Infant feeding method and obesity: body mass index and dual-energy X-ray absorptiometry measurements at 9–10 y of age from the Avon Longitudinal Study of Parents and Children (ALSPAC)[1–3]

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ABSTRACT

Background: Previous studies reported inconsistent associations between breastfeeding and body mass index (BMI; in kg/m^2). Associations with body fatness are unknown.

Objective: We investigated the association of breastfeeding with fatness measured by dual-energy X-ray absorptiometry.

Design: The prospective cohort study involved 4325 singletons with measurements at 9–10 y of age to assess the main outcomes of BMI and total and trunk fat masses.

Results: Prevalence of any breastfeeding was 82%. In crude analyses, breastfeeding was inversely associated with total fat mass [% change per category increase (4 categories)] in breastfeeding duration (−4.4%; 95% CI: −3.1%, −5.6%) and trunk fat mass (−0.5%; 95% CI: −1.1%, 0.1%); the odds of adiposity were measured by total [odds ratio (OR): 0.81; 95% CI: 0.75, 0.88] and trunk (OR: 0.78; 95% CI: 0.71, 0.84) fat masses in the top decile. In adjusted models, the inverse association of breastfeeding with mean total fat mass was attenuated by 59% (% change per category increase in breastfeeding duration: −1.8%; 95% CI: −0.5%, −3.1%), but associations with trunk fat mass (% change per category increase in breastfeeding duration: −0.6%; 95% CI: 0.0%, −1.3%) and the ORs for total (0.76; 95% CI: 0.69, 0.84) and trunk (0.74; 95% CI: 0.67, 0.81) fat masses in the top decile were little altered. Children breastfed ≥6 mo had the lowest odds of total fat mass in the top decile (OR: 0.45; 95% CI: 0.33, 0.62). In multivariate models, there was little evidence that breastfeeding was associated with mean or threshold values of BMI.

Conclusions: The protective association of breastfeeding with mean total fat mass was attenuated somewhat after adjustment for confounders, which indicated that confounding may explain this association. Breastfeeding may protect against obesity if maintained for ≥6 mo. *Am J Clin Nutr* 2007;85:1578–85.

KEY WORDS Avon Longitudinal Study of Parents and Children, ALSPAC, epidemiology, diet, prevention and control, energy metabolism, feeding behavior

INTRODUCTION

Overweight and obesity are the most common nutritional disorders in industrialized countries, and their prevalence continues to rise (1–3). Effective strategies to prevent childhood obesity are needed because obesity in childhood predicts obesity in adulthood (4–6) and later cardiovascular disease (7–9), but therapeutic interventions are expensive and tend to have poor long-term results (3, 10).

Various critical time periods for the development of later obesity, including the perinatal period, have been proposed (11). A World Health Organization report suggested that breastfeeding is one perinatal factor that is probably associated with reduced obesity risk (12). Evidence to support a protective effect of breastfeeding on obesity has come largely from epidemiologic studies, but recent systematic reviews (13–16) suggest that the evidence base is less secure than was previously assumed (13, 14, 16). One of these reviews failed to observe a protective association with mean body mass index (BMI; in kg/m^2) (15), whereas the others suggested a small protective association with obesity (13, 14, 16), but the association was of uncertain public health importance. These reviews have also highlighted that almost all of the evidence on this issue relies on BMI, a surrogate measure of adiposity, rather than on a more direct measure to assess excess fat mass, such as dual-energy X-ray absorptiometry (DXA). To our knowledge, only 2 previous studies investigated infant feeding method and later adiposity with the use of DXA measurements (17, 18). However, the sample size of each of those 2 studies was small (<400 subjects). Another issue is that breastfeeding is associated with less obesogenic parental characteristics, such as higher educational level, lower prevalence of parental obesity, and absence of maternal smoking in pregnancy (19), but most previous studies do not adequately adjust for these potential confounding variables (20, 21). In a previous analysis

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of the Avon Longitudinal Study of Parents and Children (ALSPAC), an inverse association of breastfeeding with obesity defined by BMI thresholds was observed [odds ratio (OR) for exclusive compared with never breastfed: 0.64] (22); this association was reversed after adjustment for a wide range of potential confounders (OR: 1.22), although overadjustment for risk factors on the causal pathway was suggested (23).

The main aim of this study was to prospectively examine associations of breastfeeding with adiposity at 9–10 y of age, measured by DXA, with comprehensive but sequential control for potential confounding factors. The secondary aim was to examine these same associations with BMI as a proxy for adiposity.

SUBJECTS AND METHODS

Study population and data sources

ALSPAC is a longitudinal birth cohort study of the determinants of development, health, and disease during childhood and beyond. It is described in detail elsewhere (24). Briefly, 14 541 pregnant women with an expected date of delivery between April 1991 and December 1992 were enrolled; 13 971 of their children formed the original cohort at 1 y of age.

The parents of each subject in the original study gave written informed consent. Ethical approval was granted by the ALSPAC Law and Ethics Committee and local research ethics committees.

Breastfeeding measures

Data on the method of infant feeding were obtained from self-completion questionnaires sent to each mother when her child was 6 and 15 mo of age. As in previous reports, prospective information on breastfeeding duration was available as a categorical variable, and for this study we had information on the exclusivity of breastfeeding up to and including 2 mo of age. Duration of breastfeeding was coded as never, <3, 3–5, and ≥6 mo (25, 26). At 32 wk of gestation, mothers were asked whether they intended to breastfeed or bottle-feed their child for the first 3 mo.

