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ORIGINAL ARTICLE

Maternal weight, smoking, and diabetes provided early predictors of longitudinal body mass index growth patterns in childhood

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Abstract

Aim: The aim of this study was to identify factors affecting overweight growth development using extended body mass index (BMI) data combined with birth and maternal records from Finnish national registries.

Methods: The longitudinal data consist of growth measurements of 7372 from six birth cohorts in Finland: 1974 ($n = 1109$), 1981 ($n = 983$), 1991 ($n = 607$), 1994–1995 ($n = 829$), 2001 ($n = 821$), and 2003–2004 ($n = 3023$). Anthropometric data were collected from birth to age 15 years from the health records. Pregnancy health data were included for the four most recent birth cohorts ($n = 2810$). A statistical method called trajectory analysis was used to identify different BMI development trajectories. Factors associated with abnormal growth tracks were analysed using logistic regression models.

Results: High pre-pregnancy BMI, gestational diabetes mellitus, maternal smoking, and greater gestational weight gain than the Institute of Medicine (United States) recommendations were associated with the overweight growth track. Two of the trajectories didn't seem to follow the normal growth pattern: overweight growth track appeared to lead to overweight, while low birth BMI track showed accelerating growth after the adiposity rebound point of BMI growth.

Conclusion: These findings suggest that maternal overweight before pregnancy, excessive gestational weight gain, gestational diabetes mellitus, and smoking could potentially be associated with the risk of obesity in children.

KEYWORDS
childhood obesity, development of body mass index, gestational diabetes mellitus, gestational weight gain, trajectory analysis

Abbreviations: aOR, adjusted odd ratio; BMI, body mass index; CI, confidence interval; OR, odds ratio.

1 | INTRODUCTION

The perinatal period and the early years of a child's life are a critical time in the development of obesity.[1–7] Associations between childhood body mass index (BMI) and later cardiometabolic outcomes have been shown.[8,9] Maternal factors are also known risk factors for child obesity and these include pre-pregnancy BMI, gestational weight gain, gestational diabetes mellitus, and maternal smoking.[1–7] The global prevalence of maternal obesity, gestational diabetes mellitus, and gestational weight gain has increased.[6,10] In Finland, the prevalence of maternal overweight was 45.3% in 2021 and gestational diabetes occurred in 20.6% of pregnant women in 2019.[11,12] Over the past few decades, there has been a decline in the prevalence of maternal smoking and by 2021 smoking during pregnancy had fallen to 7.9% in Finland.[11]

Traditionally the factors affecting the development of BMI have been studied cross-sectionally.[2,3,7,13] However, examining BMI trajectories is an opportunity to understand better longitudinal growth patterns and related factors.[9,14–17]

Our previous longitudinal growth study identified two BMI trajectories that predicted the development of overweight in early childhood. These were a stable high or low BMI at birth and excessive weight gain after the adiposity rebound.[18] The aim of this study was to investigate maternal factors associated with these BMI trajectories, using extended BMI data and birth and maternal records from national Finnish registries.

Key notes

- This study improves understanding by identifying factors that affect overweight growth development by using longitudinal BMI data and birth and maternal records.
- High pre-pregnancy BMI, gestational diabetes mellitus, maternal smoking, and gestational weight gain was found to be associated with the growth track that appeared to lead to overweight.
- The study indicates that early primary prevention strategies for child obesity may be beneficial, with a focus on maternal factors such as overweight before pregnancy, excessive gestational weight gain, gestational diabetes mellitus, and smoking.

2 | MATERIALS AND METHODS

The growth measurements of 7372 Finnish children from six birth cohorts: 1974 ($n=1109$), 1981 ($n=983$), 1991 ($n=607$), 1994–1995 ($n=829$), 2001 ($n=821$), and 2003–2004 ($n=3023$) from the Pirkanmaa district in Finland, based on longitudinal data from two previous studies.[19,20]

The anthropometric data between birth and 15 years of age were collected from health records. In addition, pregnancy health data for the birth cohorts 1991, 1994–1995, 2001, and 2003–2004 were also collected. The number of children in each birth cohort is shown in Table 1.

Children with missing anthropometric data after the age of seven ($n=1269$) or with less than four measurement points ($n=336$), and children of mothers with Type 1 diabetes ($n=68$) were excluded from the analyses. In the trajectory analysis, information from a total of 5698 children was used. In further analyses, when studying maternal factors that lead to an abnormal growth track, data from 2810 children and their mothers were used (Table 2, Figure S1).

The pregnancy health data were collected from Maternity Health clinics, the Finnish Medical Birth Register, and the National Register for Health Care (Table S1). The child's anthropometric data between birth and the age of 15 years were collected from the Child Health Clinic records. The Maternal Health clinics data include information from 8 to 9 health check-ups during pregnancy and two health check-ups postpartum. Data of potential confounders, such as maternal pre-pregnancy BMI, gestational weight gain, gestational diabetes mellitus, and smoking, were included in the study dataset. Missing values in maternity information were imputed using multiple imputation.

