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Breast-feeding, rapid growth in the first year of life and excess weight at the age of 2 years: the 3D Cohort Study

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Abstract

Objective: To assess relationships between breast-feeding, rapid growth in the first year of life and overweight/obesity status at the age of 2 years.

Design: As part of an observational, longitudinal study beginning in early pregnancy, multivariable logistic regressions were used to assess associations between breast-feeding duration (total and exclusive) and rapid weight gain (RWG) between birth and 1 year of age, and to determine predictors of overweight/obesity status at the age of 2 years.

Setting: Nine hospitals located in the province of Quebec, Canada.

Participants: A sample of 1599 term infants who participated in the 3D Cohort Study.

Results: Children having RWG in the first year and those having excess weight at the age of 2 years accounted for 28 % and < 10 %, respectively. In multivariable models, children breastfed < 6 months and from 6 months to < 1 year were, respectively, 2·5 times (OR 2·45; 95 % CI 1·76, 3·41) and 1·8 times (OR 1·78; 95 % CI 1·29, 2·45) more likely to show RWG up to 1 year of age compared to children breastfed ≥ 1 year. Children exclusively breastfed < 3 months had significantly greater odds of RWG in the first year (OR 1·94; 95 % CI 1·25, 3·04) compared to children exclusively breastfed for ≥ 6 months. Associations between breast-feeding duration (total or exclusive) and excess weight at the age of 2 years were not detected. RWG in the first year was found to be the main predictor of excess weight at the age of 2 years (OR 6·98; 95 % CI 4·35, 11·47).

Conclusions: The potential beneficial effects of breast-feeding on rate of growth in the first year of life suggest that interventions promoting breast-feeding are relevant for obesity prevention early in life.

Keywords
Infancy
Breast-feeding duration
Rapid weight gain
Overweight or obesity
Longitudinal study
Early-life factors

The first 1000 d of life (i.e. from conception to 2 years of age) constitute a period when human beings are exposed to influences that may have long-lasting effects on health[1,2]. Since obesity has become a major public health concern worldwide[3,4], identifying how modifiable early-life risk factors influence young children's weight status is of utmost importance for designing relevant prevention initiatives as early as possible. Children who experienced rapid growth in infancy or who were already overweight in their early years appear to be at higher risk of excess weight later in life[5–7].

Infant feeding practices are among modifiable early-life factors that have the potential to influence both the rate of growth and weight status during the first 2 years[6,8]. Both the WHO and Canadian public health and professional organisations have made recommendations on infant feeding that include exclusive breast-feeding for the first 6 months of life and continuous breast-feeding thereafter,

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up to the age of 2 years or older, along with the gradual introduction of complementary foods[1,9]. Although breast-feeding has a number of known benefits, controversies regarding its role in preventing overweight and obesity persist[10,11]. Over the years, numerous studies have examined the relationship between breast-feeding and weight status during childhood, adolescence and even later[12–18]. Few studies, however, have investigated this association in children aged as young as 2 years while taking breast-feeding recommendations and early growth into account. The present study will assess the relationship between breast-feeding duration on the one hand and rapid growth in the first year of life and overweight/obesity status at the age of 2 years on the other hand, while considering other important early-life risk factors (i.e. infant sex, birth weight and gestational age at birth; maternal smoking during pregnancy; gestational diabetes; prepregnancy maternal weight status; caesarian delivery; parity; maternal age, education and immigrant status; and household income). We hypothesise that breast-feeding practices that comply with current guidelines during the first year (i.e. exclusive breast-feeding for 6 months and continuous breast-feeding thereafter) have protective effects on rapid growth during the first year and on overweight and obesity at the age of 2 years.

Materials and methods

Study population

Our study relies on data collected as part of the 3D Cohort Study, an observational, longitudinal study that covers the prenatal period. Details about rationale and objectives, recruitment, and data collection procedures were reported in an earlier publication[19]. In brief, the 3D Cohort Study enrolled 2366 pregnant women from May 2010 to August 2012. The women received care in nine urban obstetric clinics in the province of Quebec, Canada. The study was designed primarily to investigate how exposures to various risk factors during pregnancy were related both to adverse birth outcomes and to health status and early childhood development. An exhaustive array of prenatal and neonatal data was collected in the first, second and third trimesters of pregnancy and at delivery. The children participated in postnatal follow-up assessments at 3 months, 1 year and 2 years.