Anthropometry

Height, weight, and body composition were measured at 9–10 y of age. Height was measured with the use of a Harpenden stadiometer (Holtain Ltd, Crymych, United Kingdom) while the child was not wearing shoes or socks, and weight was measured with the use of a body fat analyzer and weighing scales (Tanita TBF 305; Tanita UK Ltd, Yewsley, United Kingdom). BMI was calculated. Total fat, trunk (central) fat, and lean masses were estimated with the use of a Lunar Prodigy DXA scanner (GE Medical Systems Lunar, Madison, WI). The scans were visually inspected and realigned when necessary. Trunk mass was estimated with the use of the automatic default region that included the chest and the abdominal and pelvic areas (27). Although DXA cannot distinguish between intraabdominal and subcutaneous fat, research in children showed strong correlations between trunk fat mass measured with DXA and intraabdominal fat measured with computed tomography or magnetic resonance imaging (28).

Definitions of overweight and obesity

We defined overweight and obesity according to age- and sex-specific cutoffs as proposed by the International Obesity Task Force (29). Well-established reference data from which to identify cutoffs for overweight or obesity in children on the basis of body-composition data from DXA scans are lacking. Therefore, we categorized total fat and trunk fat masses into a binary variable with the division at the top decile, after adjustment for age, height, and height squared. These definitions identify those children who are most likely to experience comorbidity, such as obesity tracking, presence and clustering of cardiovascular risk factors, and psychological problems (30). We examined the above binary outcomes because breastfeeding may be associated with the upper end of the adiposity distribution without affecting the mean (31).

Potential confounding factors

The following variables that were previously shown to be associated with obesity in ALSPAC and other cohorts were considered a priori as potential confounders: parental factors, prenatal factors, and later lifestyle factors (22, 32, 33). Parental factors included maternal education, maternal BMI, and the social class of the mother or father (whichever was higher). Prenatal factors included birth weight, gestational age, and intrauterine tobacco exposure. Later lifestyle factors included time spent sleeping at night at 42 mo of age, time spent in a vehicle per weekend day, time spent watching television per week, age at introduction of solid foods, and the dietary patterns of 4 food groups as defined in previous publications (labeled as junk, healthy, traditional, and fussy eating patterns) at 38 mo of age (22, 34). These data were collected by means of mailed questionnaires, which were completed by the mother prenatally or while her child was in infancy or childhood (22). Birth weight was extracted from routine hospital birth records; gestational age was estimated from the date of the last menstrual period and findings from the routine (<20 wk) prenatal ultrasound scan.

Statistical analysis

Because BMI, total fat mass, and trunk fat mass had skewed distributions, log-transformed values were used for analyses. For continuous and categorical outcomes, linear and logistic regression analyses, respectively, were used to control for age at adiposity measurement, sex of the child, and the potential confounding factors listed earlier. Lean mass and total and trunk fat masses were also adjusted for height and height squared to take into account differences in stature. Geometric means for continuous adiposity measures by infant feeding method were calculated from dummy variables included in respective models for each continuous outcome variable. For categorical outcomes (overweight, obesity, and categorical DXA fat and lean mass measures), ORs (and 95% CIs) were calculated according to the binomial distribution (35). *P* for trend values were derived from models that included infant feeding method as a linear variable.

The following multivariate models are presented, which are based on the potential confounders identified earlier (22, 32, 33, 36): *1)* a basic model that controlled for age and sex (and height and height squared for DXA measures); *2)* model 2, which included the basic model and also controlled for parental factors (maternal BMI, maternal education, and parental social class); *3)* model 3, which included model 2 and also controlled for prenatal factors (gestational age, birth weight, and maternal smoking during pregnancy); and *4)* model 4, which included model 3 and also controlled for the child's later lifestyle (television watching,

TABLE 1
Distribution of potential confounders by duration of breastfeeding[1]

Potential confounders	Breastfeeding None (n = 782)	Breastfeeding <3 mo (n = 994)	Breastfeeding 3–5 mo (n = 759)	Breastfeeding ≥6 mo (n = 1790)	P[2]
Maternal education to at least A-level (%)	19.8 ± 1.4	26.4 ± 1.4	34.0 ± 1.7	33.2 ± 1.1	< 0.001
Maternal BMI (kg/m^2)	23.8 ± 0.2	23.1 ± 0.1	22.8 ± 0.1	22.4 ± 0.1	< 0.001
Parental Registrar General's social class between IIIm and VI (%)	60.0 ± 1.8	47.8 ± 1.6	38.7 ± 1.8	28.6 ± 1.1	< 0.001
Gestational age (wk)	39.4 ± 0.1	39.5 ± 0.1	39.4 ± 0.1	39.5 ± 0.0	0.094
Birth weight (g)	3384 ± 20.6	3413 ± 16.8	3405 ± 18.5	3481 ± 11.9	< 0.001
Intrauterine tobacco exposure (%)	25.2 ± 1.6	17.5 ± 1.2	17.0 ± 1.4	9.5 ± 0.7	< 0.001
Television watching ≥1 h per weekday (%)	80.6 ± 1.4	76.3 ± 1.4	70.2 ± 1.7	64.1 ± 1.1	< 0.001
Night sleep at 42 mo (h)	11.3 ± 0.0	11.2 ± 0.0	11.3 ± 0.0	11.2 ± 0.0	0.067
In a vehicle ≥1 h/d on weekend day (%)	38.4 ± 1.7	34.7 ± 1.5	32.4 ± 1.7	30.2 ± 1.1	< 0.001
Introduction of solid foods in first 3 mo (%)	76.3 ± 1.5	78.0 ± 1.3	75.6 ± 1.6	61.6 ± 1.1	< 0.001

[1] All values are $\bar{x}$ ± SE.
[2] Derived from linear or logistic regression as appropriate.

duration of night sleep, time per day spent in a vehicle on a weekend day, age at introduction of solid foods, and dietary patterns of 4 food groups at 38 mo of age) (34). Multicollinearity of respective covariates was identified by a variance inflation factor > 2.5 (37). Because of recent evidence, the possible interactions of breastfeeding with maternal BMI (18, 38), maternal smoking (22), and sex for later childhood adiposity were investigated a priori with the use of the likelihood ratio test in logistic models.