Maternal pre-pregnancy BMI was calculated using self-reported height and weight in the first maternal clinic health check-up. The Finnish Medical Birth Register began to collect information about pre-pregnancy BMI in 2004, from where the information was obtained for the 2004 birth cohort. For the 1991, 1994–1995, 2001, and 2003–2004 birth cohorts, the pre-pregnancy BMI was collected from the Maternity Health Clinic records. Pre-pregnancy BMI was classified as (1) normal weight (BMI < 25), (2) overweight ($25 \le$ BMI < 30), and (3) obese (BMI ≥ 30). Pre-pregnancy BMI was missing for 5% ($n=146$) of the participants in analyses data. These missing BMI values were imputed in two different ways: some were imputed using early pregnancy BMI in the first trimester ($n=43$) and the rest of the missing values were filled using multiple imputation ($n=103$).

Gestational weight gain was defined using the last maternal clinic health check-up weight at 3rd trimester and the pre-pregnancy weight and adjusting for the length of gestation. Gestational weight gain was classified according to the 2009 Institute of Medicine guideline recommendations,[21] which takes the pre-pregnancy category into account (Table 3).

Gestational diabetes mellitus was diagnosed in high-risk women with a two-hour glucose tolerance test in weeks 12–14 or 24–28 of pregnancy. During the study period, the recommended cut-off values were ≥4.8 mmol/L (fasting glucose), ≥10.0 mmol/L (1 h), and ≥8.7 mmol/L (2 h).

2.1 | Statistical analysis

The trajectory analysis[22] was used to identify trajectories for BMI development. Trajectory analysis identifies distinct groups or clusters

TABLE 1 The number of children in each cohort.

	1974	1981	1991	1994–1995	2001	2003–2004	Total
Number	1109	983	607	829	821	3023	7372
Birth weight							
Mean	3469	3557	3574	3548	3528	3493	3516
SD	545	534	582	562	562	545	552
Sex							
Boy	608 (55%)	582 (59%)	316 (52%)	390 (48%)	426 (52%)	1382 (51%)	3704 (53%)
Girl	499 (45%)	401 (41%)	291 (48%)	424 (52%)	387 (48%)	1344 (49%)	3346 (47%)
Gestational weeks							
Mean	39.7	40	39.7	39.9	39.7	39.7	39.8
SD	2	1.7	1.8	1.8	1.8	1.8	1.8
0.5 years, BMI							
Number	1105	981	586	788	770	2442	6672
Mean	17.2	17.1	17.2	17.3	17.4	17.4	17.3
SD	1.4	1.4	1.5	1.5	1.5	1.6	1.5
1 years, BMI							
Number	1108	982	586	789	780	2485	6730
Mean	17.6	17.2	17.1	17.1	17.1	17.1	17.2
SD	1.4	1.4	1.3	1.4	1.4	1.4	1.4
2 years, BMI							
n	1107	982	586	791	798	2430	6694
Mean	16.8	16.6	16.4	16.4	16.3	16.3	16.5
SD	1.4	1.3	1.4	1.4	1.4	1.4	1.4
5 years, BMI							
n	1086	978	584	790	799	1899	6136
Mean	15.8	15.8	15.7	15.8	15.8	15.7	15.8
SD	1.5	1.6	1.6	1.6	1.8	1.5	1.6
7 years, BMI							
n	1107	978	584	790	736	1736	5931
Mean	16.2	16.2	16.3	16.4	16.3	16.2	16.2
SD	1.9	2.1	2.1	2.3	2.3	2.0	2.1
12 years, BMI							
Number	1104	976	591	801	657	1599	5728
Mean	18.3	18.6	19.1	19.3	18.9	19.0	18.8
SD	2.9	3.5	3.5	3.6	3.5	3.5	3.4
15 years, BMI							
Number	1104	975	598	766	560	1559	5562
Mean	20.4	20.5	21.2	21.4	21.2	21.2	20.9
SD	3.2	3.7	3.8	4.0	4.0	3.9	3.8

of individuals who have the same type of developmental trajectories. Trajectory analysis assumes that the population is composed of a mixture of distinct subgroups and each of these subgroups is defined by its unique developmental trajectory. The initial step of the analysis involves using the Maximum Likelihood method to estimate the parameters of the assumed trajectory curves and the proportion of each subgroup in the total sample. Next, using the obtained estimates, the posterior probability of each individual belonging to each subgroup is estimated, and individuals can then be assigned to the subgroup where their posterior probability is the highest.

In the study, methods of nonparametric regression were applied to model the mean development of BMI. The second-degree regression spline model were fit to the inverse of BMI development: $y = \beta_0 + \beta_1 t + \beta_2 t + \beta_3 (\kappa_1 - t)_+^2 + \beta_4 (\kappa_2 - t)_+^2 + \epsilon$, were the knot points κ_1 and κ_2, and the function $(.)_+$ is defined such that it equals (.) if (.) ≥ 0 and 0 otherwise. The fitted function is a second-degree

TABLE 2 Maternal factors by birth year.

