Infant Feeding and Weight Gain: Separating Breast Milk From Breastfeeding and Formula From Food

Meghan B. Azad, PhD,[a,b,c] Lorena Vehling, MSc,[a,b] Deborah Chan, RN,[a,b] Annika Klopp, MD,[a,b] Nathan C. Nickel, PhD,[b,d] Jonathan M. McGavock, PhD,[a,b] Allan B. Becker, MD,[a,b] Piushkumar J. Mandhane, MD,[e] Stuart E. Turvey, MD,[f,g] Theo J. Moraes, MD,[h] Mark S. Taylor, PhD,[c,i] Diana L. Lefebvre, PhD,[j] Malcolm R. Sears, MB,[j] Padmaja Subbarao, MD,[h] on behalf of the CHILD Study Investigators

abstract

OBJECTIVES: Studies addressing breastfeeding and obesity rarely document the method of breast milk feeding, type of supplementation, or feeding in hospital. We investigated these practices in the CHILD birth cohort.

METHODS: Feeding was reported by mothers and documented from hospital records. Weight and BMI *z* scores (BMIzs) were measured at 12 months. Analyses controlled for maternal BMI and other confounders.

RESULTS: Among 2553 mother-infant dyads, 97% initiated breastfeeding, and the median breastfeeding duration was 11.0 months. Most infants (74%) received solids before 6 months. Among "exclusively breastfed" infants, 55% received some expressed breast milk, and 27% briefly received formula in hospital. Compared with exclusive direct breastfeeding at 3 months, all other feeding styles were associated with higher BMIzs: adjusted β: +.12 (95% confidence interval [CI]: .01 to .23) for some expressed milk, +.28 (95% CI: .16 to .39) for partial breastfeeding, and +.45 (95% CI: .30 to .59) for exclusive formula feeding. Brief formula supplementation in hospital did not alter these associations so long as exclusive breastfeeding was established and sustained for at least 3 months. Formula supplementation by 6 months was associated with higher BMIzs (adjusted β: +.25; 95% CI: .13 to .38), whereas supplementation with solid foods was not. Results were similar for weight gain velocity.

CONCLUSIONS: Breastfeeding is inversely associated with weight gain velocity and BMI. These associations are dose dependent, partially diminished when breast milk is fed from a bottle, and substantially weakened by formula supplementation after the neonatal period.

Departments of [a]Pediatrics and Child Health and [d]Community Health Sciences, Manitoba Centre for Health Policy, University of Manitoba, Winnipeg, Canada; [b]Developmental Origins of Chronic Diseases in Children Network (DEVOTION), Children's Hospital Research Institute of Manitoba, Winnipeg, Canada; [c]London School of Hygiene and Tropical Medicine, University of London, London, United Kingdom; [e]Department of Pediatrics, University of Alberta, Edmonton, Canada; [f]Department of Pediatrics, Child and Family Research Institute and British Columbia Children's Hospital, Vancouver, Canada; [g]Department of Pediatrics, University of British Columbia, Vancouver, Canada; [h]Department of Pediatrics, Hospital for Sick Children and University of Toronto, Toronto, Canada; [i]Department of Public Health, Faculty of Health Care and Social Work, University of Trnava, Trnava, Slovakia; and [j]Department of Medicine, McMaster University, Hamilton, Canada

Dr Azad conceptualized and designed the study, performed statistical analyses, drafted the initial manuscript, reviewed and revised the manuscript, and this work was undertaken in partial fulfillment of her MSc in Epidemiology at the London School of Hygiene and Tropical Medicine; Ms Vehling created the infant feeding variables and reviewed the manuscript; Ms Chan performed hospital chart reviews to validate hospital feeding data and reviewed the manuscript; Dr Klopp created the infant feeding mode variable and reviewed the manuscript; Dr Nickel conceptualized

WHAT'S KNOWN ON THIS SUBJECT: Breastfeeding has been inconsistently associated with lower obesity risk. Most studies do not distinguish between feeding at the breast and consuming bottled breast milk or between supplementation with formula versus foods, and few account for feeding in hospital.

WHAT THIS STUDY ADDS: In the Canadian CHILD birth cohort, breastfeeding was inversely associated with weight gain velocity, BMI, and overweight risk during infancy. This association was dose dependent, diminished with formula supplementation, and weaker when breast milk was fed from a bottle.

To cite: Azad MB, Vehling L, Chan D, et al. Infant Feeding and Weight Gain: Separating Breast Milk From Breastfeeding and Formula From Food. *Pediatrics*. 2018;142(4):e20181092

Obesity is a major public health challenge worldwide,[1] and it is rooted in early life.[2] Rapid weight gain during infancy is an established obesity risk factor,[3] and excess body weight tracks from infancy into childhood[4] and adulthood.[5]

Breastfeeding has many established benefits for maternal and child health,[6] but its impact on obesity is unclear. In a meta-analysis of 113 studies, it was found that breastfed infants have a 26% reduced risk of obesity later in life[7]; however, considerable heterogeneity was observed, and the association was attenuated among high-quality studies. Aside from methodological differences, inconsistent findings may reflect differences in the way breastfeeding is defined,[8,9] measured, or practiced in different settings, but these differences are rarely documented.

In most studies, researchers typically do not distinguish between direct breastfeeding (at the breast) and consumption of expressed breast milk (from a bottle) or between supplementation with formula versus other complementary foods, and few account for early feeding exposures in hospital. These are important distinctions because expressing and storing breast milk could reduce its bioactivity,[10] feeding from a bottle may discourage self-regulation,[11] and even brief formula supplementation could potentially alter the developing gut microbiota and influence weight gain.[12]

In a large prospective birth cohort, we characterized the association of breastfeeding, infant weight gain, and body composition in the first year of life and further assessed the impact of feeding method, type and timing of complementary feeding, and formula supplementation during the neonatal period.

TABLE 1 Infant Feeding Exposure Variables in the CHILD Birth Cohort

Exposure Variable	Definition and Categories
BF exclusivity at 3 mo	• No BF (formula only) • Partial BF (breast milk supplemented with formula) • Exclusive BF after hospital (received some formula in hospital but only breast milk after discharge) • Exclusive BF[a] (breast milk only, both in hospital and after discharge)
BF mode at 3 mo	• No BF (formula only) • Partial BF with formula (direct or expressed breast milk and formula) • BF only, some expressed (has received some breast milk expressed with a pump but no formula) • BF only, all direct[a] (no expressed milk or formula since hospital discharge)
BF exclusivity at 6 mo	Categorized in 6 groups according to BF status and type of complementary feeding; collapsed into 4 groups for regression modeling • No BF: formula only, or formula plus solid food • Partial BF with formula: breast milk plus formula, or breast milk plus formula plus solid food • Partial BF without formula: breast milk plus solid food • Exclusive BF[a]: breast milk only, with no formula or solid food
Introduction of solid foods	Age of infant at first introduction of solid (or semisolid) foods, in mo Evaluated as a continuous variable (for covariate adjustment) or categorized in 4 groups for regression modeling: <4, 4 to <5, 5 to <6, ≥6[a] mo
Duration of any BF	Age of infant at weaning, determined from the first reported date of breastfeeding cessation. For breastfed infants with no reported cessation date because of skipped questionnaires (*N* = 367), the minimum confirmed breastfeeding duration was used. Evaluated as a continuous variable (for covariate adjustment) or categorized in 5 groups for regression modeling: never breastfed, <3, 3 to <6, 6 to <12, ≥12[a] mo
Duration of exclusive BF	Age of infant at first introduction to formula, nonhuman milk, juice, or solid foods, in mo. Water and vitamin supplements were not considered. Evaluated as a continuous variable or categorized in 5 groups: never, <2, 2 to <4, 4 to <6, ≥6 mo[a]

BF, breastfeeding.
[a] Reference categories for regression modeling, selected according to WHO recommendations.[14]

METHODS

Study Population

Pregnant women were enrolled in the Canadian Healthy Infant Longitudinal Development (CHILD) birth cohort (www.childstudy.ca) between 2009 and 2012.[13] Infants born before 38 + 0 weeks or missing gestational age or anthropometric data were excluded from the current analysis (Supplemental Fig 3). This study was approved by the Human Research Ethics Boards at the University of London, McMaster University, and the Universities of Manitoba, Alberta, Toronto, and British Columbia.

Infant Feeding Exposures

Feeding exposures are summarized in Table 1. Feeding in hospital was recorded by nursing staff and validated by chart review for Manitoba participants with available hospital records (*N* = 847), revealing strong agreement for breastfeeding (98.3% agreement) and formula supplementation (87.6%).