To determine whether breastfeeding is simply a marker for other unmeasured factors correlated with both the decision to breastfeed and later adiposity, we investigated associations of measures of adiposity with the prenatal intention of a mother to breastfeed or to bottle-feed her newborn child. We also investigated whether any breastfeeding-adiposity associations were observed among children whose mothers had originally intended to bottle-feed their child, because the act of breastfeeding in these mothers may be less strongly associated with other healthy behaviors that protect against obesity in their offspring than it is in mothers who always intended to breastfeed. All analyses were performed with the use of SAS statistical software (version 9.1; SAS Institute Inc, Cary, NC) and R (version 2.3.0; http://www.r-project.org/).

RESULTS

After the exclusion of multiple births, analysis was confined to 4325 children with complete data on infant feeding, sex, anthropometric measures and corresponding age, potential confounders, and DXA measurements. The final sample consisted of 2178 boys (50.4%) and 2147 girls (49.6%). The mean (±SD) age at height and weight measurements was 9.8 ± 0.3 y (range: 8.8–11.7 y); the age did not differ significantly between boys and girls (P = 0.50).

Description of infant feeding method and body composition

Never breastfeeding was reported by 782 (18.0%) mothers, whereas 994 (23.0%) children were breastfed only in the first 3 mo, 759 (17.5%) children were breastfed from age 3 to 5 mo, and 1790 (41.4%) children were breastfed ≥6 mo. There was no evidence that patterns of breastfeeding differed significantly between boys and girls (P = 0.35). A total of 13.1% started solid foods within the first 2 mo. Mean values of BMI (17.4 ± 1.31), total fat mass (7.11 ± 0.53 kg), trunk fat mass (2.67 ± 0.08 kg), and total lean mass (24.32 ± 6.25 kg) were adjusted for age and sex and also for the DXA measures, height, and height squared. The age-, sex-, height-, and height squared–adjusted top decile thresholds for total and trunk fat mass were at 10.8 kg and 3.9 kg, respectively. Total and trunk fat masses from DXA measurements were highly correlated (Pearson's r = 0.99), whereas the correlations between fat mass measures and BMI in the 4325 children were slightly lower (Pearson's r = 0.88). Among obese children (n = 261), the correlations between BMI and total or trunk fat mass were lower (Pearson's r = 0.75 and 0.71, respectively).

Description of potential confounders

Overall, 59.5% of mothers and fathers had a Registrar General's social class between IIIm (skilled manual) and VI (armed forces), whereas 47.6% of mothers had at least an A-level (ie, grades 12 and 13) education. Mean maternal BMI, birth weight, and gestational age values were 22.9 ± 3.7, 3435 ± 525 g, and 39.5 ± 1.7 wk, respectively. Smoking during pregnancy was reported by 15.5% of the mothers. Overall, 33.1% of children spent a minimum of 1 h/weekend day in a vehicle, whereas 70.9% of the children watched television at age 4 y age for ≥1 h/weekday. At 42 mo, the mean time spent sleeping per night was 11.3 ± 0.9 h. Breastfeeding duration was positively associated with maternal education, higher parental social class, and birth weight and was inversely associated with maternal BMI, maternal smoking during pregnancy, introduction of solid foods in the first 3 mo, television watching, and time spent in a vehicle per weekend day; gestational age and night sleep time were not related to breastfeeding (**Table 1**).

Representativeness of the final sample

The final sample of 4325 children did not differ in key characteristics from those potentially eligible singleton children who did not take part. The mean values for birth weight, gestational age, and maternal BMI were 3435 g, 39.5 wk, and 22.9 in the final

TABLE 2
Univariate and multivariate linear regression analyses showing associations of duration of breastfeeding with mean BMI and mean total fat, trunk fat, and lean masses measured by dual-energy X-ray absorptiometry (DXA)[1]

