Maternal Gestational and Postdelivery Weight Gain and Child Weight

Lenie van Rossem, PhD[a], Alet H. Wijga, PhD[b], Ulrike Gehring, PhD[c], Gerard H. Koppelman, MD, PhD[d], Henriette A. Smit, PhD[a]

abstract

BACKGROUND: Maternal gestational weight gain (GWG) is a risk factor for the development of overweight in her child. It is unknown whether GWG programs the child's health or whether GWG indicates a shared familial lifestyle during childhood. To disentangle these influences, we studied the association of GWG and postdelivery maternal weight change simultaneously with child's weight development.

METHODS: We used data from 3367 children participating in a birth cohort that started in 1996 in the Netherlands. Weight and height were self-reported. GWG was categorized as "inadequate," "adequate," and "excessive." Multivariable regression and mixed models were used to study maternal and child weight changes.

RESULTS: Children of mothers with excessive GWG had a higher BMI *z* score and overweight prevalence (odds ratio [OR] 1.20; 95% confidence interval [CI], 0.99 to 1.46) throughout childhood. Children of mothers with a high (≥1 kg/year) postdelivery weight gain had a 0.14 (95% CI, −0.08 to 0.36) higher change in BMI *z* score between age 1 and 14 years than children of mothers with a low (<0.5 kg/year) postdelivery weight gain. Children of mothers with excessive GWG in combination with a high postdelivery weight gain had the highest BMI *z* score and overweight risk at age 14 years (OR 3.53; 95% CI, 1.70 to 7.33).

CONCLUSIONS: Maternal GWG and postdelivery weight gain contribute to child's weight development up to adolescence independently.

WHAT'S KNOWN ON THIS SUBJECT: Maternal gestational weight gain is associated with childhood overweight. It is unknown whether gestational weight gain programs the child's health or whether gestational weight gain is an indicator of postnatal behavioral factors.

WHAT THIS STUDY ADDS: We disentangled these influences by studying the effect of gestational weight gain simultaneously with postdelivery maternal weight change as an indicator for shared family lifestyle on child's weight development and found that both had an independent effect.

[a]*Julius Center for Health Sciences and Primary Care, University Medical Center Utrecht, Utrecht, Netherlands;* [b]*Center for Prevention and Health Services Research, National Institute of Public Health and the Environment, Bilthoven, Netherlands;* [c]*Institute for Risk Assessment Sciences (IRAS), Utrecht University, Utrecht, Netherlands; and* [d]*Department of Pediatric Pulmonology and Pediatric Allergology, Beatrix Children's Hospital, University Medical Center Groningen, University of Groningen, Groningen, Netherlands*

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Address correspondence to Lenie van Rossem, PhD, Julius Center for Health Sciences and Primary Care, University Medical Center Utrecht, Universiteitsweg 100, 3584 CG, PO Box 85500, 3508 GA, Utrecht, Netherlands. E-mail: l.vanrossem@umcutrecht.nl

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A mother's gestational weight gain (GWG) is a risk factor for the development of overweight in her child.[1–3] However, it is not clear to what extent this effect is due to genetics,[4] a programming effect of maternal GWG on the fetus,[5] or a result of maternal lifestyle that already points toward a shared "obesogenic" environment in the course of childhood.[6] Maternal postdelivery weight gain could well represent this shared "obesogenic" environment. One study reported that children whose mothers kept similar weight for 20 years after delivery were less likely to be overweight in childhood and adolescence, but the effect of maternal GWG was not studied.[7] Another study observed that both GWG and postdelivery maternal weight gain up to 1 year after delivery had an independent effect on the child's overweight in early childhood.[8] It is unknown whether these effects remain throughout childhood.

In a life course approach we aimed to elucidate the effect of maternal GWG as a programming factor for childhood overweight, and maternal postdelivery weight gain representing an obesogenic home environment, by studying their combined effect on weight development in their children up to adolescence.

