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Horizons in Nutritional Science

Duration of exclusive breast-feeding: introduction of complementary feeding may be necessary before 6 months of age

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The WHO recommends exclusive breast-feeding for the first 6 months of life. At present, $<2\,\%$ of mothers who breast-feed in the UK do so exclusively for 6 months. We propose the testable hypothesis that this is because many mothers do not provide sufficient breast milk to feed a 6-month-old baby adequately. We review recent evidence on energy requirements during infancy, and energy transfer from mother to baby, and consider the adequacy of exclusive breast-feeding to age 6 months for mothers and babies in the developed world. Evidence from our recent systematic review suggests that mean metabolisable energy intake in exclusively breast-fed infants at 6 months is 2·2–2·4 MJ/d (525–574 kcal/d), and mean energy requirement approximately 2·6–2·7 MJ/d (632–649 kcal/d), leading to a gap between the energy provided by milk and energy needs by 6 months for many babies. Our hypothesis is consistent with other evidence, and with evolutionary considerations, and we briefly review this other evidence. The hypothesis would be testable in a longitudinal study of infant energy balance using stable-isotope techniques, which are both practical and valid.

Infant nutrition: Lactation: Energy metabolism

The WHO recommends exclusive breast-feeding for the first 6 months of postnatal life (World Health Organization, 2002*a*). The evidence base for this recommendation is limited (Michaelsen *et al.* 2000; Lanigan *et al.* 2001; Kramer & Kakuma, 2002), and at present $<2\,\%$ of mothers who breast-feed exclusively in the UK do so for 6 months (Department of Health, 2002). In the present paper we consider an important test of the recommendation – is exclusive breast-milk feeding adequate to meet average infant energy needs for up to 6 months? We suggest that energy from breast milk alone will be inadequate by 6 months for the average infant, and propose that introducing complementary feeding before 6 months of age in the developed world is an appropriate response to increasing infant energy needs. To support the hypothesis we draw upon a recent systematic review of milk energy transfer, summarise other evidence consistent with it, and take an evolutionary perspective.

Energy balance of exclusively breast-fed infants

Energy intake from breast milk

We recently reviewed systematically (Reilly *et al.* 2005) a large, high-quality, and consistent body of evidence on the quantity of breast milk transferred, and on the energy content of breast milk. At 3–4 months old, mean milk transfer (thirty-three studies of 1041 mother–infant pairs) was 779 g/d. At 6 months old (five studies, seventy-two pairs), mean transfer was 894 g/d. Metabolisable energy content of breast milk (twenty-five studies of 777 pairs) was 2·6 kJ/g (0·62 kcal/g). For the typical exclusively breast-fed infant metabolisable energy intake is approximately 2124 kJ/d in boys, and 1924 kJ/d in girls at 4 months, and 2439 kJ/d in boys and 2207 kJ/d in girls at 6 months (pooled intake estimates adjusted to account for higher intakes in boys; Reilly *et al.* 2005).

Energy requirements of exclusively breast-fed infants at 4 and 6 months

Mean daily energy requirements from systematic reviews of breast-fed infants were 325–330 kJ/kg for boys at age 4 and 6 months. Mean daily energy requirement of girls was 330–335 kJ/kg between 4 and 6 months of age (World Health Organization, 2002*b*)

Energy balance calculations at 6 months of age

To estimate typical energy needs we used 50th percentile body weights from UK 1990 reference data for girls and boys at age 6 months (7·7 kg and 8·0 kg) (Freeman *et al*. 1995). Energy balance is: (metabolisable energy intake) – (energy requirement).

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Fig. 1 combines these mean data and shows that mean milk energy transfer in the exclusively breast-fed infant is likely to be inadequate at 6 months of age.