	BMI[2] (kg/m^2)	Total fat mass[3] (kg)	Trunk fat mass[3] (kg)	Total lean mass[3] (kg)
Model 1[4]				
Never	17.50 (16.86, 18.17)	7.52 (7.16, 7.90)	2.87 (2.73, 3.01)	24.29 (23.13, 25.51)
<3 mo	17.70 (17.05, 18.37)	7.55 (7.19, 7.93)	2.86 (2.72, 3.00)	24.38 (23.21, 25.60)
3–5 mo	17.49 (16.85, 18.15)	7.17 (6.83, 7.53)	2.70 (2.57, 2.84)	24.34 (23.18, 25.57)
≥6 mo	17.15 (16.52, 17.80)	6.69 (6.37, 7.02)	2.48 (2.36, 2.61)	24.28 (23.12, 25.50)
Percentage change per category increase in breastfeeding duration (%)	−0.9 (−0.5, −1.3)	−4.4 (−3.1, −5.6)	−0.5 (0.1, −1.1)	−0.1 (0.1, −0.2)
P for trend	< 0.001	< 0.001	0.101	0.467
Model 2[5]				
Never	17.27 (16.54, 18.02)	7.20 (6.82, 7.61)	2.71 (2.57, 2.87)	24.22 (22.92, 25.58)
<3 mo	17.64 (16.90, 18.41)	7.47 (7.07, 7.89)	2.82 (2.67, 2.98)	24.36 (23.06, 25.74)
3–5 mo	17.51 (16.77, 18.28)	7.20 (6.81, 7.60)	2.71 (2.57, 2.87)	24.35 (23.05, 25.73)
≥6 mo	17.27 (16.55, 18.03)	6.84 (6.84, 7.23)	2.56 (2.42, 2.70)	24.32 (23.02, 25.69)
Percentage change per category increase in breastfeeding duration (%)	−0.3 (0.1, −0.7)	−2.4 (−1.1, −3.7)	−0.7 (−0.1, −1.3)	0.1 (0.3, −0.1)
P for trend	0.189	< 0.001	0.027	0.441
Model 3[6]				
Never	17.27 (16.49, 18.10)	7.18 (6.77, 7.61)	2.70 (2.55, 2.86)	24.23 (22.85, 25.68)
<3 mo	17.66 (16.86, 18.50)	7.48 (7.05, 7.93)	2.82 (2.66, 2.99)	24.38 (22.99, 25.85)
3–5 mo	17.51 (16.72, 18.35)	7.19 (6.78, 7.62)	2.71 (2.55, 2.87)	24.36 (22.98, 25.83)
≥6 mo	17.26 (16.47, 18.08)	6.85 (6.46, 7.26)	2.56 (2.42, 2.72)	24.30 (22.92, 25.76)
Percentage change per category increase in breastfeeding duration (%)	−0.3 (0.1, −0.7)	−2.3 (−1.0, −3.5)	−0.6 (0.0, −1.3)	−0.0 (0.2, −0.2)
P for trend	0.099	< 0.001	0.044	0.733
Model 4[3]				
Never	17.26 (16.34, 18.23)	6.86 (6.42, 7.33)	2.63 (2.46, 2.81)	24.25 (22.69, 25.92)
<3 mo	17.64 (16.70, 18.63)	7.14 (6.68, 7.63)	2.75 (2.57, 2.94)	24.38 (22.82, 26.06)
3–5 mo	17.52 (16.59, 18.50)	6.91 (6.46, 7.38)	2.66 (2.49, 2.84)	24.36 (22.79, 26.04)
≥6 mo	17.27 (16.36, 18.24)	6.62 (6.19, 7.08)	2.54 (2.37, 2.71)	24.29 (22.72, 25.96)
Percentage change per category increase in breastfeeding duration (%)	−0.2 (0.2, −0.6)	−1.8 (−0.5, −3.1)	−0.6 (0.0, −1.3)	−0.0 (0.2, −0.2)
P for trend	0.238	0.006	0.055	0.897

[1] All values are geometric $\bar{x}$; 95% CI in parentheses.
[2] Adjusted for age and sex.
[3] Adjusted for age, sex, height, and height squared.
[4] Model 1 controls for age and sex (and height and height squared for DXA measures).
[5] Model 2 includes model 1 and additionally controls for parental factors (maternal BMI, maternal education, and parental social class).
[6] Model 3 includes model 2 and additionally controls for prenatal factors (gestational age, birth weight, and maternal smoking during pregnancy).
[7] Model 4 includes model 3 and additionally controls for child's later lifestyle (television watching, duration of night sleep, time per day spent in a vehicle on a weekend day, age at introduction of solid foods, and dietary patterns of 4 food groups at 38 mo of age).

sample analyzed and 3378 g, 39.4 wk, and 23.0 in the entire sample.

Association of breastfeeding with mean BMI and DXA measures of fat and lean masses

The associations of breastfeeding with mean BMI and DXA-measured mean total fat, trunk fat, and lean masses are shown in **Table 2**. In the basic models, there was evidence that greater duration of breastfeeding was associated with a reduction in total fat mass (*P* for trend < 0.001), but the association was attenuated by 59% in the fully adjusted model (from a coefficient of −4.4 to −1.8). There was only weak evidence of an association of breastfeeding with trunk fat mass ($P = 0.06$ in fully adjusted models), and no association of breastfeeding with lean mass was observed ($P = 0.90$ in fully adjusted models). There was an inverse association of duration of breastfeeding with BMI in the basic model, but the association was attenuated by nearly 80% in the fully adjusted model (from a coefficient of −0.9 to −0.2).

Association of breastfeeding with overweight and obesity

In the basic models, there was strong evidence that the prevalence of overweight and obesity (defined by BMI thresholds) and the prevalence of total and trunk fat masses in the top decile were lower in those who were breastfed for longer than in those breastfed for a shorter time (*P* for trend < 0.01 for all; **Table 3**). After adjustment for potential confounding factors, there was no evidence of an association between duration of breastfeeding and later overweight or obesity estimated from BMI measurements (*P* for trend > 0.45 for all; **Table 4**). However, in fully adjusted models, there was still strong evidence that the risks of total and trunk fat masses in the top decile were lower in those who were breastfed for longer than in those breastfed for a shorter time (*P*

TABLE 3
Prevalence of overweight and obesity defined by BMI and total and trunk fat masses in the top decile measured by dual-energy X-ray absorptiometry according to duration of breastfeeding