Subsequent feeding was reported by mothers at 3, 6, 12, 18, and 24 months postpartum, including the following: breastfeeding initiation and cessation, feeding of expressed breast milk, use of formula, other fluids, and foods. The end of exclusive breastfeeding was defined as the introduction of any formula, food, juice, or nonhuman milk. Water and vitamin supplements were not considered.

Anthropometric Outcomes

The primary outcome was BMI *z* score. In large cohort studies, researchers have demonstrated its equivalence or superiority as a predictor of childhood obesity, compared with weight-for-length.[4] Secondary outcomes included overweight, weight gain velocity, and rapid weight gain. Weight and length were recorded at birth by nurses and at 12 months (mean: 12.5 ± 1.5 months) by CHILD staff, following a standardized protocol. Sex-specific weight-for-age (WFA) and BMI-for-age *z* scores were calculated according to the World Health Organization (WHO) Child Growth reference.[15] BMI *z* score was dichotomized to define overweight (*z* score >2).[16] Weight gain velocity was calculated as the change in WFA *z* score from birth to 12 months[3] and dichotomized to define rapid weight gain (weight gain velocity >0.67).[3]

Covariates

Potential confounders based on existing literature[17] were documented from hospital records (maternal age, diabetes, mode of delivery, parity, infant sex, gestational age, and birth weight) or self-reported (maternal ethnicity, education, smoking during pregnancy, and diet quality[18]) (Supplemental Table 6). Maternal prepregnancy BMI was determined from measured height and self-reported prepregnancy weight (*N* = 1751) or estimated from measured weight 12 months postpartum (*N* = 837). Validation against health records in a subset (*N* = 224) revealed strong agreement for both measures (mean difference: −1.0 kg [95% confidence interval (CI): −1.5 to −0.4] and +1.3 kg [95% CI: 0.5 to 2.2], respectively).

Statistical Analysis

Potential confounders were screened in bivariate analyses (*t* tests, analysis of variance [ANOVA], χ^2) to identify associations with feeding exposures and anthropometric outcomes. Multivariable regression models were used to estimate the independent effects of feeding exposures on anthropometric outcomes, with adjustment for infant sex, birth weight, established obesity risk factors (maternal smoking, prepregnancy BMI), and potential confounders identified through bivariate screening (study site, maternal age, parity, ethnicity, education, marital status, and infant gestational age). We also applied a propensity score approach, in which the same covariates were used to predict feeding exposures in multinomial regression models, and outcome models were weighted for the inverse predicted probability of feeding exposures.

Next, because different feeding exposures may be interrelated, models were mutually adjusted to evaluate the independent effects of breastfeeding exclusivity, solid food introduction, and breastfeeding duration. For example, mothers who cease breastfeeding earlier may also introduce foods earlier to their infant; these exposures were evaluated together in the same model to determine if one explained the other, or if they were independently associated with infant BMI.

Interaction terms were tested in regression models to evaluate the a priori hypothesis that breastfeeding effects may be modified by maternal obesity or infant sex.

Results are presented as crude and adjusted odds ratios (aORs) and adjusted β estimates (aβ) with 95% CIs. Multivariable regression analyses were conducted for mother-infant dyads with available feeding and covariate data and confirmed in the full eligible subset (*N* = 2553) following multiple imputation of missing covariate data. Multiple imputation (20 imputed data sets) was performed with fully conditional specification (chained equations) by using the covariates listed above. All analyses were performed by using SAS version 9.4 (SAS Institute, Inc, Cary, NC).

RESULTS

Population Characteristics

Of 2870 eligible term infants, 2553 (89.0%) were assessed at 12 months (Supplemental Fig 3, Table 2). The mean maternal age was 32.4 ± 4.6 years, and the mean prepregnancy BMI was 24.7 ± 5.4. The majority of mothers were white (75.1%), had a postsecondary (57.0%) or postgraduate (19.8%) degree, and delivered vaginally (75.7%). The mean infant BMI *z* score at 12 months was +0.21 ± 1.07. Nearly one-fourth of infants (*N* = 566, 22.3%) experienced rapid weight gain, and 126 (4.9%) were overweight at 12 months. Infants with missing outcome data were more likely to be of nonwhite ethnicity, have mothers who smoked, and be breastfed for a shorter duration.

Infant Feeding

Nearly all women in the CHILD cohort (96.6%) initiated breastfeeding (Supplemental Table 7, Fig 1). The majority (73.8%) continued beyond 6 months, and 43.5% were still breastfeeding at 12 months. The median duration of exclusive breastfeeding was 4.0 months (interquartile range [IQR]: 0.5–5.0), and the median duration of any breastfeeding was 10.0 months (IQR: 5.0–14.0). Most infants (73.9%) received solid foods before 6 months, although only 17.9% received them before 4 months.

At 3 months, 1686 infants (60.8%) were exclusively breastfed according to maternal report; however, 460 of these infants (27.3% of exclusively breastfed infants, 16.6% overall) briefly received formula supplementation in hospital. Over half of exclusively breastfed infants had received some expressed breast milk (*N* = 879, 54.6% of exclusively breastfed infants; 33.0% of all infants). By 6 months, only 18.0% of infants were exclusively breastfed. An additional 59.4% were partially breastfed, including 33.6% receiving solid foods, 5.4% receiving formula, and 20.4% receiving both formula and solids.

TABLE 2 Characteristics of the Study Population, Comparing Those With and Without Infant BMI Data

	With BMI Data (N = 2553)		Without BMI Data (N = 317)	
	N or n	Mean ± SD, Median (IQR), or (%)	N or n	Mean ± SD, Median (IQR), or (%)
Mother, N, mean ± SD				
Age, y	2553	32.4 ± 4.6	317	31.4 ± 5.2
Diet quality (HEI score)	2380	73.0 ± 8.5	248	72.6 ± 8.7
Prepregnancy BMI	2476	24.7 ± 5.4	103	25.3 ± 6.5
Infant, N, mean ± SD				
Gestational age, wk	2553	39.9 ± 1.0	317	39.8 ± 1.0
Birth wt, g	2532	3509 ± 443	317	3482 ± 465
WFA at birth, z score	2532	0.41 ± 0.89	310	0.36 ± 0.95
WFA at 12 mo, z score	2553	0.30 ± 0.98	—	—
Wt gain velocity, birth to 12 mo, change in WFA z score	2532	−0.11 ± 1.05	—	—
BMI at 12 mo, z score	2553	0.21 ± 1.07	—	—
Feeding, N, median (IQR)				
Duration of exclusive BF, mo	2493	4.0 (0.5–5.0)	197	2.3 (0.3–5.0)
Duration of any BF, mo	2320	11.0 (6.0–15.0)	141	6.0 (2.0–11.0)
Introduction to solid foods, mo	2447	5.0 (4.5–6.0)	143	5.0 (3.5–5.0)
Study site, n (%)				
Edmonton	560	(21.9)	110	(34.7)
Toronto	597	(23.4)	95	(30.0)
Vancouver	577	(22.6)	51	(16.1)
Winnipeg	819	(32.1)	61	(19.2)
Maternal ethnicity, n (%)				
Asian	369	(14.6)	45	(15.3)
White	1901	(75.1)	192	(65.3)
First Nations	94	(3.7)	23	(7.8)
Other	167	(6.6)	34	(11.6)
Missing	22	—	23	—
Maternal education, n (%)				
High school or less	205	(8.3)	37	(13.2)
Some postsecondary	368	(14.9)	41	(14.6)
Postsecondary	1412	(57.0)	150	(53.6)
Postgraduate	491	(19.8)	52	(18.6)
Missing	77	—	37	—
Maternal marital status, n (%)				
Married or common-law	2368	(94.7)	256	(90.1)
Single (never married)	118	(4.7)	23	(8.1)
Divorced or separated	15	(0.6)	5	(1.8)
Missing	52	—	33	—
Maternal smoking, n (%)				
No	2305	(92.1)	247	(86.7)
Yes	198	(7.9)	38	(13.3)
Missing	50	—	32	—
Parity, n (%)				
0	1386	(54.3)	165	(52.1)
1	844	(33.1)	117	(36.9)
2+	322	(12.6)	35	(11.0)
Missing	1	—	0	—
Infant sex, n (%)				
Female	1224	(47.9)	154	(48.6)
Male	1329	(52.1)	163	(51.4)

Percentages reflect proportions of nonmissing data. Comparisons by t test, Mann–Whitney test, or χ^2 test. N = 2870 infants from the CHILD cohort born ≥38 + 0 wk gestation. BF, breastfeeding; HEI, healthy eating index. —, not applicable.