Implications

Our calculations suggest that exclusive breast-feeding would supply only about 90 % of infant energy requirements at age 6 months on average. For energy requirements to be met, either (1) the average infant would need to weigh less than the average from UK 1990 reference data, or (2) energy content of breast milk would need to be above the 95 % CI in our systematic review (Reilly *et al.* 2005) or (3) average milk intake would need to exceed 1000 g/d (higher than the 95 % CI in our systematic review; Reilly *et al.* 2005). The notion that the average breast-fed infant weighs less than the average formula-fed infant is plausible (the UK 1990 reference data include both groups), and the WHO is currently addressing this issue by collecting data on growth of exclusively breast-fed infants (Wright, 2005). Using our calculations, the average energy transfer in breast milk would support infants with average mass-specific energy requirements of 7·2 kg (boys) and 6·4 kg (girls), equivalent to approximately 1 and 1·7 SD below the UK 1990 reference in boys and girls respectively. Marked increases in the energy content of breast milk seem unlikely, but this issue would benefit from an empirical study. It is usually assumed that mothers will increase milk output as the energy requirements of their infants increases, but the empirical evidence does not support this assumption (Reilly *et al.* 2005), and this assumption also ignores the physiological dynamics and evolutionary context of lactation (discussed later). In addition, the magnitude of the increase in milk transfer, which is necessary, seems unrealistic.

Consistency with other evidence

Our hypothesis is consistent with several independent lines of evidence. First, when mothers who exclusively breast-feed are asked what influences their decision to introduce complementary feeds, they consistently report the perception that their infants are hungry and 'unsatisfied' by breast milk alone (Savage *et al.* 1998; Fewtrell *et al.* 2003). Second, mothers of babies with higher-birth-weight, boys, and larger babies, tend to introduce complementary foods earlier (Savage *et al.* 1998; Wilson *et al.* 1998; Fewtrell *et al.* 2003). These variables predict timing of introduction of complementary foods prospectively and may indicate that larger babies (with greater energy needs) experience limited breast-milk energy transfer earlier. Third, studies of the energy cost of lactation for the mother consistently report peak breast-milk (gross) energy outputs of about 2·0–2·2 MJ/d (478–526 kcal/d; Goldberg *et al.* 1991; Lovelady *et al.* 1993; Butte *et al.* 2001), and this is inadequate to support average infant energy needs at age 6 months.

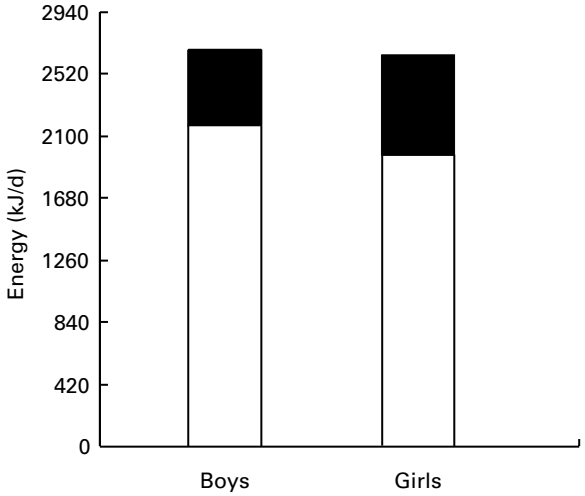

Fig. 1. Energy requirement (kJ/d) at age 6 months in girls and boys, with estimated energy supply from breast milk (□) and energy deficit (■).

Lactation and complementary feeding in evolutionary perspective

Proponents of the recommendation to breast-feed exclusively for 6 months argue that the infant 'drives' lactation, by increasing milk transfer where necessary, and the mother is relatively passive. This view is inconsistent with evolutionary considerations related to the cost of lactation and the degree of maternal–offspring 'conflict'. Lactation is costly in energetic and other terms (Goldberg *et al.* 1991; Lovelady *et al.* 1993; Butte *et al.* 2001; Wells, 2003) and it reduces both maternal and offspring inclusive 'fitness' by restricting reproductive capacity via lactational amenorrhoea. Selection pressure has acted to reduce lactation duration in man compared with other apes (Wells, 2003) and Aiello & Key (2002) have argued that a shorter duration of lactation has been a key component in the evolution of our genus. Mothers are in conflict with their offspring over the optimum duration of lactation (they share only 50 % of their genes with each offspring; Trivers, 1974), and have evolved to distribute total maternal resources amongst their total offspring (Wells, 2003). From evolutionary considerations the optimal time for introducing complementary foods is predicted to be earlier for the mother than for the infant (so that she can conceive the next offspring), while the infant still gains from breast-milk consumption (Aiello & Key, 2002; Wells, 2003).

