

Timing of Solid Food Introduction and Risk of Obesity in Preschool-Aged Children



WHAT'S KNOWN ON THIS SUBJECT: Limited, conflicting data suggest that the timing of solid food introduction in infancy may be associated with an increased risk of obesity in childhood.



WHAT THIS STUDY ADDS: Among infants who were never breastfed or those who stopped breastfeeding before the age of 4 months, the introduction of solids before the age of 4 months was associated with a sixfold increase in the odds of obesity at the age of 3 years.

abstract



OBJECTIVE: To examine the association between timing of introduction of solid foods during infancy and obesity at 3 years of age.

METHODS: We studied 847 children in Project Viva, a prospective pre-birth cohort study. The primary outcome was obesity at 3 years of age (BMI for age and gender ≥ 95 th percentile). The primary exposure was the timing of introduction of solid foods, categorized as <4 , 4 to 5, and ≥ 6 months. We ran separate logistic regression models for infants who were breastfed for at least 4 months ("breastfed") and infants who were never breastfed or stopped breastfeeding before the age of four months ("formula-fed"), adjusting for child and maternal characteristics, which included change in weight-for-age z score from 0 to 4 months—a marker of early infant growth.

RESULTS: In the first 4 months of life, 568 infants (67%) were breastfed and 279 (32%) were formula-fed. At age 3 years, 75 children (9%) were obese. Among breastfed infants, the timing of solid food introduction was not associated with odds of obesity (odds ratio: 1.1 [95% confidence interval: 0.3–4.4]). Among formula-fed infants, introduction of solid foods before 4 months was associated with a sixfold increase in odds of obesity at age 3 years; the association was not explained by rapid early growth (odds ratio after adjustment: 6.3 [95% confidence interval: 2.3–6.9]).

CONCLUSIONS: Among formula-fed infants or infants weaned before the age of 4 months, introduction of solid foods before the age of 4 months was associated with increased odds of obesity at age 3 years. *Pediatrics* 2011;127:e544–e551

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KEY WORDS

obesity, infant feeding, complementary foods

ABBREVIATIONS

OR—odds ratio

CI—confidence interval

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Obesity, the leading public health challenge facing children today, is prevalent even among infants and preschool-aged children.¹ Novel prevention strategies, begun as early in childhood as possible, are urgently required.²

The first few months after birth may be a critical window for the development of obesity.³ Parental feeding practices during early infancy, such as the timing of solid food introduction, may be 1 key modifiable determinant of childhood obesity. Data suggest that the introduction of solid foods earlier than 4 months of age is associated with increased body fat or weight in childhood⁴ or with greater weight gain during infancy,^{5,6} which itself predicts later adiposity.⁷ Other studies have found no association between the timing of solid food introduction and body fat^{8–11} or an association between delayed introduction of solid foods after 6 months and greater adiposity.¹²

Limitations of previous studies include small study size, reliance on retrospective recall of infant feeding practices, and failure to account for a possible interaction between breastfeeding status and timing of solid food introduction.^{8–10,12,13} Mothers who initiate breastfeeding or continue breastfeeding beyond 3 to 5 months are more likely to adhere to guidelines regarding the timing of solid food introduction.⁹ One previous report⁹ identified an interaction between the duration of breastfeeding and the timing of solid food introduction. Few studies have examined the relationship between the timing of solid food introduction and child adiposity stratified according to breastfeeding status. Our goal was to examine, separately among breastfed and formula-fed infants, the extent to which the introduction of solid foods at earlier than 4 months of age is associated with an increased risk of child obesity.

PATIENTS AND METHODS

Participants

Study participants were from Project Viva, a longitudinal prebirth cohort of mother–offspring pairs.¹⁴ The human subjects committees of Harvard Pilgrim Health Care, Brigham and Women's Hospital, and Beth Israel Deaconess Medical Center approved study protocols.¹⁴ All mothers provided informed consent.