Breastfeeding duration and exclusivity were positively associated with maternal age and education and negatively associated with maternal obesity, smoking, cesarean delivery, and single parenthood (Table 3). Breastfeeding rates also differed by study site and were highest in Vancouver. Formula supplementation in hospital and feeding of expressed breast milk after discharge were more common in first-time mothers. Many of these factors were also associated with infant BMI and/or weight gain velocity (Table 3), and all were balanced effectively in the propensity score analyses (Supplemental Tables 8 and 9).

Infant Feeding Practices and BMI *z* Score at 12 Months (Primary Outcome)

Breastfeeding Exclusivity and Type of Complementary Feeding

Infants who achieved the WHO recommendation[14] of 6 months of exclusive breastfeeding had a mean BMI z score of −0.04 ± 1.06, closely matching the WHO infant growth standard (Fig 2A, Table 4). BMI z scores were half a SD higher among infants who were not breastfed for at least 6 months (mean: +0.51 ± 1.07 above the WHO standard; crude β = +.54; 95% CI: .41 to .67). This association remained significant after adjustment for study site, maternal age, prepregnancy BMI, ethnicity, education, marital status, smoking, mode of delivery, parity, infant sex, gestational age, and birth weight (aβ = +0.44; 95% CI: 0.30 to 0.57). Partial breastfeeding with formula supplementation appeared to have an intermediate effect (mean: +0.30 ± 1.08; aβ = 0.25; 95% CI: 0.13 to 0.38), whereas partial breastfeeding without formula (ie, with solid foods only) was not significantly associated with infant BMI (mean: +0.07 ± 1.03; aβ: +0.07; 95% CI: −0.05 to 0.19).

Breastfeeding Duration and Timing of Solid Food Introduction

Breastfeeding duration was inversely associated with BMI z score in a dose-dependent manner (aβ = +0.48 for <3 months, +0.29 for 3 to 6 months, +0.19 for 6 to 12 months, compared with breastfeeding beyond 12 months; P for trend <.0001) (Fig 2A, Table 4). These associations were relatively unchanged after further adjustment for the timing of introduction to solid foods (eg,

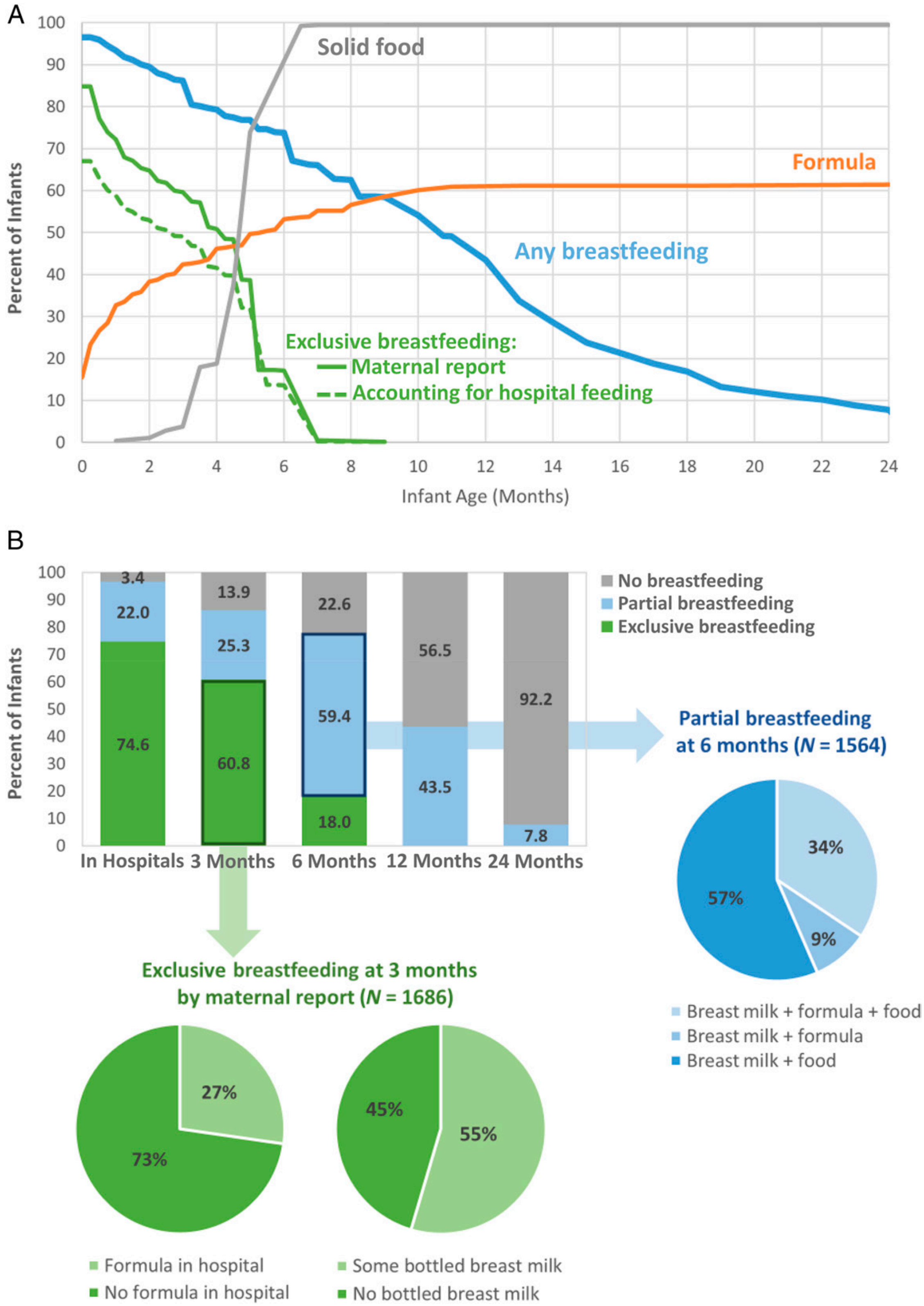

FIGURE 1

Infant feeding practices in the CHILD cohort ($N = 2870$ term infants). A, Proportion of infants breastfeeding, exclusively breastfeeding, receiving formula, and receiving solid food. B, Breastfeeding status in hospital and at 3, 6, 12, and 24 months of age. Exclusive breastfeeding at 3 months was further categorized according to formula supplementation in hospital (any or none) and feeding of expressed and bottled breast milk (any or none). Partial breastfeeding at 6 months was further categorized according to the type of complementary feeding (formula and/or solid foods). Newborn feeding was recorded by hospital nurses; infant feeding was reported by mothers.

mutually adjusted β = +0.48, +0.32, +0.18 for <3 months) (Table 4).

Introducing solid foods before 5 months was associated with a higher BMI z score (aβ = +0.17; 95% CI: 0.04 to 0.29) compared with introduction after 6 months. This association was attenuated after adjusting for breastfeeding duration (mutually adjusted β = +0.12; 95% CI: −0.01 to 0.25). By contrast, introducing solid foods between 5 and 6 months was not significantly associated with BMI z score (mutually adjusted β = +0.05; 95% CI: −0.06 to 0.16). Thus, consistent with the above results, shorter breastfeeding duration and introduction of solid foods before 5 months (but not between 5 and 6 months) was associated with a higher BMI z score at 12 months.

Breastfeeding Exclusivity and Duration

Mutual adjustment for breastfeeding exclusivity and duration revealed that these factors were independently associated with infant BMI (Table 4). Effect estimates for partial breastfeeding with formula were attenuated but remained significant after adjustment for breastfeeding duration (eg, aβ = +0.24; 95% CI: 0.14 to 0.35 for formula supplementation before 3 months; attenuated to aβ = +0.14; 95% CI: 0.03 to 0.26 after adjustment for breastfeeding duration).

Mode of Breastfeeding

Exclusively breastfed infants receiving some expressed breast milk had higher BMI z scores than those receiving only direct breast milk (mean: +0.14 ± 1.00 vs −0.02 ± 1.06; aβ +0.12; 95% CI: 0.01 to 0.23) (Fig 2A, Table 4); however, they remained leaner than infants who were partially breastfed (aβ +0.28; 95% CI: 0.16 to 0.39) or not breastfed (aβ +0.45; 95% CI: 0.30 to 0.59).

Brief Formula Supplementation in Hospital

Among infants who were "exclusively breastfed" for at least 3 months according to maternal report, those who briefly received formula supplementation as neonates had slightly higher BMI z scores at 12 months (mean: +0.11 ± 1.04 vs +0.04 ± 1.04); however, this difference was not significant in crude or adjusted models (aβ = +0.05; 95% CI: −0.07 to 0.17) (Fig 2A, Table 4).