Duration of any breastfeeding	Overweight[1]	Obesity[1]	Total fat mass[2]	Trunk fat mass[2]
		n (%)		
Never (n = 782)	192 (24.6)	46 (5.9)	94 (12.0)	101 (12.9)
<3 mo (n = 994)	268 (27.0)	86 (8.7)	123 (12.4)	130 (13.1)
3–5 mo (n = 759)	171 (22.5)	54 (7.1)	89 (11.7)	81 (10.7)
≥6 mo (n = 1790)	359 (20.1)	75 (4.2)	124 (6.9)	120 (6.7)
Total (n = 4325)	990 (22.9)	261 (6.0)	430 (9.9)	432 (10.0)
P for trend[3]	< 0.001	0.002	< 0.001	< 0.001

[1] Cutoffs from Cole et al (29).
[2] Adjusted for age, sex, height, and height squared.
[3] Derived from logistic regression analysis.

for trend < 0.001 for all), and this adjustment only slightly altered the effect sizes estimated in the basic models. The magnitude of the association with total and trunk fat masses in the top decile was large in those who were breastfed for ≥6 mo; the risk of being in the top decile for trunk and total fat masses was 55–58% lower in those breastfed for ≥6 mo than in those never breastfed. There was no strong evidence of any interaction between duration of breastfeeding and maternal BMI or sex or

TABLE 4
Multivariate logistic regression analysis showing associations of duration of breastfeeding with overweight and obesity measured by BMI and total and trunk fat masses in the top decile measured by dual-energy X-ray absorptiometry[1]

	Overweight[2]	Obesity[2]	Total fat mass[3]	Trunk fat mass[3]
Model 1[4]				
Never	Reference	Reference	Reference	Reference
<3 mo	1.13 (0.92, 1.41)	1.51 (1.05, 2.20)	1.03 (0.78, 1.38)	1.02 (0.77, 1.34)
3–5 mo	0.89 (0.71, 1.13)	1.23 (0.82, 1.84)	0.97 (0.71, 1.32)	0.81 (0.59, 1.10)
≥6 mo	0.77 (0.63, 0.94)	0.70 (0.48, 1.02)	0.55 (0.41, 0.72)	0.48 (0.37, 0.64)
Category increase in breastfeeding duration	0.89 (0.84, 0.95)	0.84 (0.76, 0.94)	0.81 (0.75, 0.88)	0.78 (0.71, 0.84)
P for trend	< 0.001	0.002	< 0.001	< 0.001
Model 2[5]				
Never	Reference	Reference	Reference	Reference
<3 mo	1.38 (1.10, 1.73)	2.13 (1.43, 3.16)	1.02 (0.76, 1.36)	1.02 (0.77, 1.35)
3–5 mo	1.17 (0.91, 1.50)	1.93 (1.25, 2.98)	0.94 (0.68, 1.29)	0.80 (0.58, 1.11)
≥ 6mo	1.12 (0.90, 1.40)	1.29 (0.86, 1.96)	0.51 (0.38, 0.69)	0.48 (0.36, 0.65)
Category increase in breastfeeding duration	1.00 (0.93, 1.07)	1.01 (0.90, 1.14)	0.79 (0.72, 0.87)	0.77 (0.70, 0.85)
P for trend	0.990	0.810	< 0.001	< 0.001
Model 3[6]				
Never	Reference	Reference	Reference	Reference
<3 mo	1.39 (1.11, 1.75)	2.13 (1.44, 3.17)	0.99 (0.74, 1.33)	1.00 (0.75, 1.,34)
3–5 mo	1.17 (0.91, 1.50)	1.92 (1.24, 2.96)	0.93 (0.67, 1.27)	0.79 (0.57, 1.09)
≥6 mo	1.11 (0.89, 1.39)	1.28 (0.85, 1.94)	0.48 (0.36, 0.65)	0.44 (0.33, 0.60)
Category increase in breastfeeding duration	1.00 (0.93, 1.07)	1.01 (0.90, 1.14)	0.78 (0.71, 0.86)	0.75 (0.68, 0.82)
P for trend	0.918	0.854	< 0.001	< 0.001
Model 4[7]				
Never	Reference	Reference	Reference	Reference
<3 mo	1.38 (1.10, 1.74)	2.20 (1.47, 3.27)	0.99 (0.74, 1.33)	0.99 (0.74, 1.32)
3–5 mo	1.18 (0.92, 1.52)	2.04 (1.31, 3.16)	0.89 (0.65, 1.23)	0.77 (0.55, 1.06)
≥6 mo	1.14 (0.91, 1.43)	1.40 (0.92, 2.14)	0.45 (0.33, 0.62)	0.42 (0.31, 0.57)
Category increase in breastfeeding duration	1.01 (0.94, 1.08)	1.05 (0.93, 1.18)	0.76 (0.69, 0.84)	0.74 (0.67, 0.81)
P for trend	0.832	0.473	< 0.001	< 0.001

[1] All values are odds ratios; 95% CI in parentheses.
[2] Cutoffs are from Cole et al (29).
[3] Adjusted for age, sex, height, and height squared.
[4] Model 1 controls for age and sex (and height and height squared for DXA measures).
[5] Model 2 includes model 1 and additionally controls for parental factors (maternal BMI, maternal education, and parental social class).
[6] Model 3 includes model 2 and additionally controls for prenatal factors (gestational age, birth weight, and maternal smoking during pregnancy).
[7] Model 4 includes model 3 and additionally controls for child's later lifestyle (television watching, duration of night sleep, time per day spent in a vehicle on a weekend day, age at introduction of solid foods, and dietary patterns of 4 food groups at 38 mo of age).

maternal smoking in pregnancy for later childhood obesity risk as defined by BMI (P for interaction = 0.37, 0.20, and 0.11, respectively).