	1991	1994–1995	2001	2003–2004	Total
Number	291	583	513	1423	2810
Birth weight					
Mean	3556	3573	3570	3506	3537
Median	3560	3570	3580	3540	3552
SD	547	544	526	549	544
<2500 g	8 (3%)	22 (4%)	15 (3%)	62 (4%)	107 (4%)
2500 g ≤ Birth weight < 4000 g	227 (78%)	439 (75%)	392 (76%)	1129 (79%)	2187 (78%)
≥4000 g	56 (19%)	122 (21%)	106 (21%)	232 (16%)	516 (18%)
Sex					
Boy	149 (51%)	47% (276)	270 (53%)	707 (50%)	1402 (50%)
Girl	142 (49%)	307 (53%)	243 (47%)	716 (50%)	1408 (50%)
Gestational weeks					
Mean	39.8	39.9	39.9	39.7	39.8
Median	40.1	40.1	40	40	40
SD	1.6	1.6	1.7	1.8	1.7
Maternal age					
Mean	29.9	30.1	30.5	30.3	30.2
Median	29.4	30.1	30.3	30.1	30
SD	5.2	5	5.5	5.5	5.4
Previous births					
Nulliparous	117 (40%)	230 (39%)	197 (38%)	683 (48%)	1227 (44%)
One previous birth	116 (40%)	206 (35%)	202 (39%)	466 (33%)	990 (35%)
Two or more previous births	58 (20%)	147 (25%)	114 (22%)	274 (19%)	593 (21%)
Pre-pregnancy BMI					
Mean	22.9	23.3	23.8	23.6	23.5
Median	22.1	22.5	23.0	22.8	22.7
SD	3.8	4.0	4.2	4.2	4.1
BMI < 25 kg/m^2	225 (77%)	437 (75%)	359 (70%)	1019 (72%)	2040 (73%)
25 kg/m^2 ≤ BMI < 30 kg/m^2	49 (17%)	109 (19%)	99 (19%)	293 (21%)	550 (20%)
BMI ≥ 30 kg/m^2	17 (6%)	37 (6%)	55 (11%)	111 (8%)	220 (8%)
Gestational diabetes mellitus					
No	289 (99%)	569 (98%)	474 (92%)	1182 (83%)	2514 (89%)
Yes	2 (1%)	14 (2%)	39 (8%)	241 (17%)	296 (11%)
Pre-pregnancy BMI and gestational diabetes mellitus					
BMI < 25 kg/m^2, no gestational diabetes mellitus	223 (77%)	428 (73%)	352 (69%)	946 (66%)	1949 (69%)
BMI < 25 kg/m^2, yes gestational diabetes mellitus	2 (1%)	9 (2%)	7 (1%)	73 (5%)	91 (3%)
BMI ≥ 25 kg/m^2, no gestational diabetes mellitus	66 (23%)	141 (24%)	122 (24%)	236 (17%)	565 (20%)
BMI ≥ 25 kg/m^2, yes gestational diabetes mellitus	0 (0%)	5 (1%)	32 (6%)	168 (12%)	205 (7%)
Maternal smoking during pregnancy					
No smoking	220 (76%)	468 80%)	450 (88%)	1293 (91%)	2431 (87%)
Quit smoking (≤12 weeks of gestation)	6 (2%)	25 (4%)	5 (1%)	19 (1%)	55 (2%)
Smoking (>12 weeks of gestation)	65 (22%)	90 (15%)	58 (11%)	111 (8%)	324 (12%)

(Continues)

TABLE 2 (Continued)

	1991	1994–1995	2001	2003–2004	Total
Gestational weight gain versus recommendation					
Normal	131 (45%)	265 (45%)	224 (44%)	605 (43%)	1225 (44%)
Under	56 (19%)	89 (15%)	76 (15%)	226 (16%)	447 (16%)
Greater	104 (36%)	229 (39%)	213 (42%)	592 (42%)	1138 (40%)
Multiple birth					
No	282 (97%)	570 (98%)	501 (98%)	1358 (95%)	2711 (96%)
Yes	9 (3%)	13 (2%)	12 (2%)	65 (5%)	99 (4%)
Delivery					
Normal delivery	274 (94%)	534 (92%)	486 (95%)	1203 (85%)	2497 (89%)
C-section	17 (6%)	49 (8%)	27 (5%)	220 (15%)	313 (11%)
Breastfeeding 3 months after delivery					
No	23 (8%)	81 (14%)	59 (12%)	174 (12%)	337 (12%)
Partially	40 (14%)	65 (11%)	63 (12%)	205 (14%)	373 (13%)
Predominantly	228 (78%)	437 (75%)	391 (76%)	1044 (73%)	2100 (75%)

TABLE 3 Institute of Medicine 2009 Gestational Weight Gain Guidelines by Pre-Pregnancy BMI.[21]

	Recommended range of total weight (kg)		Rates of Weight Gain 2nd and 3rd Trimester (mean range, kg/week)	
Pre-pregnancy BMI category	Singleton	Multiple births	Singleton	Multiple births
Underweight, BMI < 18.5 kg/m^2	12.5–18.0 kg	17.0–25.0 kg	0.51 (0.44–0.58)	0.72 (0.60–0.84)
Normal weight, BMI 18.5–24.9 kg/m^2	11.5–16.0 kg	17.0–25.0 kg	0.42 (0.35–0.50)	0.72 (0.60–0.84)
Overweight, BMI 25.0–29.9 kg/m^2	7.0–11.5 kg	14.0–23.0 kg	0.28 (0.23–0.33)	0.63 (0.49–0.76)
Obese, BMI ≥ 30 kg/m^2	5.0–9.0 kg	11.0–19.0 kg	0.22 (0.17–0.27)	0.50 (0.38–0.62)

polynomial over three intervals with $0 \le \kappa_1 \le \kappa_2 \le t_{max}$, and it has continuous derivatives. For this study, we opted to use only two quite natural knot points κ_1 and κ_2, which were selected based on our knowledge of the sections of BMI development. The knot points were chosen to minimise the criterion function AIC, we chose $\kappa_1 \in [0.5, 1.2]$ and $\kappa_1 \in [3, 7.5]$. Based on this selection process, we ultimately decided on $\kappa_1 = 0.69$ and $\kappa_2 = 7.27$ for our data. To identify the number of trajectory groups (or clusters) K, we used criterion functions AIC or BIC, and diagnostic plots (Table S4 and Figure S2). Based on these, we proposed a solution consisting of four main trajectories. Detailed information on trajectory analysis can be found in our previous study.[18]