METHODS

Study Design and Setting

We used the data from the ongoing population-based Dutch birth cohort: the Prevention and Incidence of Asthma and Mite Allergy Study. Details of the study have been described elsewhere.[9] Pregnant women were recruited from the general population during their first antenatal visit in 1996 and 1997. The study started with 3963 newborns. Questionnaires were sent to the mothers during the third trimester of pregnancy, at 3 months after birth, yearly from 1 to 8 years, and at 11 and 14 years. Medical examinations were performed at the ages of 4, 8, 12, and 16 years.

The study protocol was approved by the medical ethics committees of the participating institutes, and all participants gave written informed consent. The study followed the principles as stated in the Declaration of Helsinki.

Study Population

For this study, we included all mothers with a known prepregnancy weight (n = 3463), with a known GWG (n = 3400), and at least 1 known postdelivery maternal BMI (which was reported at child's age of 1 [n = 3525], 8 [n = 3171], and 14 [n = 2261] years), and ≥2 known BMI measurements in the child (n = 3810). Therefore, our population for analyses consisted of 3367 participants.

Child's Weight Status and Weight Gain

Child's height (in centimeters) and weight (in kilograms) were obtained at the age of 3 months, annually from 1 year to 8 years, and at ages 11 and 14 years. Parents were asked to report the child's weight and height, measured by a medical professional during the regular scheduled visits to a youth health center if this measurement was within the last 3 months. Otherwise, parents were asked to measure their child's weight and height themselves without shoes or heavy clothes. At ages 4, 8, 12, and 16 years, we performed a standardized measurement of height and weight during the medical examination of a large sample of the children. We reported on the validity of self-reported versus measured height and weight at age 4 and 8 years. There was a high agreement in ranking, and we concluded that BMI measured and reported by the parents is a valid alternative to use in epidemiologic analyses as a substitute for observed BMI.[10,11] BMI was calculated as weight in kilograms divided by height in square meters, and age- and gender-specific z scores were calculated according to national growth curves.[12] Childhood overweight was defined according to the age- and gender-specific cutoff points of the International Obesity Task Force.[13]

GWG and Postdelivery Weight Gain

The mothers' GWG (in kilograms) was obtained at 1 year after birth and categorized as inadequate, adequate, or excessive weight gain, according to the Institute of Medicine (IOM) recommendation, taking into account weight status at the start of pregnancy.[14] For normal weight mothers, adequate GWG is between 11.5 and 16 kg, and for overweight and obese mothers, adequate GWG is between 7.0 and 11.5 kg and between 5.0 and 9.0 kg, respectively.

Maternal postdelivery weight gain was defined as the change in weight (in kg) between the child's ages of 1, 8, and 14 years. Maternal weight was self-reported at the ages of 1, 8, and 14 years. We categorized maternal postdelivery weight gain into low (<0.5 kg/year), moderate (0.5–1 kg/year), and high (≥1 kg/year) for each period (1–8 years, 8–14 years, and 1–14 years).

Covariates

Maternal prepregnancy BMI was obtained by questionnaire at 1 year after birth. Maternal prepregnancy overweight (including obesity) was defined as a BMI ≥25. Parental age at childbirth (in years) was reported at 3 months after birth. Parental educational level, reported when the child was 1 year old, was used as a categorical (low, intermediate, high) variable in the analyses. Presence of siblings was established at 3 months after birth. Maternal smoking was reported during pregnancy and defined as positive when mother smoked ≥4 weeks after onset of pregnancy. Birth weight (in kilograms), gestational age (in weeks), and child's gender was obtained from

the child's delivery chart. Breastfeeding duration (number of weeks) was assessed by questionnaire at 3 months and at 1 year.

Statistical Analyses

We compared baseline characteristics by GWG category and tested differences by means of a χ^2 test for categorical variables and analysis of variance for continuous variables. Analyses were performed in 3 steps (Fig 1). We adjusted all associations for the covariates described earlier, except for birth weight, because this variable may be on the pathway of the association between GWG and child's BMI and overweight.