Infant Feeding Practices, Overweight Risk, and Weight Gain Velocity (Secondary Outcomes)

Consistent with BMI z score results, there was an inverse dose-dependent association between breastfeeding duration and the risk of overweight at 12 months ($P < .0001$) (Table 4). The risk of overweight was threefold higher among infants who were not breastfed at 6 months compared with those who were exclusively breastfed (8.3% vs 2.4%, aOR = 3.20, 95% CI: 1.58 to 6.51). There was an intermediate association for partial breastfeeding with formula (6.1%, aOR = 2.03, 95% CI: 1.00 to 4.11) and no association for partial breastfeeding without formula (3.2%, aOR = 0.93, 95% CI: 0.44 to 1.97). Brief formula supplementation in hospital was not associated with overweight risk. Similar patterns of association were observed for weight gain velocity and risk of rapid weight gain (Fig 2B, Table 5).

Sensitivity Analyses and Effect Modification

Results were confirmed after inverse probability weighting for propensity scores and essentially unchanged with multiple imputation of missing data (Supplemental Table 10). There was no evidence of effect modification by infant sex or maternal obesity (not shown).

DISCUSSION

In the prospective CHILD birth cohort, we found that breastfeeding was inversely associated with weight gain velocity, BMI, and overweight risk in the first year of life. These associations were dose dependent (stronger with longer and more exclusive breastfeeding) and independent of maternal BMI and socioeconomic status, using multiple approaches to address confounding bias. After controlling for these and other potential confounders, breastfeeding cessation before 6 months was associated with a twofold increased risk of rapid weight gain, a +0.44 SD increase in BMI by 12 months of age, and a threefold increased risk of overweight, compared with exclusive breastfeeding. These effects are substantial, surpassing the estimated effect of maternal obesity (+0.20, in the same multivariable model).

Further analysis of specific feeding practices revealed stronger associations for direct breastfeeding versus expressed breast milk and stronger attenuation from supplementation with formula versus solid foods. Finally, brief formula supplementation during the neonatal period did not measurably alter these associations, so long as exclusive breastfeeding was established and sustained for at least 3 months after hospital discharge.

Strengths and Limitations

A major strength of this study is the prospective collection of infant feeding data, including many details that are rarely captured in other studies. Still, these exposure measurements were limited by a lack of quantitative information about the amount of expressed milk

TABLE 3 Univariate Associations of Potential Confounders With Infant Feeding, Weight Gain, and BMI in the First Year of Life

	N	Infant Feeding Exposures					Anthropometric Outcomes	
		Formula Feeding in Hospital	Expressed Milk Feeding[a] at 3 Mo	Solid Foods Introduced Before 4 Mo	Exclusive Breastfeeding at 6 Mo	Any Breastfeeding at 12 Mo	Wt Gain Velocity[b] 0–12 Mo	BMI *z* Score at 12 Mo
		%	%	%	%	%	Mean ± SD	Mean ± SD
Overall	2870	25.0	56.9	17.1	18.1	46.6	−0.11 ± 1.06	0.21 ± 1.07
Site								
Edmonton	670	32.2***	49.5**	17.7***	15.1***	38.3***	−0.04 ± 1.12**	0.36 ± 1.12***
Toronto	692	15.2	63.0	21.4	16.1	42.9	−0.05 ± 1.00	0.37 ± 1.01
Vancouver	628	10.5	57.3	6.3	25.6	64.1	−0.10 ± 1.07	0.11 ± 1.04
Winnipeg	880	32.7	56.6	20.8	16.4	42.8	−0.21 ± 1.04	0.06 ± 1.07
Maternal age, y								
<30	861	28.5*	60.4**	25.3***	12.6***	35.4***	−0.08 ± 1.11	0.20 ± 1.11
30–35	1223	25.9	58.3	15.9	18.9	49.7	−0.11 ± 1.03	0.19 ± 1.06
≥35	786	19.2	51.5	10.0	22.8	53.8	−0.13 ± 1.05	0.24 ± 1.04
Prepregnancy BMI								
<25	1656	20.6***	56.1	15.1**	19.5**	52.1***	−0.11 ± 1.03	0.12 ± 1.07***
≥25–30	546	24.8	57.2	17.5	18.5	46.4	−0.12 ± 1.11	0.26 ± 1.04
≥30	377	39.7	59.8	24.3	12.6	29.4	−0.10 ± 1.13	0.48 ± 1.04
Diabetes in pregnancy								
No	2714	24.1***	57.1	16.9	18.4	46.9	−0.11 ± 1.06	0.21 ± 1.08
Yes	126	41.2	54.7	19.7	12.1	39.8	−0.15 ± 1.15	0.24 ± 0.98
Maternal ethnicity								
Asian	414	29.3***	53.7	12.9**	19.0	53.7*	−0.10 ± 1.05	0.01 ± 1.02**
White	2093	22.5	58.1	17.1	18.6	45.6	−0.13 ± 1.05	0.22 ± 1.06
FN	117	40.4	52.8	25.2	15.0	41.8	0.04 ± 1.00	0.48 ± 1.06
Other	201	30.9	53.9	21.6	12.9	47.9	0.05 ± 1.18	0.28 ± 1.23
Maternal education								
High school or less	242	38.7***	41.9**	33.5***	9.0***	26.4***	−0.14 ± 1.13	0.27 ± 1.13
Some postsecondary	409	28.8	56.9	20.1	14.7	39.6	−0.04 ± 1.04	0.31 ± 1.06
Postsecondary	1562	23.0	59.0	15.3	18.7	48.1	−0.13 ± 1.06	0.19 ± 1.07
Postgraduate	543	18.3	56.9	12.9	23.4	58.5	−0.11 ± 1.04	0.13 ± 1.03
Marital status								
Married	2624	23.5***	56.9	16.5**	18.7**	47.5**	−0.12 ± 1.06**	0.20 ± 1.06
Single	161	40.4	58.8	27.2	9.1	35.0	0.11 ± 1.07	0.27 ± 1.20
Diet quality (HEI score)								
<70	855	28.7**	57.1	23.9***	13.2***	36.2***	−0.09 ± 1.09	0.24 ± 1.03
70–75	605	23.6	53.8	15.5	18.6	44.8	−0.11 ± 1.05	0.21 ± 1.09
>75	1168	22.0	58.6	14.4	21.2	55.0	−0.13 ± 1.04	0.18 ± 1.06
Parity								
0	1551	28.6***	67.5***	18.2	16.6	46.3	0.04 ± 1.04***	0.23 ± 1.06
1	961	21.8	47.2	15.2	20.0	47.3	−0.28 ± 1.05	0.15 ± 1.08
≥2	357	19.0	38.0	16.7	19.3	46.1	−0.32 ± 1.07	0.26 ± 1.09
Maternal smoking								
No	2552	23.5***	57.0	15.8***	19.3***	49.0***	−0.14 ± 1.05***	0.19 ± 1.07**
Yes	236	35.5	57.9	31.7	6.0	22.6	0.22 ± 1.10	0.43 ± 1.04
Infant sex								
Female	1378	25.0	55.8	14.7**	19.8*	47.2	−0.14 ± 1.04	0.18 ± 1.03
Male	1492	25.0	57.9	19.2	16.5	46.0	−0.08 ± 1.08	0.23 ± 1.11
Birth mode								
CS, elective	302	34.8***	57.9	18.0	13.3	37.5**	0.04 ± 1.07	0.37 ± 1.07**
CS, emergency	398	43.3	60.1	16.7	17.0	45.3	−0.13 ± 1.02	0.31 ± 1.03
Vaginal	2167	20.7	56.1	17.0	19.0	48.1	−0.12 ± 1.06	0.17 ± 1.07
Infant gestational age, wk								
38	557	30.6**	58.6*	19.1	15.9	38.9**	0.27 ± 1.02***	0.29 ± 1.06
39–40	1813	22.8	54.8	15.8	18.6	47.7	−0.14 ± 1.04	0.18 ± 1.06
41	500	26.9	62.6	19.3	18.8	51.0	−0.42 ± 1.03	0.20 ± 1.12
Infant birth wt, g								
<3000	330	32.6**	58.3	17.3	19.9	46.7	0.72 ± 1.00***	−0.14 ± 1.06***
3000 to <3500	1137	23.0	57.2	16.1	18.3	45.8	0.15 ± 0.91	0.06 ± 1.02
3500 to <4000	991	23.2	56.9	17.3	18.0	48.1	−0.32 ± 0.94	0.35 ± 1.06
≥4000	393	29.6	54.9	18.8	16.1	44.0	−0.97 ± 1.05	0.57 ± 1.10

N = 2870 infants from the CHILD cohort born ≥38 + 0 wk gestation. BF, breastfeeding; CS, cesarean delivery; FN, First Nations; HEI, healthy eating index.