We previously described recruitment, retention, and data collection procedures.¹⁴ We recruited women at their initial prenatal visit between 1999 and 2002 at obstetrical offices of a multi-specialty group practice in eastern Massachusetts. Eligibility criteria included being fluent in English, having a gestational age of less than 22 weeks at the initial visit, and having a singleton pregnancy. A research assistant conducted in-person visits at the end of the first and second trimesters, after delivery, and at 6 months and 3 years after birth. At each postpartum visit, we collected data on infant feeding practices and measured child length/height and weight; at 3 years of age, we also measured the children's skinfold thicknesses. At one and 2 years after delivery, mothers completed mailed questionnaires updating infant feeding practices.

Of 2128 live-born infants, 1579 were considered eligible for the 3-year follow-up because their mothers had completed prenatal nutrition assessments and consented for their children to participate in the follow-up. We excluded 36 participants whose mothers refused participation in the 3-year follow-up, 148 who were lost to follow-up, 105 who completed the 3-year assessment only by mail or telephone (not in person), and 34 with missing data on anthropometry. We also excluded 46 children with missing data on breastfeeding, 142 with missing

data on the timing of the introduction of solids, 190 with missing 4-month weight for length (from clinical charts), and 31 with missing covariate data. Thus, our sample size for the analysis was 847 children. Compared with the 732 eligible children excluded from our analyses, included children were more likely to be white (71% vs 59%), have college-educated mothers (74% vs 60%), live in a household with an annual income of more than \$70 000 (67% vs 56%), and have been breastfed for at least 4 months (67% vs 60%) but did not differ in mean maternal prepregnancy BMI (24.6 vs 25.0), child birth weight (3.50 vs 3.45 kg), BMI z score at 3 years of age (0.45 vs 0.47), or introduction of solids before 4 months of age (16% vs 17%).

Exposure: Timing of Solid Food Introduction

Six months after delivery, each mother completed a questionnaire¹⁵ querying the timing of the first introduction of each of 10 solid foods or food groups, including infant cereal, other starches (for example, teething biscuits and crackers), fruit, vegetables, meat, chicken or turkey, peanut butter, other cow's milk dairy products (for example, yogurt and cheese), eggs, fish, and sweets (for example, candy, soft drinks, cookies, and ice cream). Each question had 5 categorical response options: "Have not fed this to my child," "<2 months old," "2 or 3 months old," "4 or 5 months old," or "6 months or older." Because only 2% of mothers reported introducing solid foods before their infants were 2 months old, we combined the categories of "<2 months old" and "2 or 3 months old." We defined the timing of the introduction of solid foods as the child's age at the earliest introduction of any solid food, divided into 1 of 3 age categories: less than 4, 4 to 5, or 6 months or older. National and international guidelines recommend delaying the introduction

of solids to at least 4 months of age¹⁶ and preferably to 6 months of age.^{16,17}

Mothers reported breastfeeding status, including the child's age when breastfeeding was stopped, at the 6-month visit and on the 1-year questionnaire. We divided children into 2 groups: breastfed, defined as children who were at least partly breastfed for at least 4 months, and formula-fed, defined as children who were never breastfed or stopped breastfeeding before the age of 4 months.

Outcome Measure: Obesity at 3 Years of Age

A research assistant measured each child's height using a research-standard stadiometer (Shorr Productions, Olney, MD) and weight using a digital scale (Seca model 881; Seca Corporation, Hanover, MD). We calculated BMI (weight in kilograms divided by the square of height in meters).² We calculated age- and gender-specific BMI percentiles and z scores using the United States National Reference Data.¹⁸ We defined obesity as a BMI in the 95th percentile or higher for age and gender^{19,20} and used a BMI of less than the 85th percentile as the comparison group. For an additional adiposity measure, we calculated the sum of the children's subscapular and triceps skinfold thicknesses, each measured by using Holtain calipers (Holtain LTD, Crosswell, United Kingdom).