In additional analyses, we found lower unadjusted mean values of adiposity measured by BMI and trunk and total fat masses for exclusive compared with partial breastfeeding at 2 mo. However, after full adjustment for parental, prenatal, and later lifestyle factors, a lower mean value could be observed only for total fat mass (percentage of change compared with partial breastfeeding: −3.7%; 95% CI: −0.4%, −7.0%), whereas there were no differences with adiposity measured by BMI ($P = 0.10$) or trunk fat mass ($P = 0.24$).

Further analyses examined associations of intention to breastfeed with obesity defined by BMI and total and trunk fat masses in the top decile. Models that adjusted for child's age and sex indicated protective effects of the intention to breastfeed—ORs of 0.89 (95% CI: 0.68, 1.16) for obesity, 0.93 (0.74, 1.16) for total fat mass in the top decile, and 0.81 (0.65, 0.99) for trunk fat mass in the top decile. A protective effect on fat mass was observed after restriction of the study sample to mothers who either had originally intended to breastfeed (reference never breastfeeding, ORs: 1.00 for <3 mo, 0.92 for 3–5 mo, and 0.51 for ≥6 mo breastfeeding; $P = 0.04$) or to bottle-feed (reference never breastfeeding, ORs: 0.91 for < 3 mo, 0.83 for 3–5 mo, and 0.31 for ≥6 mo breastfeeding; $P = 0.04$).

DISCUSSION

We found little evidence of a strong protective effect of breastfeeding on mean measures of adiposity, estimated by either BMI or DXA-derived fat mass at 9–10 y of age. Although the association between breastfeeding and mean fat mass was conventionally significant even after control for a wide range of confounders, the large degree of attenuation from the basic model (59%) and the small magnitude of the fully adjusted effect size indicate that confounding (as a result of plausible degrees of measurement error in the covariates) is the likely explanation for this association. There was evidence that breastfeeding for ≥6 mo was associated with a reduction in risk of overweight, defined on the basis of a high measure of fat mass.

In contrast, inverse associations of breastfeeding with obesity defined by BMI thresholds were reversed after control for potential confounders. These findings may reflect the fact that BMI is only a surrogate measure of fatness. However, adiposity rather than weight per se is thought to explain the major health comorbidities associated with obesity. Thus, studies on obesity may be misleading when BMI is used as an outcome, because of the imprecise classification of obese children. The use of BMI as an imprecise proxy for adiposity may also be an explanation for the conflicting results found in the literature—eg, if the validity of BMI as an adiposity measure varies in different populations. Although DXA is considered a better tool for estimating body fat than is BMI, a recent report suggested that DXA may overestimate fat mass in obese children and adults (39). This possibility would account for a shift of the DXA-derived fat mass distribution. Because we used the top decile as the cutoff in categorical analyses, this bias is unlikely to explain the relation between feeding mode and childhood fat mass in the top decile observed in our analyses.

Studies on breastfeeding and BMI

Although recent meta-analyses of observational studies suggested a small protective effect of breastfeeding on adiposity measured by BMI, neither residual or uncontrolled confounding nor publication bias could be ruled out (13–16). The one recent systematic review (15) that attempted to supplement its meta-analysis with data from unpublished sources showed that any difference between mean BMI in breastfed and bottle-fed subjects is probably small and unlikely to be of any public health importance. The results of the present study support this view.

Our results for breastfeeding for ≥6 mo and childhood obesity based on thresholds of DXA-defined fat mass are also in line with a recent meta-analysis suggesting that longer duration of breastfeeding may be inversely associated with obesity defined by BMI thresholds (16). This association in those with high fat is interesting because of the magnitude of the effect size and the further observation that breastfeeding had little effect on the mean value, which is not associated with poor health. Although some studies have reported an inverse relation between BMI and duration of breastfeeding (40, 41), another study did not (42). However, that study also suggested that the most beneficial effect for breastfeeding occurred from ages 6–8 mo, but that there was an increasing prevalence of obesity defined by BMI with ≥9 mo of breastfeeding (42).

A previous analysis of ALSPAC did not yield a protective effect for breastfeeding on obesity defined by BMI at the earlier age of 7 y (22). However, breastfeeding in women who did not smoke during pregnancy (but not in women who smoked during pregnancy) was associated with a lower risk of obesity. Furthermore, it was suggested that overadjustment for risk factors on the causal pathway may have been the reason for the lack of a main effect of breastfeeding (23). Overadjustment for such collinear factors may even reverse effects (43). In the present study, we found that a careful and sequential adjustment for potential confounders not on the causal pathway did not materially attenuate associations of breastfeeding with categorized DXA-derived measures.

The 2 studies from the literature that examined a potential association between infant feeding method and DXA-derived fat mass reported conflicting results. One study observed an inverse association in children up to adolescence but did not adjust for potential parental confounders (18). The other study found 0.28-kg lower fully adjusted fat mass in 5-y-old children who had been ever breastfed than in those who had been bottle-fed, but the sample size was small ($n = 313$), and this result was not conventionally significant ($P = 0.17$) (17).

Methodologic considerations

Because the breastfeeding information was obtained near the time of actual breastfeeding and before outcome measurement, recall bias should not be an issue. To control for selection bias because of complete case analysis, crude variable estimates for the association of breastfeeding with childhood adiposity measures were compared between the entire sample with information on both adiposity measures and breastfeeding and the restricted complete case sample. Crude point estimates as well as key characteristics such as birth weight, gestational age, and maternal BMI were not significantly different, which makes selection bias due to complete case analysis unlikely.

