

Dietary Energy Intake at the Age of 4 Months Predicts Postnatal Weight Gain and Childhood Body Mass Index

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ABSTRACT

OBJECTIVE. Rapid infant weight gain has been shown to predict later obesity risk; however, it is unclear which factors influence infant diet and weight gain. The objective of this study was to determine whether different feeding patterns and energy intakes that are provided to infants affect body weight and BMI later in childhood.

METHODS. This representative birth cohort study was conducted in the United Kingdom. Energy intake at age 4 months was estimated from 1-day unweighed dietary records in 881 infants and related to their childhood weight gain and BMI.

RESULTS. Among formula- or mixed-fed infants ($N = 582$), energy intake was higher in first-born infants (mean \pm SE: 2730 ± 29.4 kJ/day; $n = 263$) than in subsequent-born infants (2620.8 ± 25.2 kJ/day; $n = 296$). Energy intake at 4 months was also higher in infants who were given solid foods earlier (1–2 months: 2805.6 ± 50.4 kJ/day, $n = 89$; 2–3 months: 2658.6 ± 25.2 kJ/day, $n = 339$; 4+ months: 2587.2 ± 46.2 kJ/day, $n = 111$). Higher energy intake at 4 months predicted greater weight gain between birth to age 1, 2, or 3 years and larger body weight and BMI at ages 1 to 5 years. No significant associations were seen in breastfed infants ($N = 299$).

CONCLUSIONS. Among formula- or mixed-fed infants, dietary energy intake at age 4 months predicted postnatal weight gain and childhood obesity risk. Both prenatal and postnatal factors may influence infant energy intake and postnatal weight gain.

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Key Words

infant, growth, diet, obesity, breastfeeding

Abbreviations

ALSPAC—Avon Longitudinal Study of Parents and Children
SDS—SD score

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THE WORK OF Hales and Barker¹ originally highlighted the possible link between early life influences and adult cardiovascular and metabolic disease. However, there is still much controversy as to whether prenatal rather than early postnatal nutrition influences later risks for obesity. Several recent population studies have reported that rapid weight gain during the first 2 to 3 years of life predicts increased obesity risk. We reported in the geographically based Avon Longitudinal Study of Parents and Children (ALSPAC) birth cohort that faster rates of weight gain between birth and 2 years predicted larger BMI, waist circumference, and body fat mass at 5 years of age.² Subsequent larger studies have confirmed that rapid weight gain during the first 4 to 12 months predicts larger BMI in later childhood^{3,4} and also in young adults.^{5,6}

The first 2 to 3 years of postnatal life represents a hypervariable period of weight gain, as many infants show relatively rapid weight gain in apparent compensation for in utero growth restraint.^{2,7,8} For example, first-born infants are thinner at birth and show subsequent rapid “catch-up” postnatal weight gain compared with a mother’s subsequent offspring.⁹ Infancy growth is largely regulated by nutrition,¹⁰ and it is proposed that early postnatal catch-up and catch-down growth may be regulated by differences in appetite and satiety.¹¹ In the ALSPAC cohort, we therefore identified factors that influence early infancy dietary energy intake and hypothesized that greater energy intake at 4 months of age could predict subsequent faster childhood weight gain and increased obesity risk.

METHODS

Participants

Recruitment of the ALSPAC cohort was described recently.¹² Briefly, ALSPAC is a geographically based cohort that was recruited from mothers who had expected delivery dates between April 1991 and December 1992 and were resident within the 3 Bristol-based health districts of the former county of Avon, United Kingdom. An estimated 85% to 90% ($N = 14\,541$) of all eligible mothers were enrolled in the study, resulting in 13 971 live infants who survived to 1 year. Details of the representative nature of the sample are displayed on the ALSPAC Web site (www.alspac.bristol.ac.uk).