Covariates

We collected information about maternal race and ethnicity, age, education, and household income. Mothers reported their prepregnancy weight and height and the paternal weight and height. We calculated gestational age at birth from the last menstrual period. If the estimate of the gestational age by second-trimester ultrasound assessment differed by more than 10 days, we used the ultrasound dat-

ing. We obtained birth weight and clinician-measured 4-month weight from medical records. We computed age- and gender-specific weight-for-age z scores using the 2000 Centers for Disease Control and Prevention Growth Charts.¹⁸ To calculate the change in the weight-for-age z score from 0 to 4 months, we subtracted the weight-for-age z score at birth from the weight-for-age z score at 4 months of age. We used the change in the weight-for-age z score from 0 to 4 months as a proxy for infant growth before solid food introduction because mothers may perceive rapidly growing infants as requiring solid food supplementation in addition to breast milk or formula.

Statistical Analysis

We used unadjusted and multivariable logistic and linear regression models to assess the association of the timing of the introduction of solid foods with obesity and with mean BMI z score and subscapular plus triceps skinfold thickness at the age of 3 years. In separate models for breastfed and formula-fed infants, we adjusted for maternal education, household income, and prepregnancy BMI; paternal BMI; and the child's age, gender, and race/ethnicity. In an additional model, we adjusted for the change in the weight-for-age z score from 0 to 4 months. We excluded potential confounders that did not change our effect estimates, including birth weight, birth weight-for-gestational age z score, gestational age at delivery, and gestational weight gain. We conducted data analyses using SAS 9.2 (SAS Institute Inc, Cary, NC).

RESULTS

Participant characteristics are shown in Table 1. At 4 months of age, 67% of the children were breastfed and 33% were formula-fed, with no substantial difference in breastfeeding status by gender or race/ethnicity. Of 279

formula-fed infants, 101 (36%) were never breastfed, and the remainder were breastfed for less than 4 months. Breastfeeding status was associated with the timing of introduction of solid foods. Mothers reported introducing solid foods before 4 months of age for 8% of breastfed infants compared with 33% of formula-fed infants; 17% of breastfed infants started solids after 6 months compared with 9% of formula-fed infants ($P < .0001$). Breastfed and formula-fed infants had similar mean birth weights, but change in weight-for-length z score from 0 to 4 months was substantially larger for formula-fed than for breastfed infants (0.54 vs 0.35 U; $P = .01$).

Breastfeeding status also was associated with obesity at the age of 3 years. Seven percent of breastfed children were obese (BMI \geq 95th percentile) compared with 13% of formula-fed children. Mean BMI z score (0.63 vs 0.36 U) and the sum of triceps plus subscapular skinfolds (17.5 vs 16.4 mm) were higher for formula-fed than for breastfed children.

In bivariate analyses, the relationship between timing of solid food introduction with obesity differed according to breastfeeding status (Table 2 and Fig 1). Among breastfed infants, the timing of solid food introduction was not related to the prevalence of obesity or other anthropometric measures at the age of 3 years. Among formula-fed infants, early or late solid food introduction was related to a higher prevalence of obesity, weight, weight-for-age z score, BMI, and BMI z score at the age of 3 years.

Table 3 shows the odds of obesity at 3 years of age, according to the timing of introduction of solids, stratified according to breastfeeding status. Among breastfed infants, the timing of introduction of solid foods was not associated with the odds of obesity. In unadjusted analyses of breastfed

TABLE 1 Characteristics of 847 Project Viva Mother-Child Dyads According to Timing of Solid Food Introduction and Breastfeeding Status at 4 Months of Age