Reverse causation for the effect of prolonged breastfeeding on obesity cannot be ruled out (44). Children with early weight gain were reported more likely to be obese (45), possibly because of a greater amount of consumed food and earlier weaning (ie, if hungry and not sleeping). Thus, children with prolonged breastfeeding may be slower-growing children with smaller appetites, and the effect of breastfeeding duration may be a marker for a predisposition to put on weight.

Breastfeeding and formula-feeding mothers differ in various ways, and residual or unmeasured confounding is a likely explanation for the small association we observed in infants between having been breastfed and mean fat mass. However, control for several potential socioeconomic, parental, prenatal, and childhood confounding factors made no difference to effect estimates for the binary outcome, fat mass above or below the top decile. This association was also observed after restriction to those mothers who were initially intending to breastfeed or to bottle-feed, which strengthens the possibility that the breastfeeding effect on the top decile of fat mass is biological rather than being related to factors influencing both breastfeeding intent and obesity.

Conclusions

Breastfeeding was not associated with an important shift in the distribution of adiposity, based either on BMI or DXA-derived fat mass. There was evidence that longer duration of breastfeeding was associated with a reduced risk of fat mass in the top decile but not with obesity based on BMI thresholds. The contrasting results may be due to greater accuracy of DXA. This finding may have implications for studies suggesting small effect sizes on obesity, because effect size and accuracy of the outcome variable directly influence sample power. Nevertheless, uncontrolled confounding can never be ruled out in an observational study (46). A clinical trial with random assignment of mothers to breastfeeding or formula feeding is not feasible and is probably unethical, but the hypothesis that breastfeeding influences later adiposity could be tested in large, randomized, controlled trials of successful breastfeeding promotion interventions with long-term follow-up (47). Analysis of such a trial on an intention-to-treat basis would provide a robust estimate of the breastfeeding effect on adiposity that should be free of the confounding that limits the interpretation of observational studies. The causal effect for components of human milk could also be tested in randomized trials with formulas of different nutrient compositions.

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REFERENCES

1. Freedman DS, Srinivasan SR, Valdez RA, Williamson DF, Berenson GS. Secular increases in relative weight and adiposity among children over two decades: the Bogalusa Heart Study. Pediatrics 1997;99:420–6.
2. Ebbeling CB, Pawlak DB, Ludwig DS. Childhood obesity: public-health crisis, common sense cure. Lancet 2002;360:473–82.
3. Koletzko B, Girardet JP, Klish W, Tabacco O. Obesity in children and adolescents worldwide: current views and future directions—Working Group Report of the First World Congress of Pediatric Gastroenterology, Hepatology, and Nutrition. J Pediatr Gastroenterol Nutr 2002;35(suppl): S205–12.
4. Charney E, Goodman HC, McBride M, Lyon B, Pratt R. Childhood antecedents of adult obesity. Do chubby infants become obese adults? N Engl J Med 1976;295:6–9.
5. Stark O, Atkins E, Wolff OH, Douglas JW. Longitudinal study of obesity in the National Survey of Health and Development. BMJ 1981;283: 13–7.
6. Abraham S, Collins G, Nordsieck M. Relationship of childhood weight status to morbidity in adults. HSMHA Health Rep 1971;86:273–84.
7. Power C, Lake JK, Cole TJ. Measurement and long-term health risks of child and adolescent fatness. Int J Obes Relat Metab Disord 1997;21: 507–26.
8. Freedman DS, Dietz WH, Srinivasan SR, Berenson GS. The relation of overweight to cardiovascular risk factors among children and adolescents: the Bogalusa Heart Study. Pediatrics 1999;103:1175–82.
9. Ravelli AC, van der Meulen JH, Osmond C, Barker DJ, Bleker OP. Infant feeding and adult glucose tolerance, lipid profile, blood pressure, and obesity. Arch Dis Child 2000;82:248–52.
10. Feldman W. Periodic health examination, 1994 update: 1. Obesity in childhood. Canadian Task Force on the Periodic Health Examination. Can Med Assoc J 1994;150:871–9.
11. Dietz WH. Periods of risk in childhood for the development of adult obesity—what do we need to learn? J Nutr 1997;127(suppl):1884–6S.
12. Diet, nutrition and the prevention of chronic diseases. World Health Organ Tech Rep Ser 2003;916:i–viii, 1–149, back cover.
13. Arenz S, Rückerl R, Koletzko B, von-Kries R. Breast-feeding and childhood obesity—a systematic review. Int J Obes Relat Metab Disord 2004;28:1247–56.
14. Harder T, Bergmann R, Kallischnigg G, Plagemann A. Duration of breastfeeding and risk of overweight: a meta-analysis. Am J Epidemiol 2005;162:397–403.
15. Owen CG, Martin RM, Whincup PH, Davey-Smith G, Gillman MW, Cook DG. The effect of breastfeeding on mean body mass index throughout life: a quantitative review of published and unpublished observational evidence. Am J Clin Nutr 2005;82:1298–307.
16. Owen CG, Martin RM, Whincup PH, Smith GD, Cook DG. Effect of infant feeding on the risk of obesity across the life course: a quantitative review of published evidence. Pediatrics 2005;115:1367–77.
17. Burdette HL, Whitaker RC, Hall WC, Daniels SR. Breastfeeding, introduction of complementary foods, and adiposity at 5 y of age. Am J Clin Nutr 2006;83:550–8.
18. Tulldahl J, Pettersson K, Andersson SW, Hulthen L. Mode of infant feeding and achieved growth in adolescence: early feeding patterns in relation to growth and body composition in adolescence. Obes Res 1999;7:431–7.
19. Toschke AM, Vignerova J, Lhotska L, Osancova K, Koletzko B, Von Kries R. Overweight and obesity in 6- to 14-year-old Czech children in 1991: protective effect of breast-feeding. J Pediatr 2002;141:764–9.
20. Dietz WH. Breastfeeding may help prevent childhood overweight. JAMA 2001;285:2506–7.
21. Parsons TJ, Power C, Logan S, Summerbell CD. Childhood predictors of adult obesity: a systematic review. Int J Obes Relat Metab Disord 1999; 23(suppl):S1–107.
22. Reilly JJ, Armstrong J, Dorosty AR, et al. Early life risk factors for obesity in childhood: cohort study. BMJ 2005;330:1357.
23. Buchan IE, Heller RF, Clayton P, Bundred PE, Cole TJ. Early life risk factors for obesity in childhood: early feeding is crucial target for preventing obesity in children. BMJ 2005;331:453–4 (letter).
24. Sherriff A, Emond A, Bell JC, Golding J. Should infants be screened for anaemia? A prospective study investigating the relation between haemoglobin at 8, 12, and 18 months and development at 18 months. Arch Dis Child 2001;84:480–5.
25. Martin RM, Holly JM, Smith GD, et al. Could associations between breastfeeding and insulin-like growth factors underlie associations of breastfeeding with adult chronic disease? The Avon Longitudinal Study of Parents and Children. Clin Endocrinol (Oxf) 2005;62:728–37.
26. Martin RM, Ness AR, Gunnell D, Emmett P, Davey Smith G. Does breast-feeding in infancy lower blood pressure in childhood? The Avon Longitudinal Study of Parents and Children (ALSPAC). Circulation 2004;109:1259–66.
27. Rogers IS, Ness AR, Steer CD, et al. Association of size at birth and

