



Original Contribution

Breastfeeding, Weight Gain in Infancy, and Overweight at Seven Years of Age The Prevention and Incidence of Asthma and Mite Allergy Birth Cohort Study

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Compared with nonbreastfed children, breastfed children tend to have a lower body mass index (BMI) at about 1 year of age. How the BMI of breastfed children develops after the first year when this difference in BMI at 1 year of age is considered is not clear. The authors studied the association between breastfeeding and BMI development from 1 to 7 years of age independently of BMI at 1 year of age. Longitudinal BMI data reported by parents of 2,347 Dutch children born in 1996–1997 who participated in the Prevention and Incidence of Asthma and Mite Allergy birth cohort study were collected. Linear regression and mixed-effects models were used for data analyses. Mean BMI at 1 year of age was 17.2 kg/m² (standard deviation, 1.4). Compared with nonbreastfed children, children breastfed for >16 weeks had a lower BMI at 1 year of age, after adjustment for confounders ($\beta = -0.22$, 95% confidence interval: $-0.39, -0.06$). The association between breastfeeding and BMI between 1 and 7 years of age was negligible, while a high BMI at 1 year of age was strongly associated with a high BMI between 1 and 7 years of age in the same model. These findings suggest that the lower BMI and lower risk of overweight among breastfed children later in life are already achieved at 1 year of age.

body mass index; body weight; breast feeding; child; child nutrition sciences; cohort studies; growth; overweight

Abbreviations: BMI, body mass index; PIAMA, Prevention and Incidence of Asthma and Mite Allergy.

The association between breastfeeding and weight and length gain in the first year of life seems to be well established (1–6). It is however less clear whether breastfed children continue to have a lower weight, height, and body mass index (BMI) during childhood and a lower risk of overweight later in life. Recent meta-analyses on the association between breastfeeding and overweight reported a lower risk

of overweight among breastfed children at different ages (7–10). To our knowledge, whether the lower risk of overweight among breastfed children is due to a lower weight gain in early life has not been elucidated yet.

Some authors who studied the association between breastfeeding and growth in the first years of life suggested that the effect on weight, height, and BMI diminished after

the first year (1, 4, 6). However, these studies had a follow-up shorter than 2 years of age. The studies included in the meta-analyses were mostly cross-sectional and retrospective. In addition, growth in the first year of life was not included in these studies. Therefore, it is not possible to separate the effect of breastfeeding from the effect of growth in the first year of life on BMI later in life.

We used longitudinal data from a large birth cohort study to investigate the association between breastfeeding duration and BMI at 1 year of age and the association of breastfeeding duration with BMI development in children from 1 to 7 years of age independently of BMI at 1 year of age.

MATERIALS AND METHODS

Study design and study population

The study population consisted of 2,347 children who participated in the Prevention and Incidence of Asthma and Mite Allergy (PIAMA) birth cohort study. In this study, mothers were recruited from the general population during pregnancy, and the children were born in 1996–1997 in the Netherlands. The parents received postal questionnaires 2 months before delivery, 3 months after the child was born, and annually starting when the child was 1 year of age. A detailed description of the study design has been published previously (11).

The baseline population of the PIAMA study consisted of 4,146 mothers. Twins and children born prematurely ($n = 136$) were excluded from analysis, and 469 children were lost to follow-up at 7 years of age. Parents of 3,541 singleton children born at term received a questionnaire when the child was 7 years of age. Parents of 3,258 children returned the questionnaire, and 2,605 reported weight and height of their child. After exclusion of children for whom data on BMI at 1 year of age ($n = 236$), breastfeeding ($n = 16$), and birth weight ($n = 6$) were missing, data for 2,347 children were available for analyses. For the majority of the children (93.5 percent), BMI values were available at four or more different points in time between 1 and 7 years of age. The study protocol was approved by the medical ethics committees of the participating institutes, and all parents gave written informed consent.