	Overall (n = 847)	Breastfed Age at Introduction of Solids, mo			P	Formula-Fed Age at Introduction of Solids, mo			P
		<4	4–5	≥6		<4	4–5	≥6	
		(n = 43)	(n = 427)	(n = 98)		(n = 91)	(n = 163)	(n = 25)	
Maternal characteristic									
Age at enrollment, y	32.7 (4.8)	32 (5.0)	32.9 (4.3)	34.8 (4.5)	.0001	30.4 (5.5)	32.4 (5.1)	33.4 (6.2)	.01
Prepregnancy BMI	24.6 (5.2)	24.7 (4.9)	23.9 (4.5)	24.6 (5)	.27	26.3 (6.7)	25.2 (6.1)	25.9 (5.2)	.41
Paternal BMI	26.5 (3.9)	27 (3.5)	26.3 (3.9)	25.7 (3.5)	.18	27.6 (4.5)	26.7 (3.6)	27.9 (4.8)	.14
College graduate or more, n (%)	630 (74.4)	26 (60)	352 (82)	87 (89)	.0003	43 (47)	106 (65)	16 (64)	.02
Married or cohabitating, n (%)	799 (94.3)	38 (88)	414 (97)	94 (96)	.02	80 (88)	149 (91)	24 (96)	.41
Annual household income < \$40 000, n (%)	81 (10.3)	9 (23)	25 (6)	10 (11)	.001	15 (19)	20 (13)	2 (8)	.36
Child characteristic									
Female gender, n (%)	426 (50.3)	16 (37)	215 (50)	54 (55)	.15	38 (42)	91 (56)	12 (48)	.10
Nonwhite race/ethnicity, n (%)	248 (29.3)	21 (49)	117 (27)	20 (20)	.002	37 (41)	44 (27)	9 (36)	.08
Birth weight, kg	3.5 (0.6)	3.5 (0.5)	3.5 (0.5)	3.5 (0.6)	.97	3.6 (0.5)	3.5 (0.6)	3.3 (0.8)	.15
Gestational age at birth, wk	39.5 (1.8)	39.7 (1.4)	39.6 (1.7)	39.5 (1.9)	.77	39.7 (1.6)	39.4 (2)	39.2 (2.1)	.25
Weight-for-age z score at birth, U	0.1 (1.1)	0.0 (0.9)	0.1 (1.0)	0.1 (1.1)	.81	0.2 (1.0)	0.0 (1.0)	-0.2 (1.4)	.23
Weight-for-age z score at 4 mo, U	0.5 (1)	0.4 (1)	0.4 (0.9)	0.3 (1.1)	.67	0.7 (1.0)	0.6 (0.9)	0.1 (1.2)	.01
Change in weight-for-age z score from 0 to 4 mo, U	0.4 (1)	0.4 (1.2)	0.4 (1)	0.2 (1.1)	.43	0.6 (1)	0.6 (0.9)	0.3 (1.1)	.32

Breastfed was defined as exclusively or partially breastfed at 4 months of age. Formula-fed was defined as exclusively formula-fed since birth or completely weaned from breast milk by 4 months of age. *P* values are from χ^2 tests for categorical characteristics and from unadjusted linear regression for continuous characteristics.

TABLE 2 Anthropometry at Age 3 for 847 Project Viva Children According to Timing of Solid Food Introduction and Breastfeeding Status at 4 Months of Age