Our analyses exclude children with gestational ages < 37 weeks at birth. Overall, the study includes 1599 term infants for whom detailed information on growth in the first year and/or weight status at the age of 2 years (Fig. 1) was available. A comparison of maternal characteristics in the original cohort indicates that the sample selected for analysis included fewer mothers with low educational attainment (secondary school or less: 7 % *v.* 10 %, $P = 0{\cdot}004$) and low-income levels (< $60 000: 27 % *v.* 32 %, $P = 0{\cdot}008$), as well as fewer immigrant mothers (30 % *v.* 35 %; $P = 0{\cdot}003$). Our analyses did not detect significant differences for other perinatal characteristics such as maternal age, parity, gestational diabetes, maternal smoking during pregnancy, maternal overweight/obesity status, mode of delivery, infant sex and birth weight (see online supplementary material, Supplemental Table 1).

Infant feeding practices

We obtained data on feeding practices from face-to-face interviews with mothers during the first two postnatal visits, which occurred at approximately 3 months and 1 year of age. On both occasions, the same series of questions were asked about breast-feeding initiation and duration. Questions concerning the introduction of commercial infant formula, other kinds of milk and complementary foods were also included in the interviews. Data collected retrospectively during the first year of life made it possible to derive categorical variables relating to (1) *total breast-feeding duration* (i.e. the period when the child received breast milk, whether or not other liquids or solids were also offered to the child), and (2) *exclusive breast-feeding duration* (i.e. the period when the child was fed only breast milk, to the exclusion of all other foods and liquids, such as water, infant formula, cow's milk and other beverages).

Anthropometric measurements

Birth weight was obtained from birth records. During postnatal visits, children's weight and length/height were measured according to a standardised protocol, using a medical scale and infantometer (for length in the first year) or stadiometer (for height at the age of 2 years). For both weight and height, two measures were taken. A third measure was added if the difference between the first two measures was ≥ 0·5 kg and ≥ 0·5 cm, respectively. The mean of the two nearest measures was used. Growth velocity during the first year was determined from differences between weight-for-age z-scores (WAZ; using WHO standards)[20] at 12 months and at birth. Differences > 0·67 SD were considered to indicate accelerated growth or rapid weight gain (RWG)[21]. BMI (weight(kg)/height(m)^2) at the age of 2 years was calculated based on measured weight and height data. Overweight/obesity status was determined both according to the age- and sex-specific cut-offs for BMI established by the International Obesity Task Force (IOTF)[22] and according to WHO Child Growth Standards (using BMI-for-age z-score > 2)[20].

Covariates

Our analyses considered various perinatal and developmental risk factors potentially related to infant feeding practices, accelerated infant growth and childhood overweight/obesity. These include maternal smoking during pregnancy, gestational diabetes, prepregnancy overweight/obesity status (BMI ≥ 25, derived from reported weight before pregnancy and height measured at first prenatal

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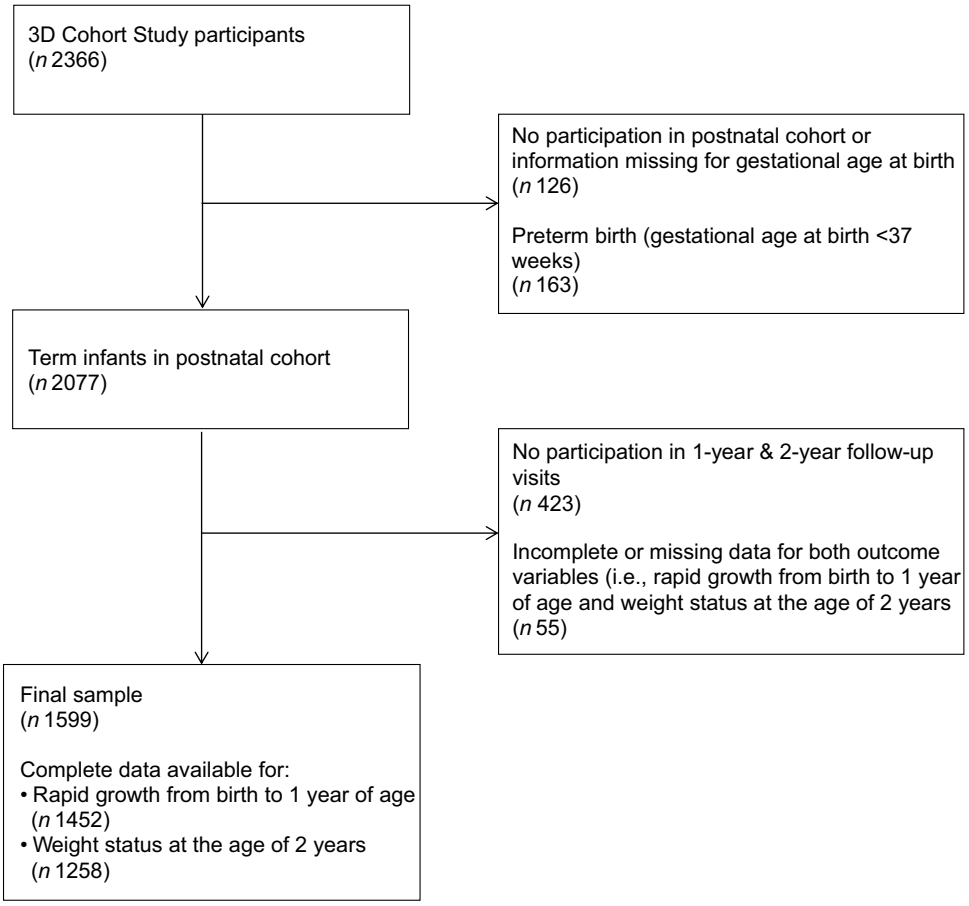