1. We used mixed models to study the association between GWG and childhood BMI *z* score, and generalized estimating equations to study the association between maternal GWG and childhood overweight at each age (2, 3, 4, 5, 6, 7, 8, 11, and 14 years). We added interaction terms for GWG by age to the model and calculated age-specific estimates by using the main term and interaction term. We used only linear terms for age because there were no indications for departure from linearity. In addition, we obtained an overall estimate for the association between GWG and childhood BMI *z* score and overweight. Because fetal weight gain and postnatal growth and development differ between genders, we investigated whether child's gender was a possible effect modifier by testing the interaction term for gender by GWG. Similarly, we investigated maternal prepregnancy overweight as a possible effect modifier because maternal overweight may have similar intrauterine effects on the developing fetus as excessive GWG, irrespective or additive to GWG.
2. We used multivariable linear and logistic regression models to study the association between change in postdelivery maternal weight (between child's age 1–8, 8–14, and 1–14 years) and change in childhood BMI *z* score in the same period (between child's age 1–8, 8–14, and 1–14 years) and childhood overweight (at child's age of 8 and 14 years).
3. We categorized combinations of GWG (inadequate, adequate, excessive) and postdelivery weight change (low, moderate, high) and used multivariable linear and logistic regression models to study the combined effect of predelivery and postdelivery weight change on childhood BMI *z* score and overweight.

As a sensitivity analysis, we restricted the analyses to children who had their weight and height measured (at ages 4, 8, 12, and 16 years) at one of our research centers instead of self-reported weight and height.

RESULTS

Characteristics of the Study Population

Mothers gained on average 13.7 (SD 5.0) kg during pregnancy, and 31% of mothers had excessive GWG. Mothers who had excessive GWG were less likely to be multiparous (43% vs 50% for adequate, 58% for inadequate; $P < .0001$), were more likely to smoke during pregnancy (23% vs 13% and 15%; $P < .0001$), and their children were heavier at birth (3644 g vs 3514 and 3359 g; $P < .0001$). GWG was not associated with maternal postdelivery weight change: Mothers with excessive GWG gained on average 4.5 (SD 8.1) kg postdelivery (child's age 1–14 years), whereas mothers with adequate and inadequate GWG gained on average 3.9 (SD 5.8) kg and 4.2 (SD 5.6) kg postdelivery, respectively ($P = .16$) (Table 1).

GWG and Childhood BMI *z* Score, and Overweight

Figure 2 shows regression lines of child's BMI *z* score throughout childhood for inadequate, adequate, and excessive GWG, respectively. Children of mothers with excessive GWG had a higher BMI *z* score throughout childhood than children of mothers with adequate and inadequate GWG (Fig 2). This difference increased with child's age (p interaction term GWG*child's age = 0.02), because BMI *z* score decreased between birth and age 14 in the adequate and inadequate GWG group but not in the excessive GWG group. This is also reflected in the associations between excessive GWG and child overweight by age (Supplemental Fig 4). Overall, children of mothers with excessive GWG were more likely to be overweight throughout childhood (odds ratio [OR] 1.20; 95% confidence interval [CI], 0.99 to 1.46) than children of mothers with adequate GWG. Maternal prepregnancy overweight (p interaction term = 0.85) and child's gender (p interaction term = 0.99) were not effect modifiers of the association between GWG and child BMI *z* score or overweight.

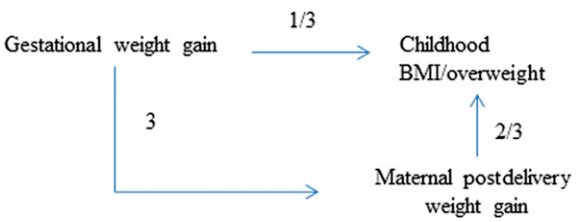

FIGURE 1
Conceptual model for associations between GWG, parental postnatal weight gain, and child's BMI/overweight.