Study variables

In the questionnaires, we asked for the child's body weight (in kilograms), height (in centimeters), and date when he or she was last measured. BMI was calculated as body weight in kilograms divided by height squared in meters (kg/m^2). Overweight at 7 years of age was defined according to standard international age- and gender-specific definitions (12). Duration of breastfeeding was assessed by questions on infant feeding in the questionnaires at 3 months and at 1 year. At 3 months, the parents were asked how long the child was breastfed and whether the mother was still breastfeeding. If the parents indicated in the questionnaire at 3 months that the mother was still breastfeeding, we used data from the 1-year questionnaire to assess total breastfeeding duration. Total breastfeeding duration was categorized as

“no breastfeeding,” “0–16 weeks of breastfeeding,” and “breastfeeding for more than 16 weeks” because we expected that a certain duration of breastfeeding is needed to influence children's weight, height, and BMI, and, until recently, the recommended breastfeeding duration was 4–6 months, and only a small percentage of the mothers breastfed for at least 6 months.

Breastfeeding was defined as any kind of breastfeeding, including partial breastfeeding. The following variables were considered potential confounders: gender, birth weight of the child, maternal education, maternal employment, maternal age, maternal overweight, and maternal smoking during pregnancy. Educational level of the mother was measured as the highest education completed and was then divided into three categories (low, intermediate, and high). Maternal employment was classified as employed or unemployed. Maternal BMI was calculated from reported body weight (in kilograms) and height (in centimeters) when the child was 1 year of age. Maternal overweight was defined as a BMI of $\geq 25 \text{ kg/m}^2$.

Data analysis

Data were analyzed by using SAS version 9.1 software (SAS Institute, Inc., Cary, North Carolina). Linear and logistic regression models were used to analyze the associations between breastfeeding and BMI at 1 year, BMI at 7 years, and overweight at 7 years of age. Besides the association between breastfeeding and BMI at these specific ages, we also studied the effect of breastfeeding on the development of BMI during the entire period between 1 and 7 years of age. We used the PROC MIXED procedure in SAS software to fit two mixed-effects models to the longitudinal BMI data to study the development of BMI between 1 and 7 years of age.

In the first mixed-effects model, BMI development between 1 and 7 years of age was modeled as a function of age, age squared, breastfeeding, gender, birth weight, maternal overweight, and maternal education. In addition, the interactions between breastfeeding and age and between breastfeeding and age squared were included in the model to allow the effect of breastfeeding to vary with age. All other interactions with age were tested and were included in the mixed-effects models when they were statistically significant, such as the interactions between gender and age and between maternal overweight and age (Appendix, equation 1). Furthermore, a random intercept and a random age-squared effect were introduced into the model. In the second mixed-effects model, BMI of the child at 1 year of age and interactions between BMI at 1 year of age and age were additionally included in the model (Appendix, equation 2) to assess the association between breastfeeding duration and BMI development independent of BMI at 1 year of age.

The parameters estimated in the two mixed-effects models were used to plot BMI development by age. The analyses of the mixed-effects models were repeated by excluding children for whom there were fewer than the maximum of seven BMI observations between 1 and 7 years of age. p values of less than 0.05 were considered statistically significant.

TABLE 1. Percentages with means and standard deviations of various variables, by breastfeeding duration, for 2,347 Dutch children in the Prevention and Incidence of Asthma and Mite Allergy study, 1996–2005

