1914) babies were wholly breast fed and for Robertson (1916) wholly or partially breast fed. For Tanner and Whitehouse (1973), Gairdner and Pearson (1971), Freeman *et al.* (1995) and National Center for Health Statistics (NCHS) (2000) babies were probably predominantly formula fed, but for WHO (2006) all babies were breast fed.

babies' throughout the first year from 6 months onwards. There is a suggestion of 'growth faltering' in the Budin (1907) and Newman (1906) babies between 3 and 5 months. There is a difference in growth rates between the 'early' (German, French and English) infants and the 'recent' (English and American) infants from at least 5 months; the former are on average a kilogram lighter thereafter. Even taking into account that not all the 'early' data distinguished girls from boys, nor how the babies were fed, they suggest that the rate and trajectory of body weight growth of infants 100 years ago was significantly different from that of mid- to late-twentieth centuries (many bottle fed) and contemporary healthy breast-fed infants (WHO, 2006). The breast-fed babies on whom the WHO charts are based achieve a weight at 1 year midway between the 'early' and 'recent' groups. These findings raise a number of questions about the construction and use of growth charts, as well as the interpretation of information derived from them.

Barker's hypothesis and modern interpretations

In the 1970s, the geographical coincidence of high Infant Mortality Rates in the past and contemporary high adult mortality rates from ischaemic heart disease was noted in Norway (Forsdahl, 1977), and the DOHAD hypothesis was proposed—that nutritional insufficiency in early life, followed by relative affluence in later life, was a risk factor for coronary heart disease. This hypothesis, exploited and developed by Barker (1992, 1994), has since had enormous influence of scientific thinking, clinical practice and public health policy in relation to the DOHAD. Although underpinned by compelling data from antenatal and postnatal records of children born in the early-twentieth century (Barker *et al.*, 1989; Osmond *et al.*, 1993), Barker's hypothesis is not novel. The idea that child health is the foundation of adult health is ancient, articulated in popular and learned literature as well as in folk-lore and animal husbandry (McCance and Widdowson, 1974). It is an intuitively plausible and attractive idea and its origin can be discerned in medical writings from the ancients to the early modern period (Tempkin, 1956). The differences in growth of boys and girls, according to birth weight, mode of feeding, social class and ethnic origin were first defined in the nineteenth century (Quetelet, 1831; Russow, 1880; Schmid-Monnard, 1892) and are now well recognised. Barker supplied hard data to propose a scientific explanation of the long-term penalties of being small at birth. However, the weights at 1 year of the infants who were the subjects of his pioneering studies were not compared against contemporary growth references. Recent research suggests that rate of weight growth is more predictive of later outcomes than weight at birth or at 1 year (Weaver, 2006a). The pattern of growth curves (Figure 2) support the hypothesis that it is mode of feeding that determines health risk through its influence on weight growth (among other things) and that breast feeding may be

protective of later disease through its effect on growth trajectory (Singhal *et al*., 2010). They also illustrate a secular increase in infant weight growth over the last century.

However, the data presented here pose the question that if slower rate of weight growth, as seen in contemporary breast-fed babies, protects against the development of cardiovascular disease, why does the same not also apply to the infants studied by Barker *et al*. (1986) (Osmond *et al*., 1993), whose mean weights at 1 year are almost exactly the same as the WHO 50th centile value at 1 year? Little is known about how Barker's babies were fed, nor how they grew between birth and 1 year (Razzell *et al*., 2004). If the distribution of weights at 1 year of 'Barker's infants' (Barker *et al*., 1989; Barker, 1992, 1994) represent that of 1-year olds born in Hertfordshire in the 1910–1920s, then their growth rates are comparable to WHO (2006) babies. The possibility that the growth trajectory of Barker's babies was much the same as that of modern WHO infants weakens the hypothesis that rate of growth in infancy alone is a determinant of the risk of later CVS.

It is worth pointing out that the pattern of infant weight growth described by Variot and Fliniaux (1914) (Figure 1) anticipates the recent observation that exclusive breast feeding can accelerate weight growth in the early months (Kramer *et al*., 2002) and that mixed feeding (early weaning) potentiates this thereafter. Throughout the first year the breast-fed infants grew faster than the artificially fed infants. However, the mixed fed had growth rates superior to both by the age of 1 year, achieving a mean body weight of 9.3 kg, as opposed to 8.9 kg (breast fed) and 8.75 kg (artificially fed). The 'early' data selected and displayed in Figure 2 may well have included more babies that were failing to thrive than healthy infants, thereby skewing the weight growth curves downwards. In the absence of information about how these babies were selected it is not possible to rule out 'selection bias'. Moreover, the data of Variot and Fliniaux (1914) are consistent with the 'reverse causality' hypothesis whereby 'hungry' breast-fed babies are likely to be weaned earlier than apparently content and thriving formula-fed infants (Elsom and Weaver 1999; Kramer *et al*., 2002).

References and standards

The quest for universal growth charts can be traced back to Quetelet who sought to define *l'homme moyen* (Quetelet, 1830) and to introduce rules and methods for the analysis and presentation of population data. He showed that there are biological as well as statistical issues, which must be taken into account when constructing growth charts. Quetelet (1831) measured Belgian foundlings, who cannot be regarded as representing healthy infants as a whole, and the children studied by Russow (1880) and Schmid-Monnard (1892) came from selected populations. Examination of textbooks of paediatrics and infant feeding from the late-nineteenth and early-twentieth centuries reveal growth charts that are not much different from the 'early' data studied here. Those of Holt (1899), Rotch (1896), Cautley (1896) and Camerer (1906) were recommended for clinical diagnostic use to assess individual infants rather than for population surveillance. The 'early' data chosen for analysis here represent the earliest to be used routinely outside hospital for population health surveillance in infant welfare clinics.