Milk transfer is a complex and dynamic process that is constrained by maternal and infant physiology, and the mother is not passive (Wells, 2003). As in other species, the provisioning of offspring operates as a signalling system maintained by tension between the two parties (Wells, 2003). Infant demand is signalled by vocalisation (need), and by suckling vigour (appetite), which both extracts milk from the breast and acts as a longer-term stimulus for milk production. Infant demand is capped by the energetic cost of these signals, and the mother has also been proposed to constrain infant appetite through the secretion in breast milk of compounds that have sedative properties (Wells, 2003). Thus, the notion that mothers will simply increase breast-milk yields to meet increasing infant energy needs to 6 months is inconsistent with the physiology and evolution of human lactation, as well as our review of empirical evidence (Reilly *et al.* 2005). Mechanical evacuation of the breast can produce higher yields of milk than are typically consumed by babies (i.e. there is spare capacity in milk production), but this does not mean that infants can access this extra milk, and the evolutionary conflict inherent in accessing it has received insufficient attention in infant feeding recommendations.

Testing the hypothesis

Our hypothesis is readily testable. Measurements of infant energy balance are possible using stable-isotope methods that are

practical (for example, do not require milk sampling or any interruption to feeding), and have been validated (Lucas *et al.* 1987). These methods would be best employed in a study in which the key energy balance variables (milk transfer, milk energy content, infant energy needs) are measured longitudinally from early in lactation to 6 months. It would also be possible to test whether an intervention (for example, lactation counselling, improved midwife support) designed to increase exclusive breast-feeding duration could actually increase milk energy transfer to accommodate the infant's increasing energy requirements.

Our hypothesis leads logically to several predictions that would be testable in observational studies. Providing sufficient energy from breast milk alone at 6 months of age is likely to require a combination of: infants with low energy needs (small infants with slow rates of growth); unusually high transfer of milk from mother to infant, above the upper limits observed from the literature; unusually energy-dense milk, above the limits observed in the literature.

Implications for public health and clinical practice

Our hypothesis predicts that many mothers who attempt to follow the recommendation to breast-feed exclusively for 6 months are likely to experience hungry and distressed babies, the consequences of insufficient milk energy transfer and a substantial chronic energy deficiency. Infants actually require an excess of energy intake over energy expenditure in order to grow adequately. Another likely consequence would be increasing workload for health visitors and general practitioners, since difficulties with infant feeding remain one of the commonest reasons for families to attend at primary care (O'Keefe, 1994).

Rapid infant weight gain has been linked to increased risk of later obesity and insulin resistance (Stettler *et al.* 2002, 2003; Singhal *et al.* 2003), and so maximal growth rates should not necessarily be regarded as optimal for long-term health. Nevertheless, the relevance of this point to the energy requirements of breast-fed infants in mid-infancy is debatable. First, most studies of long-term obesity risk have used BMI as the outcome, which may overestimate any association. Second, the association between early growth and later insulin resistance appears to be largely accounted for by growth in the first 2 weeks after birth (Singhal *et al.* 2003), and the long-term impact of growth later in infancy is less well understood. Third, by 6 months of age energy requirements for growth are lower than earlier in infancy, and energy expended on physical activity is an important component of the infant energy budget (Wells & Davies, 1998).

Conclusions

We hypothesise that breast-milk transfer of energy to the infant will often be inadequate to meet infant energy requirements by 6 months. This hypothesis is readily testable, consistent with empirical evidence from a systematic review of infant energy balance, and consistent with evolutionary considerations. We accept the mass of evidence in support of breast-feeding, and extending the duration of breast-feeding, but our hypothesis addresses the issues of the optimal and feasible duration of exclusive breast-feeding. Current English Department of Health (2003) advice appears to acknowledge the need for some flexibility in the recommendation to breast-feed exclusively to 6 months by stating that 'While exclusively breast-feeding to 6 months is recommended (footnote) all infants should be managed individually so that insufficient growth is not ignored'. Breast-feeding, in contrast to formula-feeding, is highly physiologically responsive (Fewtrell *et al.* 2003). We propose that for many mothers who breast-feed exclusively, introduction of complementary feeding before 6 months is simply another example of this degree of responsiveness to infant and maternal needs.

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