Variable	All (<i>n</i> = 2,347)		Breastfeeding duration (weeks)					
			0 (<i>n</i> = 386)		0–16 (<i>n</i> = 1,110)		>16 (<i>n</i> = 851)	
	%	No.*	%	No.	%	No.	%	No.
Gender (girls)	48.1	1,128	49.0	189	46.1	512	50.2	427
Overweight at age 7 years†	11.6	273	16.3	63	10.9	121	10.5	89
	Mean (SD*)		Mean (SD)		Mean (SD)		Mean (SD)	
Breastfeeding duration (weeks)	16.2 (15.5)		0		8.5 (4.6)		33.7 (11.5)	
Age at 1 year (months)	11.4 (0.9)		11.4 (0.9)		11.5 (0.9)		11.4 (0.9)	
Weight at 1 year (kg)	9.9 (1.1)		10.0 (1.0)		10.0 (1.1)		9.7 (1.1)	
Length at 1 year (cm)	75.6 (2.9)		75.9 (3.0)		75.8 (2.8)		75.3 (2.9)	
BMI* at 1 year (kg/m ²)	17.2 (1.4)		17.3 (1.4)		17.3 (1.4)		17.1 (1.4)	
Age at 7 years (months)	84.5 (1.7)		84.4 (1.8)		84.5 (1.8)		84.6 (1.7)	
Weight at 7 years (kg)	25.6 (4.0)		25.9 (4.5)		25.6 (4.0)		25.4 (3.9)	
Height at 7 years (cm)	127.3 (5.6)		127.5 (5.7)		127.2 (5.6)		127.3 (5.5)	
BMI at 7 years (kg/m ²)	15.7 (1.8)		15.9 (2.0)		15.8 (1.8)		15.7 (1.8)	

* No., total number of observations; SD, standard deviation; BMI, body mass index.

† Overweight definition is gender and age specific according to Cole et al. (12).

RESULTS

In total, 83.6 percent (*n* = 1,961) of the mothers breastfed, and, after 16 weeks, 36.3 percent (*n* = 851) of the mothers were still breastfeeding. In table 1, means and standard deviations of weight, height, and BMI at 1 and 7 years of age and overweight prevalence are shown by breastfeeding duration. Table 2 shows the results of the linear and logistic regression analyses of the association between breastfeeding and anthropometric outcomes at 1 and 7 years of age.

Comparison of the children included in the analyses with the excluded children showed that mothers of children included in the analyses were more often highly educated and were more likely to breastfeed. Children included in the analyses had a slightly higher birth weight than the excluded children.

Breastfeeding, weight, length, and BMI at 1 year of age

Mean BMI of the children at 1 year of age was 17.2 kg/m² (standard deviation, 1.4) (table 1). Children breastfed for more than 16 weeks had, on average, a 0.20-kg/m² (95 percent confidence interval: −0.37, −0.03) lower BMI than nonbreastfed children at 1 year of age (table 2). Weight and length at 1 year of age were also lower among children who were breastfed for more than 16 weeks. After adjustment for gender, age, birth weight, maternal overweight, and maternal education, the inverse association between breastfeeding and weight, length, and BMI at 1 year of age remained. Breastfeeding for 0–16 weeks was not associated with weight, length, and BMI at 1 year of age. Including maternal age, maternal employment, and maternal smoking during pregnancy in the regression model did not affect the asso-

ciation between breastfeeding and weight, length, and BMI at 1 year of age (data not shown).

Breastfeeding, weight, height, BMI, and overweight at 7 years of age

Mean BMI at 7 years of age was 15.7 kg/m² (standard deviation, 1.8) (table 1), and children breastfed for more than 16 weeks had, on average, a 0.21-kg/m² (95 percent confidence interval: −0.43, 0.02) lower BMI than nonbreastfed children (table 2). However, the association attenuated markedly after adjustment for gender, age, birth weight, maternal overweight, and maternal education. The covariates maternal education and maternal overweight accounted for the greatest proportion of attenuation in effect estimates of the association between breastfeeding and BMI at 7 years of age. The association between breastfeeding for more than 16 weeks and BMI at 7 years of age further weakened when BMI at 1 year of age was additionally taken into account.

At 7 years of age, the prevalence of overweight was significantly lower among the breastfed children (table 2). Respectively, 16.3, 10.9, and 10.5 percent of the nonbreastfed children, of the children breastfed for 0–16 weeks, and of the children breastfed for more than 16 weeks were overweight (table 1). After adjustment for confounders, the association between breastfeeding and overweight at 7 years of age attenuated (table 2). The effect estimate for breastfeeding for more than 16 weeks changed from 0.60 (95 percent confidence interval: 0.42, 0.85) to 0.70 (95 percent confidence interval: 0.48, 1.01). Including BMI at 1 year of age in the regression model, besides confounders, further attenuated the association between breastfeeding for more than 16 weeks and overweight at 7 years of age.