[a] Of those reporting any breast milk feeding at 3 mo.

[b] Change in WFA *z* score from birth to 12 mo. Comparisons by χ^2 test, ANOVA, or *t* test.

*** $P < .001$;

** $P < .01$;

* $P < .05$.

or formula consumed. Also, because of the high breastfeeding initiation rates in this cohort, we had limited power to examine the impact of never breastfeeding, which is an important concern in other settings. Another limitation is that we did not capture information about mothers' intentions to breastfeed, feeding styles (eg, paced bottle-feeding, infant-led weaning, level of maternal control), or reasons for supplementing, pumping, and weaning.

We used multiple statistical approaches to consider many potential confounders, including sociodemographic factors (maternal age, ethnicity, education, and marital status) to address the social patterning of breastfeeding that is reported in other populations[17] and confirmed in our cohort. However, residual confounding remains possible in this observational study. Finally, although breastfeeding rates in the CHILD cohort are nationally representative,[19] our findings may not apply in other settings with different breastfeeding practices and policies or in populations challenged with undernutrition and stunting rather than overnutrition and obesity.

Breastfeeding Exclusivity and Duration: Dose Effects

Our findings are consistent with previous observational studies, demonstrating that breastfeeding is inversely associated with infant growth velocity,[20] BMI,[21] and overweight.[7,17,21] In contrast, a randomized trial of breastfeeding promotion did not affect infant WFA[22]; however, it did not include a nonbreastfed control group, and through observational analyses, it was confirmed that infants exclusively breastfed for at least 6 months had lower WFA compared with those weaned or supplemented earlier.[22]

We provide new evidence for the independent and dose-dependent effects of breastfeeding exclusivity and duration, which are rarely examined simultaneously. In our study, these effect estimates were attenuated but remained significant in mutually adjusted models. The attenuation is expected because formula supplementation can decrease milk supply or may reflect breastfeeding difficulties, leading to shorter breastfeeding duration[23]; however, our results show that sustained breastfeeding is beneficial even if formula supplementation occurs.

At the Breast Versus in a Bottle: Modes of Human Milk Feeding

We uniquely examined the mode of breast milk feeding, distinguishing bottled breast milk from direct breastfeeding at the breast. Few studies make this distinction, despite increasing trends in milk expression.[9] In our study, over half (55%) of exclusively breastfed infants received some breast milk in a bottle; these infants had "intermediate" BMI *z* scores and weight gain velocities that were higher than infants fed exclusively at the breast, but lower than infants receiving formula. This finding is consistent with evidence that exclusively bottle-fed infants gained more weight than infants fed at the breast, regardless of the milk type (breast milk or formula) in the bottle.[11]

Together, these studies suggest that direct breastfeeding confers the strongest protection against rapid weight gain and overweight, whereas bottled breast milk provides intermediate protection. This has important policy implications because the primary reason for feeding bottled breast milk is returning to work, which is strongly impacted by national and institutional maternity leave policies.

Formula Versus Food: Type and Timing of Complementary Feeding

Another novel aspect of our study is the distinction between partial breastfeeding supplemented with formula versus solid food. At 6 months, almost half (43%) of partially breastfed infants were receiving formula, whereas the remainder were being supplemented with solids only. Compared with exclusive breastfeeding, partial breastfeeding with formula was associated with faster weight gain (aβ: +0.29), higher BMI (aβ: +0.25), and a twofold increased risk of overweight by 12 months, whereas partial breastfeeding without formula (ie, with solids only) was not significantly associated with these outcomes. This is a noteworthy finding because recent evidence indicates that introducing certain "allergenic" foods before 6 months may be beneficial for allergy prevention.[24] The optimal timing for introducing these foods remains to be determined, but our study suggests that introducing solids between 5-6 months does not adversely affect obesity-related outcomes, consistent with a recent review in which researchers concluded there is little evidence of adverse outcomes associated with introducing solids before 6 months in developed countries.[25]

Just 1 Bottle: Brief Formula Supplementation in Hospital

We uniquely investigated the potential consequences of formula supplementation in hospital. Few researchers have addressed this question, yet many neonates briefly receive formula, often without medical indication.[26] In our cohort, a striking 27% of exclusively breastfed infants (according to maternal report) had briefly received formula during the neonatal period. These infants were not significantly different from their exclusively breastfed counterparts in terms of weight gain or BMI at 12 months, suggesting that brief formula

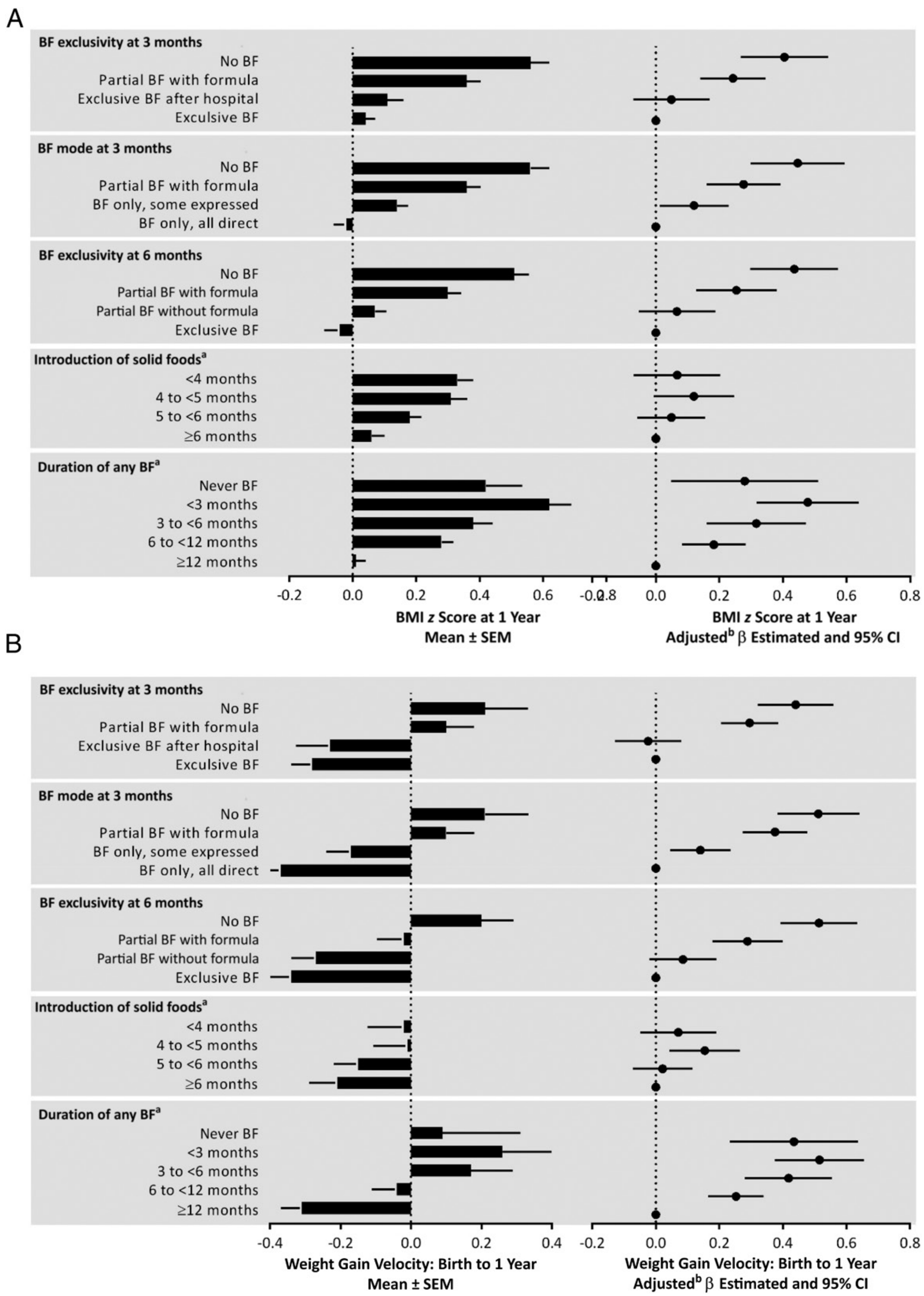

FIGURE 2
Infant feeding, BMI *z* score, and weight gain velocity in the CHILD cohort (*N* = 2553 term infants). A, BMI. B, Weight gain velocity. BF, breastfeeding. [a] Mutually adjusted for each other. [b] Adjusted for study site, maternal age, prepregnancy BMI, ethnicity, education, marital status, smoking during pregnancy, mode of delivery, parity, infant sex, gestational age, and birth weight.