Factors that lead to the identified abnormal growth tracks were analysed using logistic regression models. The outcome variable in the model was a binary variable representing the probability of which trajectory the individual belongs to. The selection of explanatory variables in the model was based on existing knowledge regarding the association between these risk factors and childhood obesity.[1,6,13] In our models, we included explanatory variables that incorporated any information preceding the outcome of interest as well as information believed to predict the outcome. The analyses were adjusted for birth year and other variables that were included in the model.

Multiple imputation was applied using logistics regression for binary variables, predictive mean matching for continuous variables and random sample from observed values for categorical variables. In the multiple imputation, different predictors and analysis were used for each variable to predict the missing values. The sample used for multiple imputation was limited to variables with the outcome of interest, and only missing predictor values were imputed. The predictor matrix that shows which variables were used to produce the predicted values for matching is shown in Table S2 and the number of imputed values. Hundred imputations of the sample were performed during the imputation process, generating 100 imputed datasets with 5 iterations per imputed dataset. The estimated regression parameters, including coefficients and variances, were combined across the imputed datasets using Rubin's rules.

The statistical analyses were conducted using R software version 4.0.1 (R Foundation for Statistical Computing, Vienna, Austria). The FlexMix package was used for trajectory analysis and the mice package was used for multiple imputation.

3 | RESULTS

The trajectory analysis identified four main trajectories of BMI growth (Figure 1 and Table 4). The highest growth track appeared to lead to overweight (the overweight growth track). The second

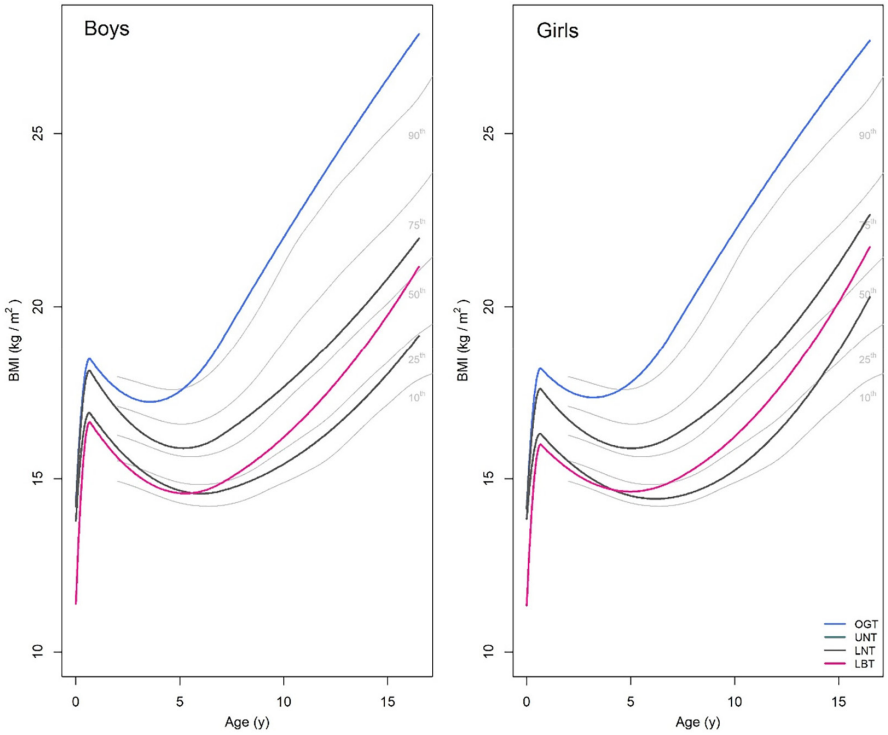

FIGURE 1 Mean trajectory curves for boys (left) and girls (right). The blue line indicates the overweight growth track (overweight growth track) and the pink line indicates the low birth BMI growth track (low birth BMI track). Finnish reference centile curves (95th, 50th, 10th, and 5th)[31] are marked in grey. LBT, Low birth BMI track; LNT, Lower normal growth track; OGT, Overweight growth track; UNT, Upper normal growth track.

TABLE 4 Mean body mass index (SD) for each trajectory by sex.