Characteristic	Overall (n = 847)	Breastfed Age at Introduction of Solids, mo			P	Formula-Fed Age at Introduction of Solids, mo			P
		<4	4–5	≥6		<4	4–5	≥6	
		(n = 43)	(n = 427)	(n = 98)		(n = 91)	(n = 163)	(n = 25)	
Height, cm	97.4 (4.3)	98.3 (4.8)	97.0 (4.1)	96.6 (4.1)	.09	98.4 (4.5)	97.7 (4.4)	98.5 (5.6)	.41
Height-for-age z score, U	0.26 (0.94)	0.34 (0.9)	0.21 (0.9)	0.14 (0.9)	.53	0.46 (0.9)	0.34 (0.9)	0.19 (1.0)	.39
Weight, kg	15.7 (2.1)	15.6 (1.8)	15.5 (1.9)	15.2 (1.9)	.40	16.7 (2.7)	15.8 (2.3)	16.6 (2.7)	.01
Weight-for-age z score, U	0.49 (1.0)	0.40 (0.8)	0.42 (0.9)	0.30 (1.0)	.55	0.92 (1.1)	0.55 (0.9)	0.66 (1.1)	.02
BMI	16.5 (1.5)	16.2 (1.1)	16.4 (1.4)	16.3 (1.2)	.37	17.2 (1.9)	16.5 (1.5)	17.0 (2.1)	.004
BMI z score, U	0.45 (1.01)	0.21 (0.9)	0.39 (1.0)	0.31 (0.9)	.45	0.90 (1.2)	0.46 (0.9)	0.77 (1.1)	.004
BMI category	—	—	—	—	.79	—	—	—	.0001
<85th percentile, n (%)	624 (74)	34 (79)	323 (76)	79 (81)	—	50 (55)	121 (74)	17 (68)	—
85th to <95th percentile, n (%)	148 (17)	6 (14)	74 (17)	12 (12)	—	18 (20)	34 (21)	4 (16)	—
≥95th percentile, n (%)	75 (9)	3 (7)	30 (7)	7 (7)	—	23 (25)	8 (5)	4 (16)	—
Sum of subscapular plus triceps skinfolds, mm	16.8 (4.1)	15.9 (3.3)	16.5 (4.0)	16.3 (3.8)	.65	18.0 (4.8)	17.2 (4.0)	17.9 (5.8)	.38

Breastfed was defined as exclusively or partially breastfed at 4 months of age. Formula-fed was defined as exclusively formula-fed since birth or completely weaned from breast milk by 4 months of age. *P* values are from χ^2 tests for categorical characteristics and from unadjusted linear regression for continuous characteristics.

infants, compared with infants who received solid foods between the age of 4 and 5 months, infants introduced to solid foods before the age of 4 months did not have an increased risk of obesity at the age of 3 years (odds ratio [OR]: 1.0 [95% confidence interval [CI]: 0.3–3.3]). Adjustment for covariates, including change in weight-for-age z score from 0 to 4

months, did not substantially change the ORs.

Among formula-fed infants, the introduction of solid foods before 4 months of age was associated with a higher odds of obesity (Table 3). Formula-fed infants who were introduced to solids before the age of 4 months (versus at 4–5 months of age)

had a sixfold increase in the odds of obesity (OR: 6.3 [95% CI: 2.3–16.9]) after adjustment for covariates. Introduction of solid foods after the age of 6 months among formula-fed infants was associated with a 3.6-fold increase in the odds of obesity after adjustment for covariates, but the CI was wide (95% CI: 0.8–16.3) and the association was not statistically significant.

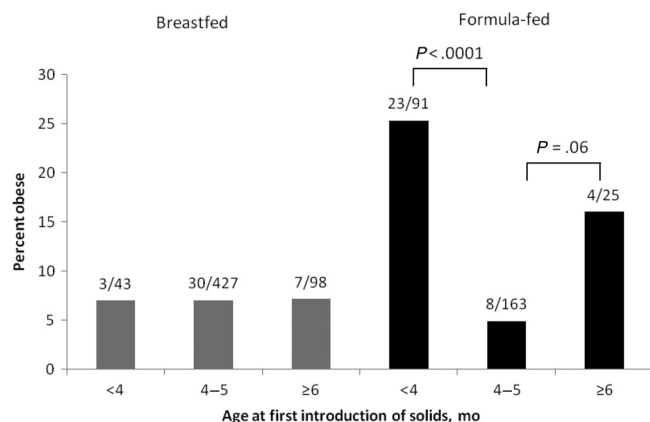


FIGURE 1 Association between timing of solid food introduction in infancy and obesity at the age of 3 years (BMI \geq 95th percentile) according to breastfeeding status ($n = 847$).