TABLE 4 Association of Infant Feeding With BMI *z* Score and Overweight Risk at 12 Months of Age in the CHILD Cohort

	N	BMI *z* Score at 12 Mo				Overweight at 12 Mo	
		Mean ± SD	Crude	Adjusted[a]	Mutual Feeding Adjustment[b]	*n* (%)	Adjusted[a]
			β (95% CI)	β (95% CI)	β (95% CI)		OR (95% CI)
BF exclusivity at 3 mo			*N* = 2536	*N* = 2353	*N* = 1972		*N* = 2353
No BF	334	0.56 ± 1.08	0.52 (0.39 to 0.65)[c]	0.40 (0.27 to 0.54)[c]	—	32 (9.6)	3.44 (1.95 to 6.09)[c]
Partial BF with formula	646	0.36 ± 1.08	0.32 (0.22 to 0.42)[c]	0.24 (0.14 to 0.35)[c]	0.14 (0.03 to 0.26)[c]	41 (6.3)	1.97 (1.18 to 3.28)[c]
Exclusive BF after hospital	427	0.11 ± 1.04	0.07 (−0.05 to 0.19)	0.05 (−0.07 to 0.17)	0.04 (−0.08 to 0.16)	15 (3.5)	0.87 (0.43 to 1.79)
Exclusive BF	1129	0.04 ± 1.04	0.00 (reference)	0.00 (reference)	0.00 (reference)	36 (3.2)	1.00 (reference)
BF mode at 3 mo			*N* = 2452	*N* = 2278	*N* = 1903		*N* = 2278
No BF	327	0.56 ± 1.08	0.58 (0.44 to 0.72)[c]	0.45 (0.30 to 0.59)[c]	—	31 (9.5)	4.49 (2.23 to 9.07)[c]
Partial BF with formula	626	0.36 ± 1.08	0.38 (0.26 to 0.49)[c]	0.28 (0.16 to 0.39)[c]	0.17 (0.04 to 0.30)[c]	40 (6.4)	2.57 (1.35 to 4.91)[c]
Exclusive BF, some expressed	824	0.14 ± 1.00	0.16 (0.05 to 0.27)[c]	0.12 (0.01 to 0.23)[c]	0.10 (−0.01 to 0.21)	31 (3.8)	1.53 (0.78 to 2.98)
Exclusive BF, all direct	675	−0.02 ± 1.06	0.00 (reference)	0.00 (reference)	0.00 (reference)	17 (2.5)	1.00 (reference)
BF exclusivity at 6 mo			*N* = 2474	*N* = 2294	*N* = 1790		*N* = 2294
No BF	552	0.51 ± 1.07	0.54 (0.41 to 0.67)[c]	0.44 (0.30 to 0.57)[c]	—	46 (8.3)	3.20 (1.58 to 6.51)[c]
Partial BF with formula	639	0.30 ± 1.08	0.34 (0.21 to 0.46)[c]	0.25 (0.13 to 0.38)[c]	0.19 (0.06 to 0.32)[c]	39 (6.1)	2.03 (1.00 to 4.11)[c]
Partial BF without formula	832	0.07 ± 1.03	0.10 (−0.02 to 0.22)	0.07 (−0.05 to 0.19)	0.06 (−0.06 to 0.18)	27 (3.2)	0.93 (0.44 to 1.97)
Exclusive BF	451	−0.04 ± 1.06	0.00 (reference)	0.00 (reference)	0.00 (reference)	11 (2.4)	1.00 (reference)
Introduction of solid foods, mo			*N* = 2447	*N* = 2271	*N* = 2271		*N* = 2271
<4	428	0.33 ± 1.01	0.27 (0.14 to 0.40)[c]	0.16 (0.02 to 0.29)[c]	0.07 (−0.07 to 0.20)	19 (4.4)	1.09 (0.56 to 2.15)
4–<5	480	0.31 ± 1.11	0.24 (0.12 to 0.37)[c]	0.17 (0.04 to 0.29)[c]	0.12 (−0.01 to 0.25)	31 (6.5)	1.45 (0.79 to 2.68)
5–<6	895	0.18 ± 1.09	0.12 (0.01 to 0.23)[c]	0.07 (−0.03 to 0.18)	0.05 (−0.06 to 0.16)	48 (5.4)	1.30 (0.75 to 2.25)
≥6	644	0.06 ± 1.05	0.00 (reference)	0.00 (reference)	0.00 (reference)	22 (3.4)	1.00 (reference)
Duration of any BF, mo			*N* = 2543	*N* = 2357	*N* = 2271		*N* = 2357
Never BF	89	0.42 ± 1.07	0.41 (0.18 to 0.63)[c]	0.27 (0.05 to 0.50)[c]	0.28 (0.05 to 0.51)[c]	6 (6.7)	2.58 (1.00 to 6.62)[c]
<3	245	0.62 ±1.08	0.60 (0.46 to 0.75)[c]	0.48 (0.33 to 0.64)[c]	0.48 (0.32 to 0.64)[c]	26 (10.6)	4.06 (2.21 to 7.45)[c]
3–<6	275	0.38 ± 1.02	0.37 (0.23 to 0.51)[c]	0.29 (0.14 to 0.43)[c]	0.32 (0.16 to 0.47)[c]	16 (5.8)	1.99 (1.02 to 3.86)[c]
6–<12	765	0.28 ± 1.05	0.27 (0.17 to 0.36)[c]	0.19 (0.09 to 0.28)[c]	0.18 (0.08 to 0.28)[c]	41 (5.4)	1.64 (0.98 to 2.74)
≥12	1169	0.01 ± 1.06	0.00 (reference)	0.00 (reference)	0.00 (reference)	36 (3.1)	1.00 (reference)

N's differ between models because of differences in the number of infants with complete feeding data for the different feeding exposures. Sensitivity analyses in which we applied multiple imputation of missing data and propensity score weighting are shown in Supplemental Table 10. BF, breastfeeding; OR, odds ratio. —, not applicable.

[a] Adjusted for study site, maternal age, prepregnancy BMI, ethnicity, education, marital status, smoking during pregnancy, mode of delivery, parity, infant sex, gestational age, and birth wt.

[b] Adjusted for covariates plus introduction of solid foods (models A, B, E) and duration of any BF (models A, B, C, D). Models A, B, C (for BF infants only, to address further BF after 3 or 6 mo), and D.

[c] Significant associations ($P < .05$).

TABLE 5 Association of Infant Feeding With Weight Gain Velocity and Risk of Rapid Weight Gain in the First Year of Life in the CHILD Cohort