TABLE 1 Baseline Characteristics of 3367 Participants by GWG Category

IOM Category[a]	Inadequate GWG		Adequate GWG		Excessive GWG		*P***
	% (*n*)	Mean (SD)	% (*n*)	Mean (SD)	% (*n*)	Mean (SD)	
	28 (926)		41 (1396)		31 (1045)		
Sociodemographics							
Mother's educational level							<.0001
Low	24 (221)		20 (273)		24 (256)		
Middle	41 (384)		40 (552)		43 (454)		
High	35 (321)		41 (568)		32 (334)		
Father's educational level							<.0001
Low	27 (243)		21 (288)		27 (282)		
Middle	33 (299)		34 (465)		37 (381)		
High	41 (371)		45 (626)		36 (365)		
Parental age at birth (y)[b]							
Mother		30.9 (4.0)		30.6 (3.8)		29.9 (3.7)	<.0001
Father		33.0 (4.5)		33.0 (4.4)		32.5 (4.8)	<.05
Siblings at child's birth (yes)	58 (541)		50 (696)		43 (448)		<.0001
Pregnancy							
Maternal smoking during pregnancy	15 (143)		13 (182)		23 (240)		<.0001
Perinatal							
Gestational age (wk)[b]		39.6 (1.8)		39.9 (1.6)		40.0 (1.5)	<.0001
Child's birth weight (g)[b]		3359 (551)		3514 (560)		3640 (547)	<.0001
Child's gender (girl)	52 (486)		47 (656)		47 (493)		<.05
Postnatal							
Breastfeeding duration							<.01
0 wk	16 (150)		17 (232)		18 (186)		
≤16 wk	46 (419)		48 (671)		52 (539)		
>16 wk	38 (346)		35 (481)		30 (310)		
Maternal and child anthropometrics							
Maternal BMI							
Prepregnancy (*n* = 3367)		22.2 (3.1)		22.4 (3.0)		24.0 (3.6)	<.0001
Age 1 (*n* = 3349)		22.2 (3.1)		22.6 (3.1)		24.8 (3.9)	<.0001
Age 8 (*n* = 2863)		23.1 (3.4)		23.5 (3.3)		25.6 (4.3)	<.0001
Age 14 (*n* = 2072)		23.7 (3.6)		23.9 (3.2)		26.2 (4.3)	<.0001
Postdelivery weight change (kg)							
Age 1–8 (*n* = 2850)		2.6 (4.6)		2.3 (5.0)		2.6 (6.9)	.41
Age 8–14 (*n* = 1977)		1.5 (4.1)		1.6 (4.7)		1.6 (6.7)	.91
Age 1–14 (*n* = 2063)		4.2 (5.6)		3.9 (5.8)		4.5 (8.1)	.16
Child overweight[c]							
Age 8 y	7 (47)		10 (100)		17 (124)		<.0001
Age 14 y	6 (29)		6 (50)		14 (79)		<.0001

***P* for differences between GWG category: χ^2 test for categorical variables and analysis of variance for continuous variables.

[a] IOM 2009; recommended weight gain during pregnancy: 12.5–18.0 kg for underweight (BMI <18.5) women, 11.5–16.0 kg for normal weight (BMI 18.5–24.9) women, 7.0–11.5 kg for overweight (BMI 25–29.9) women, and 5.0–9.0 kg for obese (BMI ≥30) women.

[b] *n* = 3360 for gestational age, *n* = 3352 for birth weight, *n* = 3354 for maternal age, and *n* = 3280 for paternal age.

[c] Defined according to criteria of International Obesity Task Force.

Postdelivery Maternal Weight Change, Childhood BMI *z* Score, and Overweight

The higher the mother's postdelivery weight gain, the higher the change in child's BMI *z* score (Table 2). For example, children of mothers who gained >1 kg/year between child's ages 1 and 8 years had a 0.16 (95% CI, 0.02 to 0.29) higher change in BMI *z* score between age 1 and 8 years than children of mothers who gained <0.5 kg/year during that period. These children were also more likely to be overweight at age 8 (OR 1.41; 95% CI, 0.99 to 2.00) (Supplemental Table 3).

Combined GWG and Postdelivery Maternal Weight Change and Childhood BMI *z* Score, Overweight, and Cardiometabolic Health

Figure 3 shows the combined effect of GWG (indicated by the color of the line) and postdelivery maternal weight gain (indicated by the line type) on childhood BMI *z* score. In concordance with Fig 2, children of mothers with excessive GWG (blue lines) had the highest BMI *z* score compared with the children of mothers with adequate (red lines) and inadequate (gray lines) GWG, at least in early and midchildhood. Additional development of child BMI *z* score differed between categories of maternal postdelivery weight gain. Child BMI *z* score increased in children of mothers with high postdelivery weight gain (dotted lines), while child BMI *z* score was stable or decreased in children of