There was debate among paediatricians and physiologists about the appropriate use, and even the clinical value of growth charts (Weaver, 2010). Some investigators preferred the simple rule of thumb that infants double their birth weight by 6 months and triple it by 12 months (Rotch, 1896; Holt, 1899). Others doubted that growth charts had any useful value (Dingwall-Fordyce, 1908), and few appreciated the significance of sex and mode of feeding to body weights. Generally the mean values of unspecified numbers of infants from undetermined populations were used in the construction of growth charts: we know little about the infants, which were the subjects of the growth charts of Budin (1907), Pritchard (1904) and Newman (1906). However, Variot and Fliniaux (1914) and Robertson (1916) deliberately selected babies according to sex and mode of feeding. But no measures of variance were shown in any of these charts. There are therefore difficulties and dangers in comparing 'early' and 'recent' data, which have been addressed in this review by using the mean weight of male breast-fed infants whenever possible.

The modern debate about the appropriate use of growth charts focuses not just on their suitability for particular populations of infants (geographically, ethnically and clinically, as well as in relation to length of gestation, gender and mode of feeding), but also on the difference between 'references' and 'standards' (Wright, 2005). This debate can be traced back to the choice between 'generalising' and 'individualising' methods of collecting and using growth data (Camerer, 1906). These methods, corresponding to the modern terms 'cross-sectional' and 'longitudinal', are each broadly appropriate for monitoring the growth of babies as a whole or individually. The 'early' and 'recent' growth curves presented here (Figure 2) are 'references' composed from 'cross-sectional' measurements, while the WHO (2006) curve is presented as a 'standard' to which all healthy infants might be expected to conform (Cameron and Hawley, 2009). This distinction is especially relevant wherein the growth charts are used in different populations (developed vs developing world; breast vs bottle fed) and also applies to the historical data presented here. Nevertheless, the WHO curves represent a useful standard against which to compare both 'early' and 'recent' data (de Onis *et al*., 2007), underlining the variability and plasticity of infant growth rates in time and place.

Conclusions

The development and construction of growth charts in the nineteenth century was an important step in the medicalisation of infant care, driven by efforts to identify and adopt

objective criteria of infant health (Weaver, 2010) and to establish rational feeding regimes (Weaver, 2009). Arising from the work of paediatricians, physiologists, social scientists and public health professionals, infant weighing led to welfare services for mothers and children in which growth monitoring had a dominant part (McCleary, 1933). In comparison with the extensive literature on the social, political and economic aspects of maternal and infant welfare (Rollet, 1997), much less has been written about the science that informed it, particularly its key surveillance tool, infant weighing. Reviews of Barker's hypothesis and attempts to put it in a historical perspective, have focused on earlier debates about the importance of child health to adult well-being (Kuh and Davey Smith, 1993), but have neglected to explore the historical origins of the scientific basis for theories of the DOHAD.

This review has endeavoured to describe how infant growth charts arose out of a search for objective measures of health at a time when infant morbidity and mortality rates were very high. During its clinical and scientific adoption, the process of weighing babies was refined and applied in a number of increasingly sophisticated and far-reaching ways: as a measure of the dimensions of the fetus and newborn, as an index of the viability of the newborn, as a means of estimating milk intake, as a way of distinguishing normality from abnormality, as a summary measure of infant health, and as an instrument of mass surveillance (Weaver, 2010). The growth chart is now an adjunct to physical examination, which provides quantifiable information that informs diagnosis, treatment and prognosis. By charting the trajectory of infant growth, it became adopted worldwide in infant welfare clinics, as the 'road-to-health' (Jelliffe and Jelliffe, 1978). A century after infant growth charts were pioneered in postnatal clinics a set of universal growth charts, applicable to all babies globally, has been produced by WHO (2006), based on the principle that it is the quality and mode of feeding (environmental factors) that are the essential determinants of infant health and growth.

On the basis of the measurement of healthy breast-fed babies the WHO growth charts represent an ideal standard to which all babies worldwide may aspire to. When used to compare how babies born and reared in former times and other places grew, they reveal secular 'increases' in growth rates that are probably determined largely by improved infant health and mode of feeding. When designing studies and testing hypotheses about the DOHAD it is vital to know not only how infants were fed and grew, but also how they compared with contemporary standards in time and place. It is also important to appreciate the inherent plasticity of developmental processes throughout the life course, especially in growth, metabolism and body composition, during fetal life, infancy, puberty and reproduction (Gluckman *et al.*, 2009). Although infancy may be a foundation of later health, an 'optimum' infant weight growth standard, as defined by WHO (2006) cannot alone be regarded as a universal ideal because of the plasticity of responses to environmental (particularly nutritional) influences during sensitive periods of development and growth (Weaver, 2006a).

Conflict of interest

The author has been a consultant for Danone Baby Nutrition, SMA and the WHO.

Acknowledgements

I thank Malcolm Nicolson and Angus Ferguson from the Centre for the History of Medicine, and Charlotte Wright of the PEACH Unit, University of Glasgow and the Wellcome Trust for their help and support.

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