	0 years	0.5 years	1 years	2 years	5 years	7 years	12 years	15 years
Boys								
Low birth BMI track	11.2 (1.3)	16.5 (1.3)	16.5 (1.4)	15.7 (1.2)	14.7 (1.1)	15.1 (1.4)	17.7 (2.8)	19.8 (3.5)
Lower normal growth track	13.7 (1.1)	16.7 (1.1)	16.6 (1.0)	15.6 (0.9)	14.6 (0.6)	14.5 (0.7)	15.9 (1.1)	17.6 (1.4)
Upper normal growth track	14.1 (1.1)	17.8 (1.3)	17.7 (1.1)	16.8 (1.0)	15.8 (0.8)	16.1 (0.9)	18.4 (1.5)	20.3 (1.8)
Overweight growth track	14.3 (1.3)	18.3 (1.6)	18.3 (1.5)	17.6 (1.5)	17.5 (1.8)	18.9 (2.2)	23.7 (3.1)	25.9 (3.9)
Girls								
Low birth BMI track	11.3 (1.5)	15.7 (1.5)	15.8 (1.4)	15.3 (1.3)	14.7 (1.2)	15.2 (1.6)	17.9 (2.9)	20.3 (3.2)
Lower normal growth track	13.7 (1.0)	16.2 (1.0)	16.1 (1.0)	15.3 (0.8)	14.4 (0.7)	14.5 (0.8)	16.0 (1.2)	18.3 (1.6)
Upper normal growth track	14.1 (1.1)	17.4 (1.2)	17.3 (1.1)	16.6 (1.1)	15.8 (0.8)	16.2 (1.0)	18.5 (1.6)	20.9 (1.8)
Overweight growth track	14.2 (1.3)	17.9 (1.5)	18.0 (1.5)	17.6 (1.5)	17.8 (1.8)	19.3 (2.2)	23.7 (3.3)	26.1 (4.0)

track (pink line), which differs from the "normal growth tracks," was named the low birth BMI track. The main characteristic of the low birth BMI track is that the early BMI level is low, but the growth acceleration follows after the adiposity rebound point. The two other trajectories were named the upper normal growth track and the lower normal growth track.

Table 5 provides the sizes and percentages of each track, including background factors. The overweight growth track contained 23% ($n=649$) of the children, while the low birth BMI track contained approximately 6% ($n=170$). On the overweight growth track, 29% of the children weighed more than 4 kgs at birth. The corresponding percentage was only 2% on the low birth BMI track. Respectively, 42% of the children on the low birth BMI track and 3% of the children on the overweight growth track weighed less than 2.5 kgs at birth.

In the whole study group, 28% of the mothers had overweight or obesity before pregnancy, and 40% had a higher gestational weight gain than recommended. On the overweight growth track, the respective percentages were 45% and 50%. Contrarily, 33% of mothers of children on the low birth BMI track had a lower gestational weight gain than recommended.

In the whole study group, 12% of the mothers smoked during the entire pregnancy, while the corresponding percentage was 16% among the mothers of the overweight growth track children. Gestational diabetes mellitus was diagnosed in 11% of the mothers overall and in 16% of the mothers of the children on the overweight growth track.

Interaction between pre-pregnancy BMI and gestational diabetes mellitus was associated with a higher risk for the overweight growth track (Figure 2). There was a 2.98-times higher risk for the

TABLE 5 Size and percentage of observations in each track with background factors.

	Low birth BMI track	Lower normal growth track	Upper normal growth track	Overweight growth track	Total
n	170	830	1161	649	2810
Birth weight					
Mean	2600	3489	3629	3680	3537
Median	2635	3460	3620	3690	3552
SD	676	445	447	533	544
<2500 g	42% (71)	1% (11)	1% (8)	3% (17)	4% (107)
2500 g ≤ Birth weight < 4000 g	56% (96)	86% (716)	80% (929)	69% (446)	78% (2187)
≥4000 g	2% (3)	12% (103)	19% (224)	29% (186)	18% (516)
Sex					
Boy	46% (78)	50% (415)	50% (583)	50% (326)	50% (1402)
Girl	54% (92)	50% (415)	50% (578)	50% (323)	50% (1408)
Gestational weeks					
Mean	37.3	40	40	39.9	39.8
Median	38.1	40	40.1	40.1	40
SD	3.3	1.3	1.4	1.5	1.7
Maternal age					
Mean	31.9	30.3	29.9	30.3	30.2
Median	31.8	30.1	29.7	30	30
SD	5.9	5.3	5.3	5.4	5.4
Previous births					
Nulliparous	50% (85)	44% (366)	44% (511)	41% (265)	44% (1227)
One previous birth	36% (62)	34% (281)	35% (409)	37% (238)	35% (990)
Two or more previous births	14% (23)	22% (183)	21% (241)	22% (146)	21% (593)
Pre-pregnancy BMI					
Mean	23.5	22.3	23.3	25.4	23.5
Median	22.8	21.6	22.6	24.4	22.7
SD	4.3	3.5	3.6	4.8	4.1
BMI < 25 kg/m^2	68% (116)	83% (690)	75% (873)	56% (361)	73% (2040)
25 kg/m^2 ≤ BMI < 30 kg/m^2	22% (37)	13% (110)	19% (216)	29% (187)	20% (550)
BMI ≥ 30 kg/m^2	10% (17)	4% (30)	6% (72)	16% (101)	8% (220)
Gestational diabetes mellitus					
No	91% (154)	93% (775)	89% (1039)	84% (546)	89% (2514)
Yes	9% (16)	7% (55)	11% (122)	16% (103)	11% (296)
Pre-pregnancy BMI and gestational diabetes					
BMI < 25 kg/m^2, no gestational diabetes mellitus	66% (112)	80% (665)	71% (830)	53% (342)	69% (1949)
BMI < 25 kg/m^2, yes gestational diabetes mellitus	2% (4)	3% (25)	4% (43)	3% (19)	3% (91)
BMI ≥ 25 kg/m^2, no gestational diabetes mellitus	25% (42)	13% (110)	18% (209)	31% (204)	20% (565)
BMI ≥ 25 kg/m^2, yes gestational diabetes mellitus	7% (12)	4% (30)	7% (79)	13% (84)	7% (205)
Maternal smoking during pregnancy					
No smoking	85% (145)	89% (740)	88% (1020)	81% (526)	87% (2431)
Quit smoking (≤12 weeks of gestation)	1% (2)	2% (15)	2% (21)	3% (17)	2% (55)
Smoking (>12 weeks of gestation)	14% (23)	9% (75)	10% (120)	16% (106)	12% (324)