One-day dietary records were sent to mothers of a 10% random selection (“Children in Focus”), which includes 1335 term (gestation: 37–42 weeks) singletons. Dietary data were available from 881 of these mothers; these responders had similar offspring birth weights to the current United Kingdom reference (United Kingdom birth weight SD score [SDS; mean \pm SD]: 0.01 ± 0.98) and were no different from nonresponders in birth weight, gestational age, gender, parity, or childhood size. At 4 months of age, 299 infants were breastfed (no

formula milk), 499 were formula-fed (no breast milk), and 83 were mixed-fed (breast milk and formula). Because of the differences in methods for estimating energy intake, breastfed infants were analyzed separately. Informed consent was obtained from mothers, and ethical approval was obtained from the ALSPAC law and ethics committee and from local research ethics committees.

Pregnancy Data and Auxology

Gestational age at birth was estimated using date of last menstrual period and confirmed by antenatal ultrasound reports; in cases of discrepancy, the data were reviewed by a single experienced clinician. Mother’s parity and smoking during pregnancy were recorded by a questionnaire that was completed during pregnancy. Birth weights were noted from hospital records, and supine length was measured using a Harpenden neonatometer (Holtain Ltd, Crosswell, Dyfed, United Kingdom) soon after birth (median: 1 day; range: 1–14 days) by the ALSPAC study team.

The children in this ALSPAC subcohort were also measured on up to 10 additional occasions until 5 years (at 4, 8, 12, 18, 25, 31, 37, 43, 49, and 61 months). Weight (Seca 724 or 835 scales [London, United Kingdom]) and standing height (Leicester height measure, Child Growth Foundation, London, United Kingdom) were measured at visits to the research clinics.

BMI was calculated as [weight (kg)/length (m²)]. Rate of postnatal weight gain was calculated as change in gender- and age-adjusted SD scores (SDS) as previously described.² Postnatal rapid weight gain was defined as an increase in weight SDS between birth and 2 years of >0.67 SDS, because 0.67 SDS represents the distance between adjacent centile lines drawn on standard growth curves (2nd, 9th, 25th, 50th, 75th, 91st, and 98th centiles).¹³

Dietary Data

Diet at age 4 months was assessed using a structured 1-day unweighed dietary record that was completed by the infant’s main caregiver. One week before the clinic visit, the dietary record and an instruction leaflet were sent to the caregiver. He or she was asked to record in household measures everything that the child was given to eat and drink and any leftover food or drink during a 24-hour period and to bring the completed record to the clinic. Mothers of breastfed infants were asked to record the duration of each feeding in minutes. Age at introduction to solid foods (weaning) was recorded by questionnaires at ages 4 weeks and 6 months. The mean, median, and mode (61%) for age of introduction of solids was 3 months.

Dietary Calculations

The completed dietary records were transformed into weights and codes that corresponded to each of the foods

or drinks taken. Portion sizes for infant foods were usually described by proportion of a jar eaten or by teaspoonfuls, thus making weight fairly simple to estimate. Family foods were allocated weights based on Ministry of Agriculture, Forestry and Fisheries, United Kingdom, Food Portion Sizes.¹⁴ Weights were also obtained from manufacturers' information, from weights given on packets, and by test-weighing of some foods. Composite foods and recipes that did not have an equivalent in the food tables were broken down into their component parts and allocated codes and weights appropriately. For breast milk, the duration of each feeding was used to estimate the likely volume of milk (12.5 mL/minute) up to 125 mL for a full feeding.¹⁵

Mean daily nutrient intakes were generated from weights and food codes using the computer software package Microdiet (University of Salford, Greater Manchester, United Kingdom) with added nutrient data obtained from food manufacturers and supermarkets. The nutrient and food group information associated with each food code was obtained from *McCance and Widdowson's The Composition of Foods, Fifth Edition* and the fruit and nut supplement.^{16,17} Nutrient intakes from dietary supplements were not included. Dietary energy intakes at age 4 months were normally distributed, but extreme outliers were excluded (<1260 kJ × 1 infant; >4200 kJ × 13 infants).