TABLE 2. Associations between breastfeeding and weight, height, and body mass index at 1 and 7 years of age and overweight at 7 years of age for 2,347 Dutch children in the Prevention and Incidence of Asthma and Mite Allergy study, 1996–2005†

	0–16 weeks of breastfeeding		>16 weeks of breastfeeding	
	β	95% CI	β	95% CI
Weight at 1 year of age (kg)				
Crude model	0.01	−0.12, 0.13	−0.25	−0.38, −0.12**
Adjusted model‡	−0.03	−0.14, 0.08	−0.26	−0.37, −0.14**
Length at 1 year of age (cm)				
Crude model	−0.04	−0.38, 0.29	−0.55	−0.89, −0.20*
Adjusted model‡	−0.15	−0.42, 0.12	−0.52	−0.81, −0.23**
BMI at 1 year of age (kg/m ²)				
Crude model	0.01	−0.15, 0.17	−0.20	−0.37, −0.03*
Adjusted model‡	−0.00	−0.16, 0.15	−0.22	−0.39, −0.06*
Weight at 7 years of age (kg)				
Crude model	−0.33	−0.80, 0.14	−0.47	−0.95, 0.02
Adjusted model‡	−0.32	−0.76, 0.13	−0.40	−0.87, 0.07
Adjusted model + weight at 1 year of age§	−0.31	−0.70, 0.08	0.07	−0.35, 0.49
Height at 7 years of age (cm)				
Crude model	−0.29	−0.94, 0.36	−0.27	−0.94, 0.40
Adjusted model‡	−0.40	−1.02, 0.22	−0.45	−1.11, 0.21
Adjusted model + length at 1 year of age¶	−0.34	−0.86, 0.17	0.12	−0.43, 0.67
BMI at 7 years of age (kg/m ²)				
Crude model	−0.12	−0.33, 0.09	−0.21	−0.43, 0.02
Adjusted model‡	−0.08	−0.29, 0.13	−0.12	−0.34, 0.10
Adjusted model + BMI at 1 year of age#	−0.08	−0.28, 0.11	−0.01	−0.22, 0.19
	OR	95% CI	OR	95% CI
Overweight at 7 years of age				
Crude model	0.63	0.45, 0.87*	0.60	0.42, 0.85*
Adjusted model‡	0.67	0.48, 0.95*	0.70	0.48, 1.01
Adjusted model + BMI at 1 year of age#	0.67	0.47, 0.95*	0.76	0.52, 1.11

* $p < 0.05$; ** $p < 0.001$. Results of linear and logistic regression analysis.

† Results are presented as regression coefficients (β) with 95% confidence interval (CI) for weight, height, and body mass index (BMI) and as odds ratio (OR) with 95% CI for overweight. Overweight definition is gender and age specific according to Cole et al. (12). 0 weeks of breastfeeding is the reference.

‡ Regression model is adjusted for age, gender, birth weight, maternal overweight, and maternal education.

§ Regression model is additionally adjusted for weight of the child at 1 year of age.

¶ Regression model is additionally adjusted for length of the child at 1 year of age.

Regression model is additionally adjusted for BMI of the child at 1 year of age.

BMI at 1 year of age was positively associated with being overweight at 7 years of age (odds ratio = 1.50, 95 percent confidence interval: 1.37, 1.64 per unit increase in BMI (kg/m²)). The association remained after adjustment for confounders (odds ratio = 1.48, 95 percent confidence interval: 1.34, 1.62 per unit increase in BMI (kg/m²)).