Early introduction of solids was associated with higher age 3 mean BMI z scores among formula-fed infants, but not breastfed infants (Table 3). Among formula-fed infants, after adjustment for covariates, including early infant growth, introduction of solids before the age of 4 months was associated with a 0.36-unit increment in BMI z scores (95% CI: 0.10–0.61) at the age of 3 years. The timing of solid food introduction was not associated

with the sum of skinfolds at the age of 3 years for either breastfed or formula-fed children (Table 3).

DISCUSSION

Among infants who were never breastfed or who stopped breastfeeding before the age of 4 months, we found that the introduction of solids before the age of 4 months was associated with a sixfold increase in the risk of obesity at age 3 years. This association was not

explained by rapid early growth. Among formula-fed infants, early introduction of solids was associated with a 0.4-unit increment in BMI z scores at age 3 years. For a 3-year-old child at the 50th percentile for weight and height, a 0.4-unit increment in BMI z score would be equivalent to an increment of 16 BMI percentile units (ie, to the 66th percentile) or 0.5 kg. Among infants breastfed for at least 4 months, the timing of solid food introduction was not associated with obesity, BMI z score, or sum of skinfolds at age 3 years.

Our finding that the association between the timing of solid food introduction and adiposity varied by breastfeeding status supports data from 2 other cohorts. Infants from the United Kingdom who were introduced to solid foods before the age of 15 weeks (versus \geq 15 weeks) had a mean BMI z score at 7 years of age that was 0.12 units higher among formula-fed infants and 0.03 units higher among infants exclusively breastfed for at least 15 weeks.⁴ An earlier report¹³ using the

TABLE 3 ORs (95% CIs) for Obesity (BMI \geq 95th Versus $<$ 85th Percentile) and Regression Estimates (95% CIs) for BMI z Score and Sum of Subscapular Plus Triceps Skinfolds at 3 Years of Age According to the Timing of the First Introduction of Solid Foods During Infancy, Stratified According to Breastfeeding Status at 4 Months of Age

	Breastfed Age at Introduction of Solids, mo			Formula-Fed Age at Introduction of Solids, mo		
	<4 ($n = 43$)	4-5 ($n = 427$)	\geq 6 ($n = 98$)	<4 ($n = 91$)	4-5 ($n = 163$)	\geq 6 ($n = 25$)
Odds of obesity (BMI \geq 95th percentile), OR (95% CI)						
Crude	1.0 (0.3 to 3.3)	1.0 (Reference)	1.0 (0.4 to 2.3)	7.0 (2.9 to 16.6)	1.0 (Reference)	3.6 (1.0 to 13.1)
Multivariable ^a	1.0 (0.3 to 3.7)	1.0 (Reference)	1.0 (0.4 to 2.4)	6.2 (2.3 to 16.3)	1.0 (Reference)	3.1 (0.7 to 13.7)
Multivariable plus change in weight-for-age z score 0-4 mo ^a	1.1 (0.3 to 4.4)	1.0 (Reference)	1.0 (0.4 to 2.5)	6.3 (2.3 to 16.9)	1.0 (Reference)	3.6 (0.8 to 16.3)
BMI z score, β (95% CI), U						
Crude	-0.17 (-0.48 to 0.13)	0.0 (Reference)	-0.08 (-0.30 to 0.13)	0.44 (0.17 to 0.70)	0.0 (Reference)	0.31 (-0.12 to 0.75)
Multivariable ^a	-0.20 (-0.51 to 0.11)	0.0 (Reference)	-0.08 (-0.30 to 0.13)	0.35 (0.09 to 0.60)	0.0 (Reference)	0.26 (-0.15 to 0.68)
Multivariable plus change in weight-for-age z score 0-4 mo ^a	-0.19 (-0.49 to 0.11)	0.0 (Reference)	-0.06 (-0.27 to 0.15)	0.36 (0.10 to 0.61)	0.0 (Reference)	0.32 (-0.09 to 0.74)
Sum of triceps and subscapular skinfolds, β (95% CI)						
Crude	-0.55 (-1.79 to 0.69)	0.0 (Reference)	-0.19 (-1.07 to 0.69)	0.79 (-0.38 to 1.96)	0.0 (Reference)	0.69 (-1.22 to 2.60)
Multivariable ^a	-0.21 (-1.44 to 1.02)	0.0 (Reference)	-0.34 (-1.20 to 0.52)	1.00 (-0.15 to 2.15)	0.0 (Reference)	0.42 (-1.44 to 2.27)
Multivariable plus change in weight-for-age z score 0-4 mo ^a	-0.19 (-1.42 to 1.04)	0.0 (Reference)	-0.30 (-1.16 to 0.56)	1.03 (-0.12 to 2.18)	0.0 (Reference)	0.48 (-1.38 to 2.35)