Fig. 1 Flow chart of 3D Cohort Study participants included in analyses

visit), mode of delivery, parity, mother's age at first prenatal visit, immigrant status (derived from reported birthplace), and education attainment (highest level reported at first prenatal visit), and annual household income. Other covariates pertaining to children include infant sex, gestational age at birth and birth weight.

Statistical analyses

Sociodemographic and anthropometric characteristics of children in the first 2 years of life were summarised using descriptive statistics, including mean and standard deviation, frequencies and percentages. Associations between categorical variables were assessed using univariate logistic regression. Multivariable logistic regressions were used to examine the association between breast-feeding practices and rapid growth in the first year of life, while also considering other important early-life risk factors, and to explore predictors of overweight/obesity status at the age of 2 years. Multicollinearity among covariates was evaluated using a generalised variance inflation factor[23]. To select a parsimonious model, we examined the univariable association between each risk factor and the outcome. Variables where the *P*-value was < 0·2, based on the likelihood ratio test, were selected for consideration in building the final model. Model selection was then carried out to minimise Akaike information criterion in a stepwise manner. All variables were tested for significant interactions. We also examined missing data patterns. In our primary analyses, individuals for whom selected covariate data were missing were removed before regression analysis. We also performed a sensitivity analysis, which allowed imputing missing values to covariates using an iterative imputation method (missForest)[24–26]. The associations between risk factors and outcomes of interest in the final models were reported as adjusted OR with 95 % CI and associated *P*-values. The significance level was set at 0·05. All the analyses were performed using R Statistical Software 3.5.0[27].

Results

Table 1 presents anthropometric characteristics of the participants (*n* 1599) over the first 2 years of life. Mean and standard deviation for birth weight were 3430 g (435); few children had birth weights lower than 2500 g (1 % of the sample), whereas 9 % had birth weights greater than 4000 g. More than a quarter (28 %) of the sample

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Table 1 Anthropometric characteristics of children in the first 2 years of life (*n* 1599)

	n	Mean	SD	%	95 % CI
Birth					
Gestational age (weeks)*	1599	39·2	1·1		
Weight (g)†	1599	3430	435		
Length (cm)	1456	51·3	2·4		
Postnatal visit – age 1 year‡					
Age (years)	1452	1·0	0·06		
Weight (kg)	1452	9·8	1·1		
Length (cm)	1446	75·3	2·8		
WAZ§	1452	0·33	0·95		
RWG – birth to 1 year‖					
No	1049			72·2	69·9, 74·5
Yes	403			27·8	25·5, 30·1
Postnatal visit – age 2 years¶					
Age (years)	1258	2·1	0·18		
Weight (kg)	1258	12·6	1·5		
Height (cm)	1258	87·1	3·7		
BMI**	1258	16·5	1·3		
BMI z-score§	1258	0·53	0·97		
Overweight or obese – IOTF criteria††					
No	1142			90·8	89·0, 92·3
Yes	116			9·2	7·7, 10·9
Overweight or obese – WHO definition‡‡					
No	1190			94·6	93·2, 95·7
Yes	68			5·4	4·3, 6·8

WAZ, weight-for-age z-score; RWG, rapid weight gain; IOTF, International Obesity Task Force.
*Term infants (≥ 37 weeks).
†Low birth weight (< 2500 g), *n* 17 (1·1 %); high birth weight (> 4000 g), *n* 145 (9·1 %).
‡Children with complete data for the rate of growth between birth and 1 year of age (*n* 1452).
§According to WHO Child Growth Standards[20].
‖Difference in WAZ (birth to 1 year of age) above 0·67.
¶Children with complete data for overweight/obesity status at the age of 2 years (*n* 1258).
**Weight (kg)/height $(m)^2$.
††Age- and sex-specific cut-offs for BMI[22].
‡‡BMI-for-age z-score (according to WHO Standards[20]) > 2.

showed RWG in their first year of life, although less than one child in ten was overweight or obese at the age of 2 years (9 % according to IOTF criteria; 5 % according to the WHO definition).