Breastfeeding and BMI development from 1 to 7 years of age

In figure 1, mean BMI from 1 month to 7 years of age of the children is plotted by breastfeeding duration. At 1 year of age, children who were breastfed for more than 16 weeks

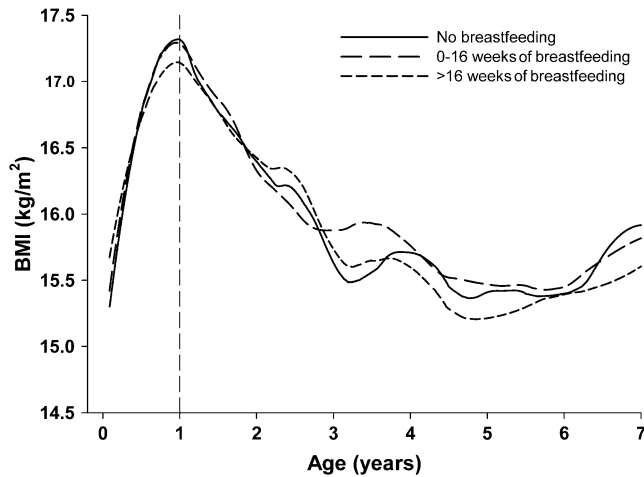


FIGURE 1. Mean body mass index (BMI) between 1 month and 7 years of age, by breastfeeding duration, of 2,347 Dutch children in the Prevention and Incidence of Asthma and Mite Allergy (PIAMA) study, 1996–2005.

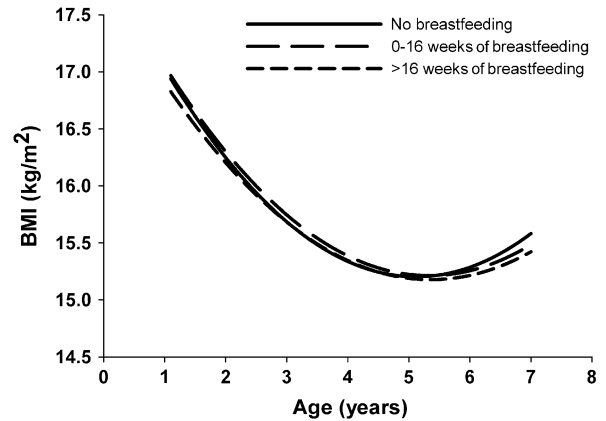
had a lower mean BMI than children who were breastfed for a shorter period or children who were not breastfed. After 1 year of age, the difference between the breastfeeding groups was less clear. In this figure, it is not possible to disentangle breastfeeding from confounding variables, however.

Figures 2A, 2B, and 2C show the results of the two mixed-effects models. Figures 2A and 2B are derived from the first and second mixed-effects models, respectively, and they show BMI development in girls from 1 to 7 years of age adjusted for confounders by breastfeeding duration. In these plots, only breastfeeding duration was varied, and the other explanatory variables were held fixed, including BMI at 1 year of age in the second mixed-effects model. The association between breastfeeding duration and BMI development in the period between 1 and 7 years of age was small and was not statistically significant in both mixed-effects models. As shown in figure 2A, the BMI at 1 year of age of children who were breastfed for more than 16 weeks was slightly lower than that of children breastfed for 0–16 weeks or not breastfed. At 7 years of age, the BMI of nonbreastfed children was higher than the BMI of the other two groups.

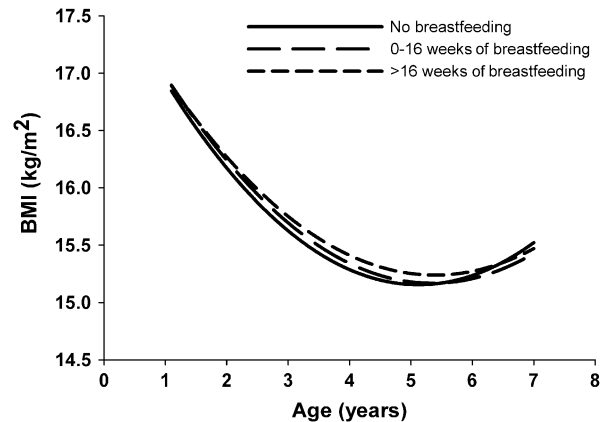
Figure 2C was derived from the second mixed-effects model and shows BMI development in girls from 1 to 7 years of age, adjusted for confounders and independent of breastfeeding duration, by BMI at 1 year of age. BMI at 1 year of age was statistically significantly positively associated with BMI throughout the period between 1 and 7 years of age. Children who had a high BMI at 1 year of age tended to have a high BMI until at least 7 years of age.