	N	Wt Gain Velocity: Change in WFA z Score From Birth to 1 y				Rapid Wt Gain: Velocity >0.67	
		Mean ± SD	Crude	Adjusted[a]	Mutual Feeding Adjustment[b]	n (%)	Adjusted[a]
			β (95% CI)	β (95% CI)	β (95% CI)		OR (95% CI)
BF exclusivity at 3 mo			N = 2527	2358	N = 1975		N = 2358
No BF	337	0.21 ± 1.14	0.49 (0.36 to 0.62)[c]	0.44 (0.32 to 0.56)[c]	—	120 (35.6)	2.70 (1.93 to 3.78)[c]
Partial BF with formula	642	0.10 ± 1.02	0.38 (0.28 to 0.48)[c]	0.30 (0.21 to 0.39)[c]	0.18 (0.08 to 0.28)[c]	170 (26.5)	1.63 (1.24 to 2.12)[c]
Exclusive BF after hospital	428	−0.23 ± 1.02	0.06 (−0.06 to 0.17)	−0.02 (−0.13 to 0.08)	−0.02 (−0.13 to 0.08)	77 (18.0)	0.93 (0.67 to 1.29)
Exclusive BF	1120	−0.28 ± 1.03	0.00 (reference)	0.00 (reference)	0.00 (reference)	193 (17.2)	1.00 (reference)
BF mode at 3 mo			N = 2440	N = 2281	N = 1905		N = 2281
No BF	328	0.21 ± 1.14	0.58 (0.45 to 0.72)[c]	0.51 (0.38 to 0.64)[c]	—	115 (35.1)	2.91 (2.00 to 4.24)[c]
Partial BF with formula	622	0.10 ± 1.01	0.48 (0.36 to 0.59)[c]	0.38 (0.27 to 0.48)[c]	0.25 (0.14 to 0.36)[c]	164 (26.4)	1.83 (1.34 to 2.49)[c]
Exclusive BF, some expressed	819	−0.17 ± 1.02	0.21 (0.10 to 0.31)[c]	0.14 (0.05 to 0.24)[c]	0.12 (0.02 to 0.21)[c]	157 (19.2)	1.22 (0.90 to 1.66)
Exclusive BF, all direct	671	−0.37 ± 1.03	0.00 (reference)	0.00 (reference)	0.00 (reference)	104 (15.5)	1.00 (reference)
BF exclusivity at 6 mo			N = 2464	N = 2294	N = 1790		N = 2294
No BF	551	0.20 ± 1.09	0.54 (0.41 to 0.67)[c]	0.51 (0.39 to 0.63)[c]	—	179 (32.5)	2.34 (1.64 to 3.35)[c]
Partial BF with formula	638	−0.02 ± 1.00	0.31 (0.19 to 0.44)[c]	0.29 (0.18 to 0.40)[c]	0.19 (0.08 to 0.31)[c]	155 (24.3)	1.54 (1.10 to 2.17)[c]
Partial BF without formula	827	−0.27 ± 1.02	0.06 (−0.06 to 0.18)	0.09 (−0.02 to 0.19)	0.07 (−0.04 to 0.17)	136 (16.4)	0.92 (0.66 to 1.30)
Exclusive BF	448	−0.34 ± 1.08	0.00 (reference)	0.00 (reference)	0.00 (reference)	76 (17.0)	1.00 (reference)
Introduction of solid foods, mo			N = 2438	N = 2276	N = 2276		N = 2276
<4	428	−0.02 ± 1.09	0.19 (0.06 to 0.32)[c]	0.18 (0.06 to 0.30)[c]	0.07 (−0.05 to 0.19)	112 (26.2)	1.43 (1.01 to 2.01)[c]
4–<5	483	−0.01 ± 1.09	0.20 (0.07 to 0.32)[c]	0.21 (0.10 to 0.32)[c]	0.15 (0.04 to 0.26)[c]	140 (29.0)	1.86 (1.36 to 2.56)[c]
5–<6	886	−0.15 ± 1.04	0.06 (−0.05 to 0.17)	0.05 (−0.04 to 0.15)	0.02 (−0.07 to 0.12)	165 (18.6)	0.92 (0.69 to 1.23)
≥6	641	−0.21 ± 1.03	0.00 (reference)	0.00 (reference)	0.00 (reference)	122 (19.0)	1.00 (reference)
Duration of any BF, mo			N = 2534	N = 2362	N = 2276		N = 2362
Never BF	91	0.09 ± 1.06	0.40 (0.18 to 0.62)[c]	0.44 (0.24 to 0.64)[c]	0.43 (0.23 to 0.64)[c]	29 (31.9)	2.59 (1.46 to 4.59)[c]
<3	246	0.26 ± 1.16	0.57 (0.43 to 0.71)[c]	0.53 (0.40 to 0.67)[c]	0.52 (0.38 to 0.66)[c]	91 (37.0)	3.36 (2.32 to 4.86)[c]
3–<6	271	0.17 ± 1.00	0.49 (0.35 to 0.62)[c]	0.42 (0.30 to 0.55)[c]	0.42 (0.28 to 0.55)[c]	76 (28.0)	1.96 (1.37 to 2.80)[c]
6–<12	766	−0.04 ± 1.01	0.28 (0.18 to 0.37)[c]	0.26 (0.18 to 0.35)[c]	0.25 (0.17 to 0.34)[c]	181 (23.6)	1.70 (1.30 to 2.20)[c]
≥12	1160	−0.31 ± 1.03	0.00 (reference)	0.00 (reference)	0.00 (reference)	186 (16.0)	1.00 (reference)

N's differ between models because of differences in the number of infants with complete feeding data for the different feeding exposures. Sensitivity analyses in which we applied multiple imputation of missing data and propensity score weighting are shown in Supplemental Table 10. BF, breastfeeding; OR, odds ratio. —, not applicable.

[a] Adjusted for study site, maternal age, prepregnancy BMI, ethnicity, education, marital status, smoking during pregnancy, mode of delivery, parity, infant sex, gestational age, and birth wt.

[b] Adjusted for covariates plus introduction of solid foods (models A, B, E) and duration of any BF (models A, B, C, D). Models A, B, C (for BF infants only, to address further BF after 3 or 6 mo), and D.

[c] Significant associations ($P < .05$).

supplementation at birth does not adversely impact weight gain, so long as the infant is exclusively breastfed after hospital discharge. This is an important caveat because supplementation can discourage or delay breastfeeding initiation[27] and reduce a new mother's confidence in her ability to breastfeed, which may lead to early cessation or sustained supplementation. Further research is needed to determine if brief supplementation influences other processes such as inflammation, immunity, or the gut microbiome.

Mechanisms

Our results suggest that shorter breastfeeding duration, feeding bottled breast milk, and formula supplementation all independently influence infant weight gain, BMI, and overweight risk. Potential mechanisms for these effects include biological differences in the macronutrient profiles of formula versus breast milk[28] or differential effects on the gut microbiota, which are profoundly impacted by formula[29] and contribute to energy absorption and weight gain.[12] In addition, many bioactive components of human milk are absent from formula and may be altered during expression and storage[10]; these include hormones that regulate satiety, microbiota that seed the infant gut, and oligosaccharides that support microbiota development.[30]

Our results also suggest that feeding method is important, which is consistent with evidence that the "baby-led" nature of breastfeeding promotes satiety responsiveness later in childhood.[31] It is thought that differential "programming" of satiety and self-regulation results from bottle-feeding versus breastfeeding because infants fed at the breast actively suckle and self-regulate, whereas those fed from a bottle (regardless of its contents) are more passive and may not learn to appropriately balance energy intake.[11]

Future Directions

The results of this study highlight the importance of documenting detailed information about infant feeding practices and may help explain the inconsistencies observed across previous studies in which these details were not precisely captured. Further work by researchers incorporating these measures (eg, duration, exclusivity, and mode of breastfeeding; type and timing of complementary foods) is required to replicate our observations and determine their generalizability to other settings and populations. Extended analysis of weight gain and body composition is also required to determine if these associations persist and influence obesity later in life.

Additional research is warranted to investigate the potentially differential effects of specific formulas (eg, containing prebiotics or probiotics) and first foods, to establish exposure thresholds (eg, differentiate between "any" and "predominantly" expressed milk feeding), to explore the role of different feeding styles, and to understand and address mothers' motivations and challenges related to infant feeding. Finally, it is important to study and define the causal mechanisms that mediate the observed associations between infant feeding practices, weight gain, and overweight risk. These future directions are essential to inform and optimize infant feeding guidelines and develop effective early-life interventions for obesity prevention, including initiatives to support breastfeeding and alternative solutions for those who cannot be breastfed.

CONCLUSIONS

This study confirms that sustained and exclusive breastfeeding is associated with favorable anthropometric outcomes during infancy, and contributes novel evidence regarding common feeding practices that are rarely addressed in other studies. Firstly, formula supplementation of breastfed infants significantly attenuated the observed associations, whereas complementary feeding of solid foods introduced between 5 and 6 months had no impact. Secondly, feeding expressed breast milk appeared to have a weaker beneficial effect compared with direct feeding at the breast, although expressed milk remained beneficial compared with formula. Finally, brief formula supplementation during the neonatal period did not measurably alter these associations so long as exclusive breastfeeding was established and sustained for at least 3 months. Altogether, this study provides new evidence to inform feeding recommendations and guide further research about infant feeding practices and how they influence the development and prevention of childhood obesity.

ACKNOWLEDGMENTS

We thank all the families who took part in this study and the whole CHILD team, which includes interviewers, nurses, computer and laboratory technicians, clerical workers, research scientists, volunteers, managers, and receptionists. We also thank Dr Atul Sharma and Ms Allison Feely (George and Fay Yee Centre for Healthcare Innovation) for their statistical expertise.