TABLE 5 (Continued)

	Low birth BMI track	Lower normal growth track	Upper normal growth track	Overweight growth track	Total
Gestational weight gain versus recommendation					
Normal	41% (70)	49% (406)	45% (522)	35% (227)	44% (1225)
Under	33% (56)	17% (144)	13% (152)	15% (95)	16% (447)
Greater	26% (44)	34% (280)	42% (487)	50% (327)	40% (1138)
Multiple birth					
No	82% (139)	98% (812)	97% (1128)	97% (632)	96% (2711)
Yes	18% (31)	2% (18)	3% (33)	3% (17)	4% (99)
Delivery					
Normal delivery	81% (138)	89% (742)	90% (1042)	89% (575)	89% (2497)
C-section	19% (32)	11% (88)	10% (119)	11% (74)	11% (313)
Breastfeeding 3 months after delivery					
No	21% (35)	11% (88)	11% (126)	14% (88)	12% (337)
Partially	20% (34)	13% (104)	12% (145)	14% (90)	13% (373)
Predominantly	59% (101)	77% (638)	77% (890)	73% (471)	75% (2100)

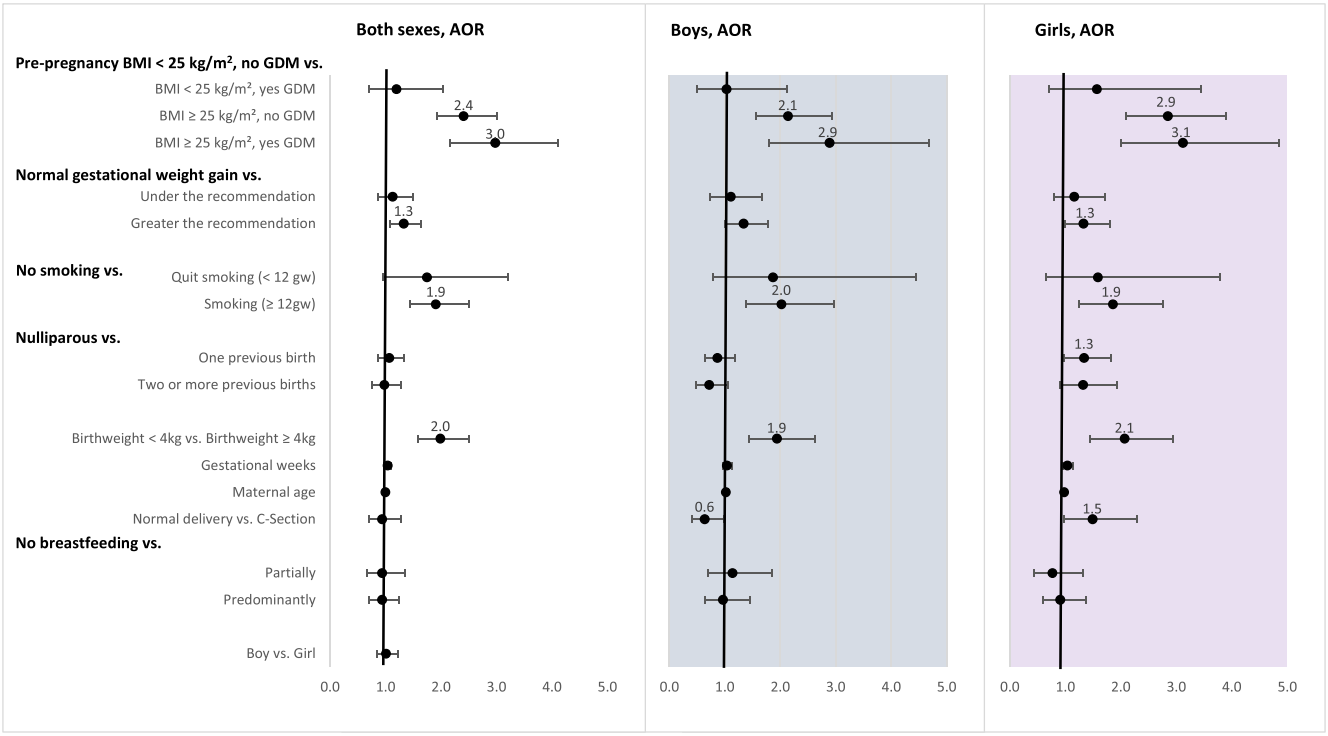

FIGURE 2 Adjusted odds ratios of overweight growth track.

overweight growth track when comparing the mothers with a normal BMI (BMI < 25 kg/m^2) and no gestational diabetes mellitus to the mothers with overweight or obesity (BMI ≥25 kg/m^2) and gestational diabetes mellitus (adjusted odds ratio [aOR]: 2.98, 95% CI 2.16–4.11).