The results of the two mixed-effects models for boys were comparable with the results for girls. The BMI curves were shown for girls and not for both genders together because gender was included in the fixed-effects model and was to be held fixed at one of the two genders. The curves for

A. Mixed-effects model 1



B. Mixed-effects model 2



C. Mixed-effects model 2

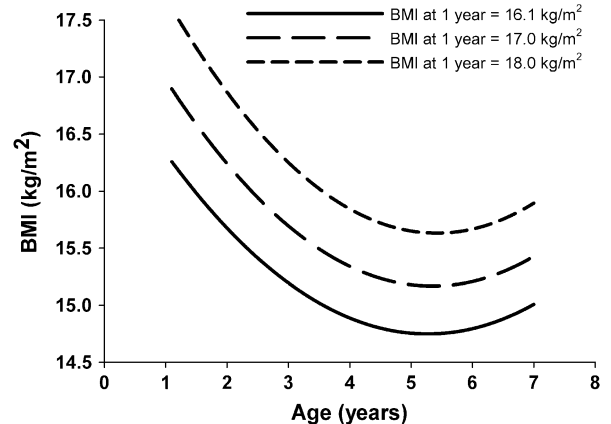


FIGURE 2. Body mass index (BMI) of girls between 1 and 7 years of age, by breastfeeding duration (A and B) and by BMI at 1 year of age (C), derived from mixed-effects model 1 (without BMI at 1 year of age) and model 2 (with BMI at 1 year of age). Values for BMI at 1 year of age (C) correspond with the median value and the first and third quartiles. Maternal overweight (no overweight), birth weight (median value), and maternal education (intermediate educational level) were held fixed in both mixed-effects models. The mixed-effects models were based on data from 2,347 Dutch children enrolled in the Prevention and Incidence of Asthma and Mite Allergy (PIAMA) study, 1996–2005.

the association between breastfeeding duration and BMI for boys were similar to the curves for girls because there was no interaction between breastfeeding and gender. Analyses in which children with fewer than the maximum of six BMI observations between 1 and 7 years of age were excluded did not change the results.

DISCUSSION

Our study showed that children who were breastfed for more than 16 weeks had a lower mean BMI and were less likely to become overweight at 7 years of age. When BMI at 1 year of age was taken into account, the association between breastfeeding for more than 16 weeks and BMI and being overweight at 7 years of age weakened. This attenuation of the association might suggest that the inverse association between breastfeeding and overweight is already achieved at the age of 1 year.

Strengths of our study were the large study population and the repeated BMI observations over a period of 7 years. These strengths made it possible to study the association between breastfeeding and BMI longitudinally and independently of BMI at 1 year of age. In addition, important confounding factors, such as birth weight, maternal overweight, and maternal education could be accounted for. Furthermore, the prospective study design eliminated recall bias of breastfeeding duration and weight and height at different ages.

A limitation of this study was that weight and height of the children were reported by the parents. Studies in which parents were asked to describe whether or not their child was overweight showed that, in general, parents of overweight children classified their child in a lower weight category (13, 14). However, at 4 years of age, only a slight difference between measured and parental reported weight and height was observed in the children who participated in the PIAMA study (15). On average, the difference between measured and reported weight and height was, respectively, 0.02 kg and 0.5 cm. The difference between measured and reported data tended to be higher among children with a high BMI. It is possible that the association between breastfeeding and overweight is somewhat attenuated by this phenomenon. Data on breastfeeding and confounders were also reported by the parents, but it is not likely this reporting affected the results. Unfortunately, no data were available on exclusive breastfeeding. However, using exclusive breastfeeding instead of any breastfeeding would probably strengthen the associations. The percentage of mothers who breastfed their child was comparable with other Dutch data on breastfeeding (16).

Lower weight and BMI at 1 year of age among breastfed children has also been found in other longitudinal studies (1–6). Shorter length at 1 year of age has been reported by a number of studies, but not by all (1, 3, 6). Evidence shows that the lower weight and length gain in breastfed children in the first months of life is not associated with adverse functional outcomes or higher morbidity (17). Rather, breastfeeding enhances behavioral and functional development and decreases infection risk (18, 19).