Statistics

Between-group differences in energy intake by gender, age at introduction of weaning foods, or rapid versus slower weight gain between 0 and 2 years were tested by analysis of variance, with adjustments made for gender and age. Associations between continuous outcome

variables and other variables were tested by linear regression, with adjustments for gender and age; regression coefficients (B) are displayed. Postnatal weight and BMI data were log-transformed to normal distributions to allow use of parametric tests. Correction for multiple testing was considered unnecessary, because all of the outcome variables were interdependent (eg, weight, height, and gains in weight and height at different ages).¹⁸ Means ± SE are displayed unless otherwise indicated.

RESULTS

Determinants of Energy Intake at 4 Months

Among both breastfed and formula- or mixed-fed infants, boys had larger energy intakes at age 4 months than girls (Table 1), and this difference was independent of body weight ($P < .0001$). Increasing energy intake was associated with larger body weight SDS at 4 months among formula- or mixed-fed infants ($B \pm SE: 100.8 \pm 21$ kJ/SD; $P < .0001$) but not among breastfed infants (-4.2 ± 37.8 kJ/SD; $P = .9$). Gender and current body weight were adjusted for in subsequent analyses.

Among formula- or mixed-fed infants, energy intake at age 4 months was higher in first-born (mean ± SE: 2730 ± 29.4 kJ/day, $n = 263$) than in subsequent-born infants (2620.8 ± 25.2 kJ/day; $P = .01$, additionally adjusted for mother's age and education; $n = 296$). Energy intake was also higher in infants who were given weaning foods earlier (1–2 months: 2805.6 ± 50.4 kJ/day, $n = 89$; 2+ to 3 months: 2658.6 ± 25.2 kJ/day, $n = 339$; 4+ months: 2587.2 ± 46.2 kJ/day, $n = 111$; $P = .002$; Fig 1). These patterns were not seen among breastfed infants ($P = .28-.35$).

TABLE 1 Size at Birth and Weight and Energy Intake at 4 Months According to Gender and Breastfeeding or Formula-Feeding at 4 Months

	Formula- or Mixed-Fed		Breastfed	
	Boys	Girls	Boys	Girls
<i>n</i>	321	261	148	151
Birth weight, kg				
Mean	3.553	3.400 ^a	3.601	3.480 ^b
SD	0.490	0.447	0.485	0.431
Gestation at birth, wk				
Mean	39.6	39.8	39.7	39.7
SD	1.1	1.2	1.2	1.2
Weight at 4 mo, kg				
Mean	6.90	6.40 ^a	6.87	6.26 ^a
SD	0.74	0.66	0.82	0.64
Weight gain 0–4 mo, kg				
Mean	3.34	3.00 ^a	3.27	2.79 ^a
SD	0.62	0.59	0.72	0.59
Energy intake at 4 mo, kJ/d				
Mean	2767.8	2549.4 ^a	2797.2	2574.6 ^a
SD	478.8	474.6	655.2	617.4

^a $P < .005$, girls versus boys.

^b $P < .05$, girls versus boys.



FIGURE 1
Dietary energy intake at age 4 months was related to age at introduction of weaning foods in formula- or mixed-fed infants ($P < .0001$ for trend) but in not breastfed infants ($P = .2$). Mean \pm 1 SE. Note: 1 kcal = 4.2 kJ.

Outcomes Related to Energy Intake at 4 Months

Higher total dietary energy intake at age 4 months was associated with greater gains in weight SDS between birth and ages 1, 2, and 3 years ($P = .007$ to $P = .0004$; Table 2) and with higher rates of rapid weight gain between 0 and 2 years ($P < .0001$; Fig 2). These associations were independent of current body weight and were seen among formula- or mixed-fed infants but not breastfed infants. Among formula- or mixed-fed infants, higher dietary energy intake at 4 months also predicted larger childhood body weight and BMI at ages 1, 2, 3, and 5 years (Table 3). In this group, each 420 kJ/day increase in energy intake at age 4 months was associated with increased risk for being obese or overweight (BMI >85th centile) at 3 years of age (odds ratio: 1.46; 95% confidence interval: 1.20–1.78), and at 5 years old (odds ratio: 1.25; 95% confidence interval: 1.00–1.55).