Table 2 presents other characteristics of the study sample, including infant feeding practices. Almost all children in the study were breastfed at least once; only 3·3 % were never breastfed. A majority of the children were breastfed for 6 months or more (69 %) and about half of those (34 % of the sample) were breastfed throughout the first year. Nevertheless, exclusive breast-feeding for 6 months, as recommended by WHO, was reported for only about 17 % of the children. Overall, longer durations of exclusive breast-feeding were associated with total breast-feeding that continued beyond the first year ($P < 0·05$, data not shown). Both total and exclusive breast-feeding durations were negatively associated with RWG in the first year ($P < 0·001$). We did not, however, detect any association between breast-feeding duration (whether total or exclusive) and overweight/obesity status at the age of 2 years (whether based on IOTF or WHO definitions).

No multicollinearity among the covariates was identified. We also examined interactions among covariates; none was significant and thus not presented. Based on multivariable logistic regression analyses, breast-feeding appears to be an important and independent protective factor for rapid growth in infancy (Table 3). After controlling for selected covariates, children breastfed for less than 6 months, and those breastfed from 6 months up to a year were 2·5 times (OR 2·45; 95 % CI 1·76, 3·41) and 1·8 times (OR 1·78; 95 % CI 1·29, 2·45) more likely, respectively, to show RWG up to 12 months compared with children breastfed for at least 1 year. Similarly, those who were exclusively breastfed for less than 3 months had significantly greater odds of RWG in the first year (OR 1·94 to 1·96; 95 % CI 1·25, 3·04) compared with children exclusively breastfed for 6 months (as recommended). Considering total and exclusive breast-feeding practices together, the odds of having accelerated growth throughout the first year were 2·5 times greater (OR 2·50; 95 % CI 1·57, 4·11) among children breastfed less than 1 year *and* exclusively breastfed for less than 6 months, compared with children fed in accordance with breast-feeding recommendations.

Other independent predictors of RWG in the first year were lower gestational age at birth (< 39 weeks compared to ≥ 39 weeks; e.g. OR 2·64; 95 % CI 2·02, 3·46 in Model I); younger maternal age (19–24 years compared to 25–34 years; e.g. OR 1·75; 95 % CI 1·07, 2·83 in Model I); maternal immigrant status (relative to being born in Canada; e.g. OR 1·54; 95 % CI 1·16, 2·05 in Model I) and maternal

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Table 2 Rapid weight gain in the first year and overweight/obesity status at the age of 2 years by selected characteristics*

	Study sample (*n* 1599)		RWG from birth to 1 year of age†		Overweight/obese at the age of 2 years (IOTF)‡,§		Overweight/obese at the age of 2 years (WHO)‡,‖	
	n	%	%	*P*-value	%	*P*-value	%	*P*-value
Maternal age¶				0·008		0·334		0·992
19–24 years	98	6·1	41·6		14·1		5·6	
25–34 years	1158	72·6	26·3		8·8		5·5	
≥ 35 years	339	21·3	28·8		9·0		5·6	
Missing	4	–						
Maternal education				0·756		0·298		0·374
Secondary school diploma or less	117	7·4	26·0		12·9		8·2	
Higher than secondary school diploma	1471	92·6	27·9		8·9		5·3	
Missing	11	–						
Household income (CAD)				0·046		0·123		0·407
< $60 000	420	27·4	31·6		11·5		6·7	
≥ $60 000	1114	72·6	25·9		8·3		5·2	
Missing	65	–						
Mother's immigrant status				0·031		0·235		0·500
Non-immigrant	1114	69·8	26·2		8·6		5·2	
Immigrant	483	30·2	32·0		11·0		6·3	
Missing	2	–						
Parity				< 0·001		0·677		0·738
0	881	55·1	31·6		8·8		5·2	
1+	718	44·9	22·9		9·7		5·8	
Mode of delivery				0·769		0·028		0·039
Vaginal	1187	74·3	27·5		8·1		4·6	
Cesarean	410	25·7	28·5		12·4		7·9	
Missing	2	–						
Maternal smoking during pregnancy				0·156		0·750		1·000
No	1389	87·1	27·1		9·1		5·5	
Yes	206	12·9	32·4		10·3		5·8	
Missing	4	–						
Gestational diabetes				0·157		0·672		0·139
No	1448	90·8	27·1		9·1		5·2	
Yes	147	9·2	33·3		10·8		9·0	
Missing	4	–						
Overweight/obese before pregnancy**				0·069		0·001		0·015
No	1061	70·2	26·3		7·4		4·4	
Yes	451	29·8	31·3		13·4		8·0	
Missing	87	–						
Infant sex				0·221		0·580		0·082
Boy	801	50·1	26·2		9·7		6·6	
Girl	798	49·9	29·3		8·7		4·3	
Gestational age at birth				< 0·001		0·938		0·469
37–< 39 weeks	423	26·5	43·3		9·5		6·4	
≥ 39 weeks	1176	73·5	22·4		9·1		5·2	
Birth weight				< 0·001		0·001		0·003
≤ 4000 g	1454	90·9	29·6		8·3		4·8	
> 4000 g	145	9·1	9·8		17·8		11·9	
Total breast-feeding duration				< 0·001		0·778		0·319
< 6 months (incl. no breast-feeding††)	468	31·0	36·5		9·7		5·6	
6–< 12 months	530	35·1	28·2		9·5		6·6	
≥ 12 months	511	33·9	19·7		8·3		4·2	
Missing	90	–						
Exclusive breast-feeding duration				< 0·001		0·362		0·432
< 1 month (incl. no breast-feeding)	572	37·4	34·7		9·4		5·6	
1–< 3 months	260	17·0	31·0		12·0		7·7	
3–< 6 months	445	29·1	22·1		7·6		4·4	
≥ 6 months	252	16·5	20·3		8·5		5·3	
Missing	70							