ABBREVIATIONS

aβ: adjusted β estimate
ANOVA: analysis of variance
aOR: adjusted odds ratio
BMI: body mass index
CHILD: Canadian Healthy Infant Longitudinal Development
CI: confidence interval
IQR: interquartile range
WFA: weight-for-age
WHO: World Health Organization

and oversaw the propensity score analyses and reviewed the manuscript; Dr McGavock provided guidance on body composition and obesity measures and reviewed the manuscript; Dr Taylor served as Dr Azad's MSc advisor at the London School of Hygiene and Tropical Medicine, provided guidance on the statistical analyses, and reviewed the manuscript; Drs Sears, Subbarao, Turvey, Becker, Mandhane, and Moraes conceptualized and designed the CHILD cohort, managed participant recruitment and data collection, and critically reviewed the manuscript; Dr Lefebvre managed the CHILD study database and critically reviewed the manuscript; and all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

DOI: https://doi.org/10.1542/peds.2018-1092

Accepted for publication Jun 29, 2018

Address correspondence to Meghan B. Azad, PhD, Children's Hospital Research Institute of Manitoba, 501G - 715 McDermot Ave, Winnipeg, MB R3E 3P4, Canada. E-mail: meghan.azad@umanitoba.ca

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

FINANCIAL DISCLOSURE: Dr Azad's travel expenses were covered by Mead Johnson for an educational presentation about breast milk composition; Medela covered travel expenses for a breast milk conference; the other authors have indicated they have no financial relationships relevant to this article to disclose.

FUNDING: The Canadian Institutes of Health Research and the Allergy, Genes and Environment Network of Centres of Excellence provided core support for the CHILD Study. This research was specifically funded by Research Manitoba. This research was supported, in part, by the Canada Research Chairs program; M.B.A. holds a Canada Research Chair in the Developmental Origins of Chronic Disease. These entities had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; and preparation, review, or approval of the manuscript.

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.

REFERENCES

1. NCD Risk Factor Collaboration (NCD-RisC). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. *Lancet*. 2017;390(10113):2627–2642
2. Symonds ME, Sebert SP, Hyatt MA, Budge H. Nutritional programming of the metabolic syndrome. *Nat Rev Endocrinol*. 2009;5(11):604–610
3. Monteiro PO, Victora CG. Rapid growth in infancy and childhood and obesity in later life–a systematic review. *Obes Rev*. 2005;6(2):143–154
4. Roy SM, Spivack JG, Faith MS, et al. Infant BMI or weight-for-length and obesity risk in early childhood. *Pediatrics*. 2016;137(5):e20153492
5. Simmonds M, Burch J, Llewellyn A, et al. The use of measures of obesity in childhood for predicting obesity and the development of obesity-related diseases in adulthood: a systematic review and meta-analysis. *Health Technol Assess*. 2015;19(43):1–336
6. Victora CG, Bahl R, Barros AJ, et al; Lancet Breastfeeding Series Group. Breastfeeding in the 21st century: epidemiology, mechanisms, and lifelong effect. *Lancet*. 2016;387(10017):475–490
7. Horta BL, Loret de Mola C, Victora CG. Long-term consequences of breastfeeding on cholesterol, obesity, systolic blood pressure and type 2 diabetes: a systematic review and meta-analysis. *Acta Paediatr*. 2015;104(467):30–37
8. Labbok MH, Starling A. Definitions of breastfeeding: call for the development and use of consistent definitions in research and peer-reviewed literature. *Breastfeed Med*. 2012;7(6):397–402
9. Rasmussen KM, Felice JP, O'Sullivan EJ, Garner CD, Geraghty SR. The meaning of "breastfeeding" is changing and so must our language about it. *Breastfeed Med*. 2017;12(9):510–514
10. Chang JC, Chen CH, Fang LJ, Tsai CR, Chang YC, Wang TM. Influence of prolonged storage process, pasteurization, and heat treatment on biologically-active human milk proteins. *Pediatr Neonatol*. 2013;54(6):360–366
11. Li R, Fein SB, Grummer-Strawn LM. Do infants fed from bottles lack self-regulation of milk intake compared with directly breastfed infants? *Pediatrics*. 2010;125(6). Available at: www.pediatrics.org/cgi/content/full/125/6/e1386
12. O'Sullivan A, Farver M, Smilowitz JT. The influence of early infant-feeding practices on the intestinal microbiome and body composition in infants [published correction appears in *Nutr Metab Insights*. 2016;8(suppl 1):87]. *Nutr Metab Insights*. 2015;8(suppl 1):1–9
13. Subbarao P, Anand SS, Becker AB, et al; CHILD Study Investigators. The Canadian Healthy Infant Longitudinal Development (CHILD) study: examining developmental origins of allergy and asthma. *Thorax*. 2015;70(10):998–1000
14. Kramer MS, Kakuma R. Optimal duration of exclusive breastfeeding. *Cochrane Database Syst Rev*. 2012;(8):CD003517
15. WHO Multicentre Growth Reference Study Group. WHO child growth standards based on length/height, weight and age. *Acta Paediatr Suppl*. 2006;450:76–85
16. de Onis M, Lobstein T. Defining obesity risk status in the general childhood population: which cut-offs should we use? *Int J Pediatr Obes*. 2010;5(6):458–460
17. Lefebvre CM, John RM. The effect of breastfeeding on childhood overweight and obesity: a systematic review of the literature. *J Am Assoc Nurse Pract*. 2014;26(7):386–401
18. Guenther PM, Casavale KO, Reedy J, et al. Update of the healthy eating index: HEI-2010. *J Acad Nutr Diet*. 2013;113(4):569–580

19. Chalmers B, Levitt C, Heaman M, O'Brien B, Sauve R, Kaczorowski J; Maternity Experiences Study Group of the Canadian Perinatal Surveillance System, Public Health Agency of Canada. Breastfeeding rates and hospital breastfeeding practices in Canada: a national survey of women. *Birth*. 2009;36(2):122–132
20. Johnson L, van Jaarsveld CH, Llewellyn CH, Cole TJ, Wardle J. Associations between infant feeding and the size, tempo and velocity of infant weight gain: SITAR analysis of the Gemini twin birth cohort. *Int J Obes*. 2014;38(7):980–987
21. Sun C, Foskey RJ, Allen KJ, et al. The impact of timing of introduction of solids on infant body mass index. *J Pediatr*. 2016;179:104–110.e1
22. Kramer MS, Guo T, Platt RW, et al; PROBIT Study Group. Breastfeeding and infant growth: biology or bias? *Pediatrics*. 2002;110(2, pt 1):343–347
23. Chantry CJ, Dewey KG, Peerson JM, Wagner EA, Nommsen-Rivers LA. In-hospital formula use increases early breastfeeding cessation among first-time mothers intending to exclusively breastfeed. *J Pediatr*. 2014;164(6):1339–1345.e5
24. Du Toit G, Sayre PH, Roberts G, et al; Immune Tolerance Network LEAP-On Study Team. Effect of avoidance on peanut allergy after early peanut consumption. *N Engl J Med*. 2016;374(15):1435–1443
25. Daniels L, Mallan KM, Fildes A, Wilson J. The timing of solid introduction in an 'obesogenic' environment: a narrative review of the evidence and methodological issues. *Aust N Z J Public Health*. 2015;39(4):366–373
26. Boban M, Zakarija-Grkovic I. In-hospital formula supplementation of healthy newborns: practices, reasons, and their medical justification. *Breastfeed Med*. 2016;11:448–454
27. Howard CR, Howard FM, Lanphear B, et al. Randomized clinical trial of pacifier use and bottle-feeding or cupfeeding and their effect on breastfeeding. *Pediatrics*. 2003;111(3):511–518
28. Abrams SA, Hawthorne KM, Pammi M. A systematic review of controlled trials of lower-protein or energy-containing infant formulas for use by healthy full-term infants. *Adv Nutr*. 2015;6(2):178–188
29. Laursen MF, Bahl MI, Michaelsen KF, Licht TR. First foods and gut microbes. *Front Microbiol*. 2017;8:356
30. Ballard O, Morrow AL. Human milk composition: nutrients and bioactive factors. *Pediatr Clin North Am*. 2013;60(1):49–74
31. Brown A, Lee M. Breastfeeding during the first year promotes satiety responsiveness in children aged 18-24 months. *Pediatr Obes*. 2012;7(5):382–390

PEDIATRICS®
OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Infant Feeding and Weight Gain: Separating Breast Milk From Breastfeeding and Formula From Food

Meghan B. Azad, Lorena Vehling, Deborah Chan, Annika Klopp, Nathan C. Nickel, Jonathan M. McGavock, Allan B. Becker, Piushkumar J. Mandhane, Stuart E. Turvey, Theo J. Moraes, Mark S. Taylor, Diana L. Lefebvre, Malcolm R. Sears, Padmaja Subbarao and on behalf of the CHILD Study Investigators

Pediatrics originally published online September 24, 2018;