DISCUSSION

In this large, prospective, contemporary cohort study, dietary energy intake as early as age 4 months in formula- or mixed-fed infants was positively related to early childhood weight gain and subsequent body weight and BMI up to 5 years of age. Recent studies in this and other cohorts have shown that rapid weight

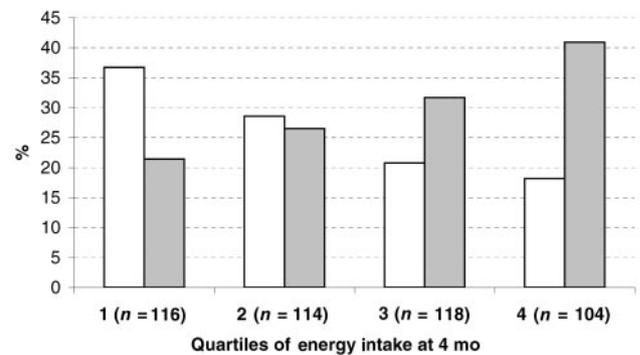


FIGURE 2
Percentages of infants who showed rapid (■) or slower (□) weight gain between 0 and 2 years, by quartiles of dietary energy intake at age 4 months, in formula- or mixed-fed infants ($P < .0001$ for trend).

gain during infancy, whether based on the first 4 months, 6 months, 12 months or 24 months of life, predicts obesity risk in children and adults.^{2–6} During infancy, diet may have a greater impact on nutrient balance and hormone responses than energy expenditure, as in a recent study, infants who were at higher risk for obesity had higher energy intakes and different sucking behaviors than low-risk infants but no difference in total and nonsleeping energy expenditure.¹⁹

Randomized trials have reported that greater dietary energy content in nasogastric tube-fed preterm infants may have remarkable long-term effects on later body size and metabolic disease risk.^{20,21} Our study in representative full-term infants now shows that more common parental choices in infant feeding, such as the amount given and the timing of introduction of weaning foods, may have an important impact on infant weight gain and childhood obesity risk. There are as yet few studies of dietary interventions in normal infants to prevent excessive weight gain, particularly in Western populations,²² and a limitation of our observational study may be that parental choice of infant diet might be associated with differences in later childhood diet and physical activity. In ALSPAC, the educational status of the mother has been associated with differences in weaning choices and in food choices later in childhood.^{23–25} However, the associations that we observed between energy intake and postnatal weight gain were unaltered by additional adjustment for maternal education and age (data not shown).

In this cohort, beneficial effects of breastfeeding on avoiding excess infant weight gain, childhood obesity, and higher blood pressure have been described previously.^{9,26,27} However, in the current study, we were unable to compare directly energy intakes between breast- and bottle-fed infants because of the large differences in methods. Among breastfed infants, there were no apparent associations between energy intake and weight gain or age at weaning. However, we did not weigh infants

TABLE 2 Linear Association Between Energy Intake at Age 4 Months and Change in Weight SDS Between Birth and 1, 2, or 3 Years of Age

Age, y	Formula- or Mixed-Fed		Breastfed	
	Mean \pm SE	P	Mean \pm SE	P
0–1	0.18 \pm 0.05	.0005	–0.01 \pm 0.04	.9
0–2	0.18 \pm 0.05	.0004	–0.02 \pm 0.04	.7
0–3	0.15 \pm 0.05	.007	–0.02 \pm 0.04	.6

Values are regression coefficients (SDS per 420 kJ), adjusted for gender and weight at 4 months. Note: 1 kcal = 4.2 kJ.