dual-energy X-ray absorptiometry measures of lean and fat mass at age 9 to 10 y of age. Am J Clin Nutr 2006;84:739–47.
28. Goran MI, Gower BA, Treuth M, Nagy TR. Prediction of intra-abdominal and subcutaneous abdominal adipose tissue in healthy prepubertal children. Int J Obes Relat Metab Disord 1998;22:549–58.
29. Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. BMJ 2000;320:1240–3.
30. Reilly JJ, Methven E, McDowell ZC, et al. Health consequences of obesity. Arch Dis Child 2003;88:748–52.
31. Grummer-Strawn LM, Mei Z. Does breastfeeding protect against pediatric overweight? Analysis of longitudinal data from the Centers for Disease Control and Prevention Pediatric Nutrition Surveillance System. Pediatrics 2004;113:e81–6.
32. Toschke AM, Montgomery SM, Pfeiffer U, von Kries R. Early intrauterine exposure to tobacco-inhaled products and obesity. Am J Epidemiol 2003;158:1068–74.
33. Toschke AM, Küchenhoff H, Koletzko B, von Kries R. Meal frequency and childhood obesity. Obesity Res 2005;13:1932–8.
34. North Stone K, Fleming P, Golding J. Socio-demographic associations with digit and pacifier sucking at 15 months of age and possible associations with infant infection. The ALSPAC Study Team. Avon Longitudinal Study of Pregnancy and Childhood. Early Hum Dev 2000;60:137–48.
35. Clopper CJ, Pearson ES. The use of confidence or fiducial limits illustrated in the case of the binomial. Biometrika 1934;26:404–13.
36. Toschke AM, Ehlin AGC, von Kries R, Ekbom A, Montgomery SM. Maternal smoking during pregnancy and appetite control in offspring. J Perinat Med 2003;31:251–6.
37. Allison PD. Logistic regression using the SAS system: theory and application. New York, NY: Wiley & Sons, 2001.
38. Bogen DL, Hanusa BH, Whitaker RC. The effect of breast-feeding with and without formula use on the risk of obesity at 4 years of age. Obes Res 2004;12:1527–35.
39. Williams JE, Wells JC, Wilson CM, Haroun D, Lucas A, Fewtrell MS. Evaluation of Lunar Prodigy dual-energy X-ray absorptiometry for assessing body composition in healthy persons and patients by comparison with the criterion 4-component model. Am J Clin Nutr 2006;83:1047–54.
40. Gillman MW, Rifas-Shiman SL, Camargo CA Jr, et al. Risk of overweight among adolescents who were breastfed as infants. JAMA 2001;285:2461–7.
41. von Kries R, Koletzko B, Sauerwald T, et al. Breast feeding and obesity: cross sectional study. BMJ 1999;319:147–50.
42. Hediger ML, Overpeck MD, Kuczmarski RJ, Ruan WJ. Association between infant breastfeeding and overweight in young children. JAMA 2001;285:2453–60.
43. Tu YK, West R, Ellison GT, Gilthorpe MS. Why evidence for the fetal origins of adult disease might be a statistical artifact: the "reversal paradox" for the relation between birth weight and blood pressure in later life. Am J Epidemiol 2005;161:27–32.
44. Kramer MS, Guo T, Platt RW, et al. Breastfeeding and infant growth: biology or bias? Pediatrics 2002;110:343–7.
45. Ong KKL, Ahmed ML, Emmett PM, Preece MA, Dunger DB. Association between postnatal catch-up growth and obesity in childhood: prospective cohort study. BMJ 2000;320:967–71.
46. Davey Smith G, Ebrahim S. Data dredging, bias, or confounding. BMJ 2002;325:1437–8 (editorial).
47. Kramer MS, Chalmers B, Hodnett ED, et al. Promotion of Breastfeeding Intervention Trial (PROBIT): a randomized trial in the Republic of Belarus. JAMA 2001;285:413–20.