The lower BMI observed among breastfed children in the present study could also be partly due to reverse causation. Hypothetically, the children who were breastfed for more than 16 weeks could have been breastfed this long because of a low growth velocity and thus low breast milk “demand,” which keeps the child satisfied (20).

Many studies have also published findings on breastfeeding and BMI at later ages. Four meta-analyses concluded that breastfeeding was inversely associated with obesity at different ages when the overall risk estimate was based on unadjusted estimates (7–10). However, Owen et al. (8) showed in a meta-analysis based on published and unpublished literature that adjusting for confounding factors abolished the effect of breastfeeding on BMI. The wide age range, from infancy to adulthood, in the studies included in the meta-analyses complicated comparison of our study results with the outcomes of the meta-analyses. A recent study by Reilly et al. (21) based on data from a British birth cohort study also showed that the crude association between breastfeeding and a lower risk of obesity at 7 years of age was no longer significant after adjustment for confounders including birth weight and parental obesity. None of the previously published studies on breastfeeding and BMI used longitudinal data and specifically looked at the role of growth in the first year of life on the association between breastfeeding and BMI later in childhood. When we considered BMI of the child at 1 year of age, the inverse association between breastfeeding for more than 16 weeks and BMI at 7 years of age disappeared. This observation suggests that breastfeeding influences BMI mainly in the first year of life and that the protective effect of breastfeeding on overweight later in childhood is probably the result of the lower BMI of breastfed children at 1 year of age.

The association between breastfeeding and BMI at 1 year of age showed a dose-response relation, which was not found for the association between breastfeeding and BMI and overweight at 7 years of age. This difference in the association between breastfeeding duration and BMI indicates that probably other factors associated with the choice to breastfeed, such as dietary and lifestyle factors, are partly responsible for the decrease in the risk of overweight at 7 years of age.

The lower BMI of breastfed children at 1 year of age might be a consequence of lower breast milk intake and hence a lower energy and nutrient intake compared with that of nonbreastfed children. Parents of nonbreastfed children have greater control over the amount of milk a child consumes. They can alter the concentration of the formula feeding or can push the child to finish the bottle if the parents think that the child has not consumed enough. A study among Dutch parents of infants younger than 6 months of age showed that 20 percent of the parents did not follow the instructions for preparing the formula feeding and added more milk powder than was advised (22). Breastfed children, on the other hand, can self-regulate their intake, and the breast milk production adapts to the child needs, resulting in a lower energy intake compared with that of nonbreastfed children (23, 24). Furthermore, the higher protein content of formulas that were available in 1996–1997 compared with breast milk has been suggested to enhance growth and weight gain in nonbreastfed infants (24). Higher protein intake tends to

stimulate secretion of insulin and insulin growth factors, which in turn stimulates weight gain and greater adipose tissue deposition (25–29).

The association between breastfeeding and BMI probably weakens after the first year of life because the child's diet and lifestyle change. When children start to share their families' diet and lifestyle, these factors may well partly undo the moderating effect on BMI that was initially achieved by breastfeeding. However, BMI at 1 year of age was a strong predictor for BMI later in childhood. Tracking of BMI has also been reported by others (30). Our results show that, in as far as breastfeeding is associated with a lower risk of overweight in later years, this lower risk is already achieved in the first year of life by preventing excessive weight gain and putting the child on a favorable "BMI track."