Maternal smoking was associated with a higher risk for the overweight growth track (no smoking vs. smoking, aOR 1.91, 95% CI 1.45–2.51).

More gestational weight gain than recommended carried a 1.3-times higher risk of the overweight growth track compared to normal gestational weight gain (aOR 1.33, 95% CI 1.08–1.64). After the adjustment, the OR was only statistically significant for the boys' overweight growth track (aOR 1.34, 95% CI 1.00–1.78).

The interaction between pre-pregnancy BMI and gestational diabetes was associated with a higher risk for the low birth BMI track in girls (Figure 3). There was a 2.4-times higher risk for the low birth BMI track when comparing mothers with a normal BMI (BMI < 25 kg/m^2) and no gestational diabetes mellitus to the mothers with overweight or obesity (BMI ≥ 25 kg/m^2) and gestational diabetes mellitus (aOR 2.39, 95% CI 1.04–5.47).

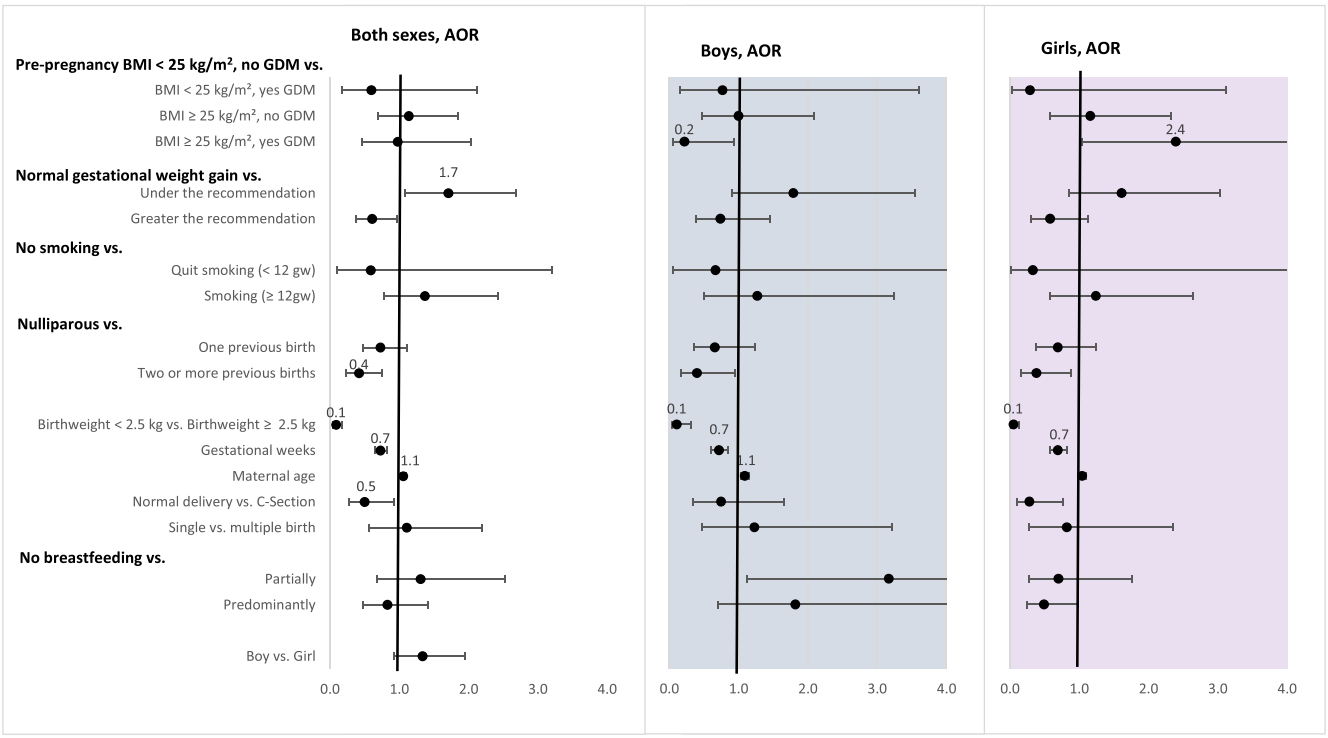

FIGURE 3 Adjusted odds ratios of low birth body mass index (BMI) growth track.

Previous births, gestational weeks, C-Section, and birth weight ≥2.5 kg were associated with a lower risk for the low birth BMI track (nulliparous vs. two or more previous births aOR 0.42, 95% CI 0.23–0.75; gestational weeks aOR 0.73, 95% CI 0.65–0.82; normal delivery vs. C-Section aOR 0.50, 95% CI 0.27–0.92; birth weight <2.5 kg vs. birth weight ≥2.5 kg aOR 0.09, 95% CI 0.04–0.17).

Less gestational weight gain than recommended implies a 1.7-times higher risk for the low birth BMI track than normal gestational weight gain (aOR 1.7, 95% CI 1.08–2.69).

4 | DISCUSSION

In this study, two trajectories that lead to the risk of overweight in early life were identified. One was characterised by a high and stable BMI and the other by highly accelerated growth around the adiposity rebound point.[18] Maternal pre-pregnancy overweight, gestational diabetes mellitus, gestational weight gain, and maternal smoking were risk factors associated with a persistently high trajectory. Maternal pre-pregnancy overweight and gestational diabetes mellitus were also associated with the lowest BMI at birth and the gaining weight track in girls. On the contrary, children of mothers with a normal weight before pregnancy and gestational diabetes mellitus during pregnancy followed the normal growth track.