RWG, rapid weight gain; IOTF, International Obesity Task Force; CAD, Canadian Dollar.
*Based on univariate logistic regression.
†Children with complete data for rate of growth between birth and age 1 (*n* 1452).
‡Children with complete data for overweight/obesity status at age 2 (*n* 1258).
§Age- and sex-specific cut-offs for BMI[22].
‖BMI-for-age z-score (according to WHO Standards[20]) > 2.
¶Mean (SD): 31·5 (4·4).
**BMI ≥ 25, derived from reported weight before pregnancy and height measured at the first prenatal visit.
††No breast-feeding, *n* 50 (3·3 %).

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Table 3 OR and 95 % CI for rapid weight gain in first year by breast-feeding practices and significant covariates*

		OR	95 % CI	*P*-value
Model I: RWG in the first year as the outcome and total breast-feeding duration as the key exposure (*n* 1369)				
(Intercept)		0·17	0·12, 0·23	< 0·001
Total breast-feeding duration	≥ 12 months	1·00	–	
	6 months–< 12 months	1·78	1·29, 2·45	< 0·001
	< 6 months	2·45	1·76, 3·41	< 0·001
Overweight/obese before pregnancy†	No	1·00	–	
	Yes	1·34	1·02, 1·76	0·034
Parity	0	1·00	–	
	1+	0·61	0·47, 0·79	< 0·001
Maternal age	25–34 years	1·00	–	
	19–24 years	1·75	1·07, 2·83	0·024
	≥ 35 years	1·23	0·90, 1·68	0·195
Mother's immigrant status	Non-immigrant	1·00	–	
	Immigrant	1·54	1·16, 2·05	0·003
Gestational age at birth	≥ 39 weeks	1·00	–	
	37–< 39 weeks	2·64	2·02, 3·46	< 0·001
Birth weight	≤ 4000 g	1·00	–	
	> 4000 g	0·32	0·17, 0·56	< 0·001
Model II: RWG in the first year as the outcome and exclusive breast-feeding duration as the key exposure (*n* 1366)				
(Intercept)		0·19	0·13, 0·28	< 0·001
Exclusive breast-feeding duration	≥ 6 months	1·00	–	
	3–< 6 months	1·23	0·82, 1·87	0·324
	1–< 3 months	1·94	1·25, 3·04	0·004
	< 1 month (or no breast-feeding)	1·96	1·33, 2·90	0·001
Overweight/obese before pregnancy†	No	1·00	–	
	Yes	1·38	1·05, 1·81	0·021
Parity	0	1·00	–	
	1+	0·62	0·47, 0·80	< 0·001
Maternal age	25–34 years	1·00	–	
	19–24 years	1·79	1·10, 2·90	0·018
	≥ 35 years	1·15	0·84, 1·56	0·392
Mother's immigrant status	Non-immigrant	1·00	–	
	Immigrant	1·36	1·03, 1·79	0·031
Gestational age at birth	≥ 39 weeks	1·00	–	
	37–< 39 weeks	2·56	1·96, 3·35	< 0·001
Birth weight	≤ 4000 g	1·00	–	
	> 4000 g	0·31	0·16, 0·55	< 0·001
Model III: RWG in the first year as the outcome and a combination of breast-feeding durations as the key exposure (*n* 1365)				
(Intercept)		0·15	0·09, 0·24	< 0·001
Combination of breast-feeding durations	≥ 12 months total & ≥ 6 months exclusive	1·00	–	
	≥ 12 months total & < 6 months exclusive	1·23	0·73, 2·11	0·447
	< 12 months total & ≥ 6 months exclusive	1·58	0·80, 3·09	0·181
	< 12 months total & < 6 months exclusive	2·50	1·57, 4·11	< 0·001
Overweight/obese before pregnancy†	No	1·00	–	
	Yes	1·38	1·05, 1·81	0·021
Parity	0	1·00	–	
	1+	0·61	0·47, 0·79	< 0·001
Maternal age	25–34 years	1·00	–	
	19–24 years	1·72	1·05, 2·79	0·029
	≥ 35 years	1·24	0·90, 1·69	0·188
Mother's immigrant status	Non-immigrant	1·00	–	
	Immigrant	1·55	1·17, 2·06	0·003
Gestational age at birth	≥ 39 weeks	1·00	–	
	37–< 39 weeks	2·66	2·03, 3·49	< 0·001
Birth weight	≤ 4000 g	1·00	–	
	> 4000 g	0·32	0·16, 0·56	< 0·001