TABLE 3 Linear Association Between Energy Intake at Age 4 Months and Childhood Weight, Height, and BMI at 1, 2, 3, 4, or 5 Years of Age in Formula- or Mixed-Fed Infants at 4 Months

Age, y	Weight, g		Height, cm		BMI, kg/m ²	
	Mean ± SE	P	Mean ± SE	P	Mean ± SE	P
1	129 ± 32	<.0001	0.15 ± 0.07	.05	0.14 ± 0.05	.003
2	211 ± 53	<.0001	0.20 ± 0.11	.08	0.17 ± 0.05	.0006
3	193 ± 72	.002	0.14 ± 0.14	.3	0.17 ± 0.06	.003
5	255 ± 139	.04	0.18 ± 0.19	.1	0.15 ± 0.07	.03

Values are regression coefficients (per 420 kJ). *P* values are based on normalized weight and BMI distributions and adjusted for gender and weight at 4 months.

Note: 1 kcal = 4.2 kJ.

before and after feeding or assess milk composition, and there could be large variability in the volume of milk consumed per minute of feeding, leading to poor estimation of energy intake. Other studies have reported lower energy intakes in breastfed than formula-fed infants,²⁸ suggesting that we may have overestimated energy intake in our breastfed infants. Alternatively, it has been suggested that breastfed infants may be better at self-regulating their total energy intake by reducing their milk intake when solid foods are introduced.^{29,30}

In contrast to breastfed infants, in formula-fed 4-month-old infants, it may be relatively easy to assess accurately energy intake, even with only a 1-day recording of dietary data, because in infancy, the number of different foods and drinks consumed is limited and there is less day-to-day variation in intakes.³¹ In these infants, the clear association between energy intake and weight gain could also reflect the large interindividual variance in weight gain during this period, compared with in later life. Indeed, infancy is a hypervariable period for weight gain, when more than half of all infants may show relatively rapid (catch-up) or slow (catch-down) weight gain, apparently in compensation for respective prenatal growth restraint or growth enhancement.^{2,32} Ounsted and Sleigh³³ observed that rapidly growing infants who were small for gestational age consumed larger volumes of milk than did infants of normal birth weight, and they suggested that infants may self-regulate their energy intakes through preset differences in appetite. More recently, study of rare genetic mutations that result in hyperphagia confirmed the strong influence of appetite and satiety on weight gain, particularly during early childhood.³⁴ Similarly, genetic factors are likely to explain to a large degree the large gender difference in energy intakes that persisted after adjustment for body size. Infant energy intake also may be preset in part by maternal factors that act in utero.¹¹ First-born infants were significantly smaller and thinner at birth than subsequent-born infants but showed a compensatory rapid postnatal weight gain,⁹ and our current observations suggest that this may be driven by greater infancy appetite and energy intake.

Of course, there may be multiple reasons for different

feeding behaviors in infancy, and we are unable to prove cause and effect. Infant energy intake presumably reflects both infant appetite and parental choice of infant feeding practices. The differences in first-born and subsequent infants were independent of maternal age and educational attainment but could still reflect possible differences in parenting behavior or attitudes. Equally, age at introduction of weaning foods is unlikely to be attributable solely to parental choice but may also reflect parental perceptions of their infant's hunger or other needs.^{35,36} Therefore, although our findings clearly support a role of early postnatal nutrition in predicting childhood obesity risk, we cannot exclude the possibility that postnatal appetite, energy intake, and obesity risks may have been programmed by in utero factors. Finally, we acknowledge that energy intake was sampled only at 1 time point. Analysis of repeated measures throughout infancy could strengthen the associations with weight gain and would provide important information on the degree of tracking of energy intake within individuals.

CONCLUSIONS

Dietary energy intake during infancy determines infant weight gain and may influence obesity risk during childhood, at least among formula- and mixed-fed infants. The difficulty in estimating intakes in breastfed infants meant that we could not make conclusions in this group. However, the association between rapid infant weight gain and later obesity risk is apparent even in populations who are largely breastfed.⁶ Additional identification of the complex parental and infant factors that determine early dietary choices could inform potential future dietary and behavioral interventions to prevent childhood obesity.

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