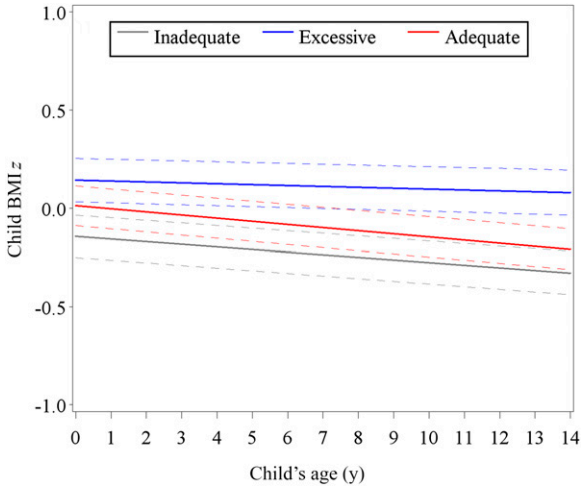

FIGURE 2
Regression lines (and their 95% CI, dashed lines) showing differences in BMI *z* score throughout childhood between children of mothers with inadequate, adequate, and excessive GWG.

mothers with moderate (dashed lines) or low (solid lines) postdelivery weight gain. Children of mothers with excessive GWG and high postdelivery weight gain had the highest BMI *z* score (blue dotted line). Similar categories were created to assess childhood overweight instead of child BMI *z* score. Children of mothers with excessive GWG and high postdelivery weight gain also had the highest overweight risk (OR 3.53; 95% CI, 1.70 to 7.33) at age 14 (Supplemental Table 4).

Sensitivity Analyses

We restricted the analyses for the association between GWG and childhood BMI *z* score to the children who had ≥1 height and weight value measured at our research center at the ages of 4, 8, 12, and 16 years (*n* = 2667). Although the mothers of these children were generally higher educated, had lower prevalence of smoking during pregnancy, and breastfed longer, and the children had a higher mean BMI *z* score around birth, the direction of the association between GWG and BMI *z* score was the same (Supplemental Fig 5). This association was similar for overweight throughout childhood (OR 1.27; 95% CI, 1.00 to 1.62 for excessive GWG) (data not shown).

DISCUSSION

Summary of Findings

Both excessive maternal GWG and high maternal postdelivery weight gain are independent determinants of child weight development up to adolescence. Children of mothers with excessive GWG and children of mothers who had a high postdelivery weight gain had a higher BMI and overweight prevalence in childhood. When GWG and maternal postdelivery weight change were combined, BMI and overweight prevalence was highest for children whose mothers had an excessive GWG and also high postdelivery weight gain.

Methodological Considerations

Strengths of this study are the prospective design with repeated measurements up to adolescence and the availability of several covariates that could be taken into account as potential confounders or effect modifiers. However, some methodological considerations should be taken into account. Maternal weight was self-reported. Generally, heavier adults tend to underreport their weight.[15] This would be a problem if the degree of underreporting was associated with the child's anthropometrics. Associations were similar when we repeated our analyses on a smaller number of children with the weight of the children measured at the research centers, which is independent of maternal self-report. Therefore, potential underreporting of maternal weight is unlikely to have biased our results. However, misclassification of maternal weight due to self-report may have affected the precision of our estimates. Also, GWG was recalled at 1 year after birth, and some missing or unclear values (*n* = 39) were checked at 14 years after birth. GWG recalled within 1 year postpartum is sufficiently reliable,[16] whereas reliability is moderate when recalled up to 12 years after birth.[17] Maternal postdelivery weight gain was used as a proxy for the family obesogenic environment. We are not aware of literature reporting associations between maternal postdelivery weight gain and family lifestyle, but we consider this a good proxy for the full spectrum of family energy

TABLE 2 Change in Child's BMI *z* Score for Each Weight Increase in the Mother in Same Period