RWG, rapid weight gain; AIC, Akaike information criterion.
*Covariates considered in the multivariable logistic regression analyses: maternal age, maternal education, household income, mother's immigrant status, parity, mode of delivery, maternal smoking during pregnancy, gestational diabetes, overweight status before pregnancy, infant sex, gestational age at birth and birth weight. In order to select a parsimonious model, we examined the univariable association between each risk factor and the outcome. Variables where the *P*-value was < 0·2, based on the likelihood ratio test, were selected for consideration in building the final model. Model selection was then carried out to minimise AIC in a stepwise manner. All variables were tested for significant interactions; none were significant. Individuals with incomplete values for selected covariates were removed before undertaking regression analyses.
†BMI ≥ 25, derived from reported weight before pregnancy and height measured at the first prenatal visit.

overweight/obesity before pregnancy (relative to not having excess weight; e.g. OR 1·34; 95 % CI 1·02, 1·76 in Model I). Conversely, children born with high birth weights (> 4000 g relative to others; e.g. OR 0·32; 95 % CI 0·17, 0·56 in Model I) and those who were not first-born children (relative to infants of primiparous mothers; e.g. OR 0·61; 95 % CI 0·47, 0·79 in Model I) appeared to be less prone to RWG in the first year.

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Table 4 OR and 95 % CI for overweight/obesity at the age of 2 years (IOTF criteria) by rapid weight gain and significant covariates (*n* 1047)*

Characteristics		OR	95 % CI	*P*-value
(Intercept)		0·06	0·03, 0·13	< 0·001
RWG in the first year of life	No	1·00		
	Yes	6·98	4·35, 11·47	< 0·001
Overweight/obese before pregnancy†	No	1·00	–	
	Yes	1·80	1·14, 2·82	0·011
Maternal education: Secondary school diploma or less	No	1·00	–	
	Yes	2·33	1·03, 5·00	0·032
Birth weight	≤ 4000 g	1·00	–	
	> 4000 g	4·71	2·46, 8·85	< 0·001

IOTF, International Obesity Task Force; RWG, rapid weight gain; AIC, Akaike information criterion.
*Covariates considered in the multivariable logistic regression analyses: breast-feeding variables, maternal age, maternal education, household income, mother's immigrant status, parity, mode of delivery, maternal smoking during pregnancy, gestational diabetes, overweight status before pregnancy, infant sex, gestational age at birth and birth weight. In order to select a parsimonious model, we examined the univariable association between each risk factor and the outcome. Variables where the *P*-value was < 0·2, based on the likelihood ratio test, were selected for consideration in building the final model. Model selection was then carried out to minimise AIC in a stepwise manner. All variables were tested for significant interactions; none were significant. Individuals with incomplete values for selected covariates were removed before undertaking regression analyses.
†BMI ≥ 25, derived from reported weight before pregnancy and height measured at the first prenatal visit.

As shown in Table 4, accelerated growth in the first year of life appears to be a major independent predictor of overweight or obesity at the age of 2 years (based on IOTF criteria). Similar results related to overweight/obesity status based on the WHO definition are presented in Supplemental Table 2. For children showing RWG between birth and 1 year, the odds of having excess weight by the age of 2 years were seven times greater than that of other children (OR 6·98; 95 % CI 4·35, 11·47). Similarly, children born with high birth weights (relative to others; OR 4·71; 95 % CI 2·46, 8·85), and those born to overweight or obese mothers (relative to others; OR 1·80; 95 % CI 1·14, 2·82), or to mothers who had earned a secondary school diploma or less (OR 2·33; 95 % CI 1·03, 5·00) had greater odds of being overweight or obese at the age of 2 years (based on IOTF criteria). However, overweight/obesity status before pregnancy and level of maternal education are not significantly associated with overweight/obesity at the age of 2 years under the WHO definition.

Concerning the sensitivity analysis, none of the data-based model fits deviated substantially, after imputing missing values to the covariates, from results based on complete-case analyses, as indicated by the results presented in Supplemental Tables 3 and 4.