Breastfed was defined as exclusively or partially breastfed at 4 months of age. Formula-fed was defined as exclusively formula-fed since birth or completely weaned from breast milk by 4 months of age.

^a Multivariable model was adjusted for maternal education, household income, and prepregnancy BMI; paternal BMI; and child's age, gender, and race/ethnicity.

same cohort found no association of early introduction of solid foods with attained weight at 1 or 2 years, but these analyses were not stratified according to breastfeeding status. In the Danish National Birth Cohort, the introduction of solid foods before (versus at or after) 16 weeks was associated with an increased weight gain in the first year of life among children breastfed for 20 weeks or less but not among children breastfed for 20 weeks or longer.⁵ That study excluded infants who were never breastfed, who constituted 36% of the 279 formula-fed infants in our study. Our results may be more generalizable to the United States and other populations with lower breastfeeding initiation and continuation rates.

We found that the association between early solid food introduction and obesity among formula-fed infants was independent of the rate of early infancy weight gain. Previous studies adjusted for attained weight at the age of solid food introduction rather than the rate of weight gain.⁴ Our finding is important because rapid weight gain during the first few months of life has been associated with an increased risk of obesity,^{3,21} and maternal perceptions of infant hunger or large infant size seem to influence the decision to introduce solid foods early.²²

Our findings differ from data showing no association between the timing of solid food introduction and child adiposity,^{8–11,23,24} and 1 study²⁵ reporting that early solid food introduction was associated with lower 3-year BMI z scores. There are several potential explanations for the discrepancies between these studies and our findings. Some studies were not stratified according to breastfeeding status,⁸ adjusted for only a few confounders,²⁵ or examined outcomes at substantially older ages than in our study.^{8,10} A few studies used different exposure defini-

tions, combining juice and solid food introduction⁹ or defining early solid food introduction as introduction earlier than 6 months of age.²⁴ Reliance on maternal recall of the timing of solid food introduction, up to several years after the exposure, may have reduced the power of some studies to detect an association.^{9,10} In a randomized trial, formula-fed infants introduced to solid foods at 3 to 4 vs 6 months of age showed no difference in fat mass at 6 and 12 months of age.¹¹ In 2 Honduran trials, breastfed infants born to low-income mothers²⁶ or born small for gestational age²⁷ were randomly assigned to either exclusive breastfeeding for 6 months or breastfeeding with the introduction of solids between 4 and 6 months; no difference was noted in weight or length gain during the first year of life.^{26,27} Additional randomized trials would be useful to confirm our findings.