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APPENDIX

Equation 1. Mixed-effects model for BMI of subject i at age age .

$$\begin{aligned} \text{BMI}_{i,\text{age}} = & \beta_0 + \beta_1 \times \text{age} + \beta_2 \times \text{age}^2 + \beta_3 \times \text{Gender}_i \\ & + \beta_4 \times \text{Gender}_i \times \text{age} + \beta_5 \times \text{Birth weight}_i \\ & + \beta_6 \times \text{Maternal overweight}_i \\ & + \beta_7 \times \text{Maternal overweight}_i \times \text{age} \\ & + \beta_8 \times \text{Intermediate maternal education}_i \\ & + \beta_9 \times \text{High maternal education}_i \\ & + \beta_{10} \times 0-16 \text{ weeks of breastfeeding}_i \\ & + \beta_{11} \times >16 \text{ weeks of breastfeeding}_i \\ & + \beta_{12} \times 0-6 \text{ weeks of breastfeeding}_i \times \text{age} \\ & + \beta_{13} \times >16 \text{ weeks of breastfeeding}_i \times \text{age} \\ & + \beta_{14} \times 0-6 \text{ weeks of breastfeeding}_i \times \text{age}^2 \\ & + \beta_{15} \times >16 \text{ weeks of breastfeeding}_i \times \text{age}^2 \\ & + \alpha_{0i} + \alpha_{1i} \times \text{age}^2 + \varepsilon_{i,\text{age}} \end{aligned}$$

β_k = fixed effects, $k = 0, 1, 2, \dots, 9$

α_{mi} = random effects, $\alpha_{mi} \approx N(0, \sigma_m^2)$, $m = 0, 1$

ε_{it} = random error, $\varepsilon_{it} \approx N(0, \sigma^2)$

age = age of child

$$\text{Gender}_i = \begin{cases} 0 = \text{Boys} \\ 1 = \text{Girls} \end{cases}$$

Birth weight $_i$ = Birth weight (kg), continuous

$$\text{Maternal overweight}_i = \begin{cases} 0 = \text{Normal weight} \\ 1 = \text{Overweight} \end{cases}$$

Intermediate maternal education $_i$

$$= \begin{cases} 0 = \text{Low education} \\ 1 = \text{Intermediate education} \end{cases}$$

$$\text{High maternal education}_i = \begin{cases} 0 = \text{Low education} \\ 1 = \text{High education} \end{cases}$$

0–16 weeks of breastfeeding $_i$

$$= \begin{cases} 0 = \text{No breastfeeding} \\ 1 = 0-16 \text{ weeks of breastfeeding} \end{cases}$$

>16 weeks of breastfeeding $_i$

$$= \begin{cases} 0 = \text{No breastfeeding} \\ 1 \geq 6 \text{ weeks of breastfeeding} \end{cases}$$

Equation 2. Mixed-effects model for BMI of subject i at age age including BMI of the child at 1 year of age.

$$\begin{aligned} \text{BMI}_{i,\text{age}} = & \beta_0 + \beta_1 \times \text{age} + \beta_2 \times \text{age}^2 + \beta_3 \times \text{Gender}_i \\ & + \beta_4 \times \text{Gender}_i \times \text{age} + \beta_5 \times \text{Birth weight}_i \\ & + \beta_6 \times \text{Maternal overweight}_i \\ & + \beta_7 \times \text{Maternal overweight}_i \times \text{age} \\ & + \beta_8 \times \text{Intermediate maternal education}_i \\ & + \beta_9 \times \text{High maternal education}_i \\ & + \beta_{10} \times 0-16 \text{ weeks of breastfeeding}_i \\ & + \beta_{11} \times >16 \text{ weeks of breastfeeding}_i \\ & + \beta_{12} \times 0-16 \text{ weeks of breastfeeding}_i \times \text{age} \\ & + \beta_{13} \times >16 \text{ weeks of breastfeeding}_i \times \text{age} \\ & + \beta_{14} \times 0-16 \text{ weeks of breastfeeding}_i \times \text{age}^2 \\ & + \beta_{15} \times >16 \text{ weeks of breastfeeding}_i \times \text{age}^2 \\ & + \beta_{16} \times \text{BMI at 1 year}_i \\ & + \beta_{17} \times \text{BMI at 1 year}_i \times \text{age} \\ & + \beta_{18} \times \text{BMI at 1 year}_i \times \text{age}^2 \\ & + \alpha_{0i} + \alpha_{1i} \times \text{age}^2 + \varepsilon_{i,\text{age}} \end{aligned}$$

BMI at 1 year $_i$ = BMI at 1 year (kg/m²), continuous