Discussion

The present study assesses associations between various early-life factors and excess weight at the age of 2 years among children in the 3D Cohort, with particular emphasis on breast-feeding and growth rates in the first year. Upon analysing an extensive array of maternal and infant characteristics, we noted that major predictors of excess weight during the first 1000 d were (in decreasing order of importance) RWG in the first year of life and high birth weight (based on IOTF and WHO definitions of overweight/obesity at the age of 2 years), and low maternal educational attainment and maternal overweight or obesity before pregnancy (based on IOTF definition of overweight/obesity at the age of 2 years). We did not detect any direct independent associations between total and exclusive breast-feeding durations and overweight/obesity status at the age of 2 years. Nevertheless, breast-feeding exclusively for 6 months as recommended (compared to < 3 months) and prolonged total breast-feeding for at least 12 months (compared to < 12 months) were inversely associated with RWG in the first year.

Few large-scale longitudinal studies have examined whether compliance with current breast-feeding recommendations (i.e. prolonged total breast-feeding and exclusive breast-feeding for 6 months) confers weight-status advantages by the age of 2 years, while also considering other early-life factors, particularly rapid growth in infancy. As for prolonged breast-feeding, a longitudinal study (*n* 878) conducted in Australia found that children who were breastfed for at least 12 months had lower odds of being overweight or obese at 29 months (mean age) compared to children breastfed for less than 17 weeks or not at all (OR 0·49; 95 % CI 0·27, 0·90)[28]. Similarly, a German cohort study (*n* 855) found that exclusive breast-feeding for at least 6 months (compared with less than 3 months; OR 0·40; 95 % CI 0·20, 0·90) had a protective effect on overweight and obesity at the age of 2 years[29]. Both studies included adjustments for a number of prenatal factors and maternal characteristics, but neither considered infancy growth rates. Our findings, however, are in agreement with the results of two other large-scale cohort studies that found no association between breast-feeding duration and overweight[30,31] or risk of overweight[31] at the age of 2 years. Interestingly, both prospective studies (conducted in the Netherlands) reported an association between longer

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breast-feeding duration and slower growth in infancy (relative to absolute weight gain in the first year[30] and growth rates between 3 and 6 months of age[31]).

In the last two decades, an extensive literature has explored the relation between breast-feeding and excess weight later in life[12–18]. However, heterogeneity in study design, outcome measures and exposure definition may have contributed to inconsistent results[11,13,15]. When considering the methodological aspects of published studies, weaker associations were observed in larger-scale longitudinal studies and in those incorporating more extensive adjustments for potential confounders, particularly socio-economic factors, birth weight, gestational age and parental weight status[13]. Such characteristics could apply to the present study, which may partly explain why we did not detect significant associations. Inadequate statistical power, however, cannot be excluded, considering the relatively low prevalence (< 10 %) at the age of 2 years of overweight/obesity in our sample.

The association between accelerated growth in infancy and overweight or obesity later in life is, by contrast, well established[5–7,32]. Indeed, we found RWG in the first year of life to be the main predictor of excess weight at the age of 2 years. Following up on patterns of growth in infancy in order to monitor, and ideally to prevent, accelerated growth remains an important strategy in early-life interventions designed to promote a healthy weight later in life. This strategy is especially relevant considering that BMI at the age of 2 years has been found to be a predictor of BMI at the age of 8 years[33]. By the end of the first year of life, the propensity for excess weight may, in fact, already be determined for the most part[34,35].

The notion that breast-feeding might be a modifiable factor that contributes to healthy growth during infancy is also widely accepted. Indeed, WHO Child Growth Standards are based on the growth patterns of breastfed children, which served as normative models of growth[20]. Compared to formula-fed infants, breastfed infants tend to have, overall, slower growth trajectories up to the age of 1 year[36,37]. By extension, our findings are consistent with those of other studies reporting that shorter-duration breast-feeding and, conversely, earlier introduction of commercial infant formula were associated with increased growth rates in infancy[31,38,39]. Nevertheless, because feeding practices and infant growth patterns might mutually influence each other over time, our research results may be correlational rather than causal. Indeed, some researchers have proposed a 'reverse causality' hypothesis[40,41], whereby a child who is growing too fast might be more likely to show signs of hunger. Such an outcome could actually accelerate the weaning process or lead to the discontinuation of exclusive breast-feeding.