Several cross-sectional studies have also shown associations between maternal pre-pregnancy BMI and offspring overweight. A recent systematic review[14] explored longitudinal growth studies that used group-based modelling to identify BMI trajectories in early childhood. According to the results, high maternal pre-pregnancy BMI was related to the rapid gain trajectory. The findings in this study are in line with the review findings. The highest track in our study was above the Finnish reference of overweight both for girls and boys after the age of 5 years. Similar growth patterns have been reported for children born large and with rapid weight gain during infancy.[23,24]

We observed not only that maternal pre-pregnancy BMI was associated with a higher risk of childhood overweight/obesity but also that the interaction of maternal pre-pregnancy BMI and gestational diabetes mellitus were associated with the overweight growth track. Previous studies of the association between gestational diabetes mellitus and childhood overweight have not always controlled for maternal pre-pregnancy BMI and other confounders, which is one reason for the conflicting results across studies.[25] This study shows that maternal pre-pregnancy overweight combined with gestational diabetes mellitus causes an even higher risk for offspring overweight than maternal pre-pregnancy overweight alone. Another Finnish growth study reported similar results.[26]

High gestational weight gain has also been observed to associate with later offspring overweight.[7] A recent systematic review reported that 47% (USA: 51%, Europe: 51%, Asia: 37%) of women had a greater gestational weight gain than the Institute of Medicine recommendations.[6] In this study, the respective prevalence figure for the whole study group was 40%, while for mothers whose children grew on a persistently high track, it was 50%. Here, the role of high gestational weight gain on the increased risk of offspring overweight does not seem to be unequivocally established. The adjusted model for both sexes suggests that gestational weight gain were associated with the risk of children ending up on the overweight growth trajectory. After modelling boys and girls separate, the associating effect

of gestational weight gain only applied to the boys. The comparably small effect of gestational weight gain we obtained differs from previous studies, which may not have always considered maternal factors such as gestational diabetes mellitus in the same manner.[7]

Many meta-analyses have confirmed the same association between maternal smoking and the offspring's overweight in later life,[27–30] as we found in this study. Our results suggest that quitting smoking in the first trimester is better for reducing the risk of offspring overweight more than smoking throughout pregnancy. Only 15% of mothers who smoked during pregnancy quit during the first trimester. In 2021, this percentage was 56% for the entire country of Finland.[11]

One of the strengths of the study is the unique longitudinal data from birth to 15 years of age combined with maternal factors. The data enabled the analysis of the BMI trajectories and the identification of the factors that lead to overweight or obesity in children later in life. Therefore, our study provides a deeper understanding of longitudinal growth patterns and related factors.

Information on the maternal diagnoses and the other maternal factors were retrieved from comprehensive and high-quality Finnish registries, which raise the reliability of the study data.

This study has a notable limitation related to potential selection bias, as the study population was confined to the relatively small geographical area of the Pirkanmaa district in Finland. However, the two identified trajectories seem to follow the normal growth pattern Finnish growth references for children and adolescents aged 0 to 20 years.[18,31] Furthermore, this study sample included both urban and rural areas, but internal migration in the 1970s and 1980s might have some influence on our analyses. The immigration of the Pirkanmaa district has been large in Finland and the population of the city of Tampere has grown 1.5 times since the 1970s. Despite these regional dynamics, we assume that the results of our study reliably reflect national growth changes as well. A second limitation of the study is that it does not consider all confounding factors that are known to be linked to child obesity. These missing factors are mostly lifestyle factors, like eating habits, physical activity, and sleep duration. One more limitation of our study is that the dataset contained missing values, which may have limited the validity and generalisability of our findings. However, we did conduct analyses on the non-imputed dataset, and the significance of the ORs was the same.

The study includes various statistical tests, which can contribute to the multiple comparisons problem. However, it is essential to exercise caution when interpreting the statistical significance of our findings, as the increased number of tests elevates the likelihood of Type I errors. Therefore, it is prudent to approach the results with a critical eye and acknowledge the potential for Type I errors due to the extensive testing procedures.

Maternal factors, like overweight and obesity, are known not only to be associated with child overweight and obesity but also with type 2 diabetes, coronary heart diseases, stroke, and asthma in later life.[32,33] It is not yet possible to explore these other health risks using these data due to the young cohort, but it would be important to study them in the future.

5 | CONCLUSION

Maternal pre-pregnancy overweight, gestational diabetes mellitus, gestational weight gain, and smoking were associated with the offspring's high BMI trajectory. On the contrary, children of mothers with gestational diabetes but normal pre-pregnancy weight followed the normal growth track. These findings suggest that maternal overweight before pregnancy, excessive gestational weight gain, gestational diabetes mellitus, and smoking could potentially be associated with the risk of obesity in children.

AUTHOR CONTRIBUTIONS

Tiina Ylöstalo: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; validation; visualization; writing – original draft; writing – review and editing. **Marja-Terttu Saha:** Conceptualization; methodology; supervision; writing – original draft. **Tapio Nummi:** Methodology; supervision; writing – original draft; writing – review and editing. **Ulla Harjunmaa:** Conceptualization; supervision; writing – original draft. **Matti K. Salo:** Supervision. **Nina Vuorela:** Conceptualization; methodology; supervision; writing – original draft; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interests to report.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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