One possible reason why we saw an association among formula-fed but not breastfed infants is that formula-fed infants may increase their energy intake when solids are introduced. Breastfeeding may promote self-regulation of an infant's energy intake, and the mother may learn to recognize her infant's hunger and satiety cues.²⁸ In the Davis Area Research on Lactation in Infant Nutrition and Growth Study, solid foods introduced before the age of 6 months displaced milk intake among breastfed but not formula-fed infants.²⁴ In a cohort from the United Kingdom, solid food introduction before the age of 4 months was related to higher energy intake in formula-fed but not breastfed infants.²⁹ These 2 studies suggest that solid foods introduced before the age of 4 to 6 months increase energy intake among formula-fed but not breastfed infants. However, in a Honduran trial²⁷ of small-for-gestational age infants, those introduced to solids

at 4 (versus after 6) months had a greater increase in daily energy intake from 16 to 26 weeks, perhaps explained in part by a lower baseline energy intake in the early solid food group. The 2 groups showed no difference in absolute energy intake at 26 weeks,²⁷ consistent with a previous Honduran trial.²⁶ Formula-fed infants in the United States who were randomly assigned to solid food introduction at the age of 3 to 4 (vs 6) months had greater displacement of formula intake, resulting in no increase in energy intake.¹¹ The reasons for these conflicting findings are unclear and require additional study.

Delayed introduction of solids after 6 months of age was not associated with obesity among breastfed infants. Among formula-fed infants, delayed introduction of solids was not associated with an increase in the odds of obesity at the age of 3 years (OR: 3.6 [95% CI: 0.8–16.3]). We are unable to exclude the possibility that delayed introduction of solid foods may increase the odds of obesity given the wide CI, reflecting the small number of infants who received solids after the age of 6 months. Agras et al¹² found that the delayed introduction of solid foods after 5 months of age was related to increased adiposity at ages 1, 2, and 3 years but not at 6 years of age. That study had a relatively small sample size of 99 children ($n = 54$ at 6 years of age), and it is unclear how many children received solid foods after 5 months.

Our results support recommendations to introduce solids after 4 months of age, at least among infants who are formula-fed or breastfed for less than 4 months. The American Academy of Pediatrics Committee on Nutrition guidelines state that solid foods can be introduced between 4 and 6 months of age.¹⁶ Among breastfed infants, both the American Academy of Pediatrics

Committee on Nutrition and the American Academy of Pediatrics Section on Breastfeeding recommend delaying the introduction of solids to at least the age of 4 months but preferably 6 months.^{16,30} The World Health Organization recommends solid food introduction at 6 months of age to promote exclusive breastfeeding for 6 months.¹⁷ In a recent cross-sectional study³¹ of 2515 infants in the United States, 26% of infants were introduced to solid foods before 4 months of age. Our data suggest that increased adherence to the American Academy of Pediatrics guidelines has the potential to reduce the risk of obesity in children in the United States, given the relatively high prevalence of infants who are formula-fed or breastfed for less than 4 months. Approximately one-quarter of infants in the United States are never breastfed, and approximately half are breastfed for less than 4 months.³² Although increasing the duration of exclusive breastfeeding remains an important national priority,³³ interventions aimed at increasing adherence

to solid food introduction guidelines, particularly among infants who are exclusively formula-fed or breastfed for less than 4 months, could provide 1 potential strategy to help lower the incidence of childhood obesity.

Strengths of this study include a well-characterized cohort and careful height and weight measurements using research standards. We cannot exclude possible residual confounding, but our analyses did control for a large set of potential confounding variables. Our cohort did have some loss to follow-up. Compared with the eligible children excluded from our analyses, included children were more likely to be white, have college-educated mothers, and be breastfed longer, but the timing of introduction of solids and BMI z score at 3 years of age were similar. Generalizability to more socioeconomically disadvantaged populations may be limited despite diverse maternal racial and ethnic backgrounds because maternal education and income levels were relatively high. Our data must be interpreted with some caution

because we observed small numbers in some cells, leading to possible chance results.

CONCLUSIONS

Among infants who were never breastfed or who stopped breastfeeding before 4 months of age, the introduction of solids before the age of 4 months was associated with almost sixfold increased odds of obesity at 3 years of age. The association was not explained by rapid early growth. Among infants breastfed for 4 months or longer, the timing of the introduction of solid foods was not associated with the odds of obesity. Increased adherence to guidelines regarding the timing of solid food introduction may reduce the risk of obesity in childhood.

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