Investigating potential reverse causality requires that anthropometric measurements precede changes in breast-feeding status[40]. Based on the model that Kramer *et al.* (2011)[40] employed in a much larger study (*n* 17 046), we carried out exploratory analyses of children who participated in the 3D Cohort Study, who were still being breastfed at 3 months, and for whom complete data were available for computing WAZ (based on WHO standards) at the time of the 3-month follow-up visit. We determined infant size at the age of 3 months according to three categories: small (WAZ < −1), normal (WAZ = −1 to 1) and large (WAZ > 1). We also measured RWG between birth and 3 months (based on criteria described in the method section for the first year). No significant association between infant size at 3 months and weaning after 3 months, up to 6 months, was found (data not shown). At 6 months, however, discontinuity in exclusive breast-feeding was higher among smaller infants compared to larger babies (72 % *v.* 53 %; $P = 0{\cdot}028$, based on χ^2 tests of association). This last result is consistent with observations made by Kramer *et al.* (2011)[40]. It suggests that mothers of smaller infants may perceive that their child is not growing properly and that maternal milk alone will not be sufficient to meet nutritional needs, thus predisposing to earlier introduction of formula or other complementary foods. In other words, in this case, patterns of growth may have determined exclusive breast-feeding duration. Still, we did not detect an association between RWG in the first 3 months and weaning (or discontinuity of exclusive breast-feeding) after 3 months, up to 6 months. Altogether, these results support the idea that prolonged total breast-feeding, at least, may prove protective against rapid growth in the first year of life.

The other independent predictors of overweight or obesity at the age of 2 years (identified in the present study as high birth weight, low maternal educational attainment, and maternal overweight or obesity) have been recognised in various reviews and meta-analyses as key risk factors for childhood obesity[32,42,43]. We found that children born with high birth weights (> 4000 g) were not likely to manifest RWG in the first year, yet were nevertheless more likely to have excess weight at the age of 2 years, independent of other covariates, including gestational diabetes, gestational age at birth and maternal overweight/obesity. Although genetics may account for some of the variability in birth weight[44], certain modifiable determinants of intrauterine growth (e.g. prenatal nutrition, gestational weight gain) have likely played a role and thus ought to be considered in preventive interventions. Similarly, the influence that low levels of educational attainment have on overweight/obesity status among young children highlights the necessity of reducing socio-economic and health status inequalities. Finally, although genetics and *in utero* programming processes may partially explain the influence that excess maternal weight has on childhood overweight and obesity, shared familial environments likely also play a major role[45]. Interventions promoting healthy weight among women of childbearing age, particularly those of low socio-economic status, will remain decisive in countering intergenerational obesity cycles[46]. Similarly,

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interventions targeting children of immigrants and of younger mothers, as well as early terms and first-born children, all of whom were found to be more prone to RWG, appear relevant.

This study relies on a longitudinal study design with a relatively large sample size. It has collected high-quality data that subsume a host of prenatal and early-life characteristics. Anthropometric data were obtained by direct measurement, based on a standardised protocol. Moreover, we used two definitions to assess overweight/obesity status at the age of 2 years. Infant feeding information was collected at two points in time during the first year of life, which minimises memory biases. The analyses took into account two key infant feeding indicators that accord with current guidelines: exclusive breast-feeding for 6 months and continued total breast-feeding (≥ 12 months)[47]. We also adopted a strict definition of exclusive breast-feeding that corresponds with the WHO definition – an approach that is rarely considered in published studies.

Although residual confounding is not impossible, we have attempted to minimise it by incorporating major potential confounders in our analyses. Still, other dietary factors beyond breast-feeding may have played a role in children's growth and weight status throughout the first 2 years (e.g. consumption of sugary drinks and ultra-processed food, consumption of vegetables and fruit). Because we did not collect detailed dietary intake information before the age of 2 years, our analyses could not take these dietary factors into account, which is a study limitation. However, age of introduction of cow's milk and of complementary foods (including cereal, fruit, vegetables, juice and meat) was assessed. In both cases, we did not detect any association with a RWG in the first year, nor with overweight status at the age of 2 years.

Attrition and missing data remain a source of concern in cohort studies; these limitations should be taken into consideration when generalising results. As for the treatment of missing data, we have recurred to the 'listwise deletion' technique, which deletes cases containing missing data in variables of relevance to the analysis being carried out, thereby avoiding potential biases in our analyses. As part of a sensitivity analysis, we also used 'missForest'[24] to impute missing values. Both methods led to similar results and identical conclusions. Finally, a majority of the mothers in our sample appear to have attained above-average educational levels and to belong to groups with higher-than-average incomes. For these reasons, our findings may not be generalisable to the Canadian population as a whole. Nevertheless, the data we have derived for breast-feeding rates and duration appear to be consistent with information presented in other large cohort studies in Canada[48,49].

In conclusion, the present study indicates that RWG in the first year is a strong predictor for excess weight at the age of 2 years. The potential beneficial effects that breast-feeding has on rate of growth in the first year suggest that interventions promoting breast-feeding are relevant for obesity prevention early in life. The relatively low level of compliance with breast-feeding recommendations observed in the 3D Cohort Study makes these efforts even more relevant for population health.

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Supplementary material

For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S1368980022000015

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