Age Period	Weight Increase in Mothers	% (*n*)	Child's BMI *z* Change (95% CI)[a]
1–8 y	Low: <0.5 kg/y	63 (1325)	0 (reference)
	Moderate: 0.5–1.0 kg/y	21 (442)	0.09 (−0.03 to 0.21)
	High: ≥1 kg/y	16 (344)	0.16 (0.02 to 0.29)
8–14 y	Low: <0.5 kg/y	63 (896)	0 (reference)
	Moderate: 0.5–1.0 kg/y	22 (311)	0.07 (−0.04 to 0.18)
	High: ≥1 kg/y	15 (214)	0.11 (−0.02 to 0.24)
1–14 y	Low: <0.5 kg/y	76 (1567)	0 (reference)
	Moderate: 0.5–1.0 kg/y	16 (322)	−0.01 (−0.17 to 0.15)
	High: ≥1 kg/y	8 (174)	0.14 (−0.08 to 0.36)

[a] Analyses are adjusted for parental education, parental age, maternal smoking during pregnancy, maternal prepregnancy BMI, gestational age, presence of older siblings, child's gender, and breastfeeding.

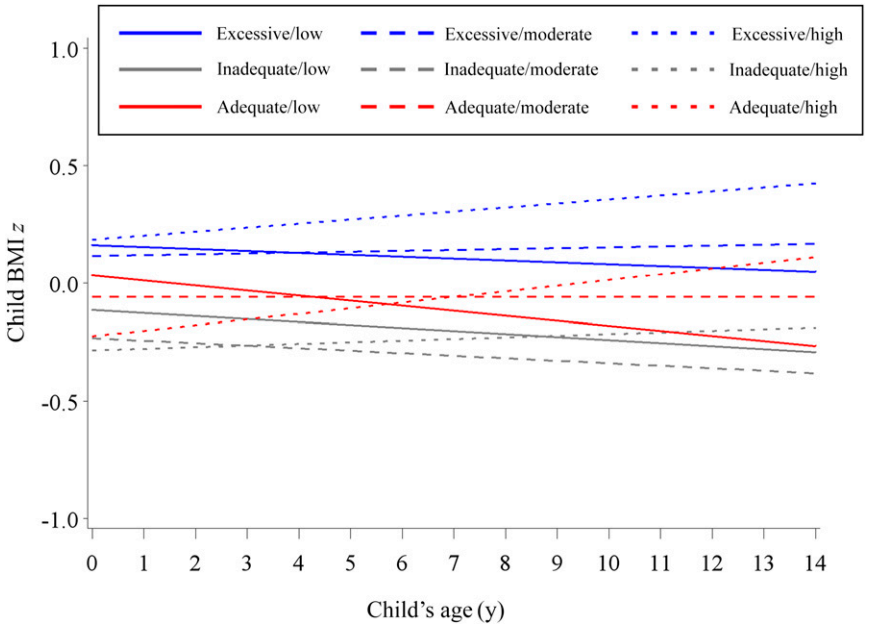

FIGURE 3

Regression lines showing combined estimates of GWG (according to IOM categories: inadequate, adequate, excessive) and postdelivery (low, moderate, high) maternal weight gain on childhood BMI *z* score.

balance–related behaviors during childhood. However, maternal postdelivery weight gain may not fully reflect the child's lifestyle; for example, it may represent weight gain due to subsequent pregnancies and may still leave some misclassification and unaccounted variation. Lastly, children who participated at age 8 but not at age 14 had a slightly higher overweight prevalence than children who participated at age 8 and 14 (13.9% vs 10.5%). However, this difference is unrelated to GWG and therefore may not have introduced bias.

Comparison With Earlier Studies and Interpretation

Earlier studies have assessed associations between GWG and child BMI and overweight. To disentangle a potential programming effect from later lifestyle, we used maternal postdelivery weight change as an indicator of the obesogenity of the family environment.

Our observation that children of mothers with excessive GWG have higher BMI *z* score and overweight prevalence is in line with previous findings. Three meta-analyses were performed on the association between GWG and childhood obesity.[1–3] However, the meta-analyses did not take postdelivery weight gain into account, which is shown to contribute to additional development of childhood BMI in our study.

The association between maternal GWG and BMI in their children may have several underlying mechanisms, mainly genetics, shared lifestyle, and programming in the intrauterine environment. Lawrence et al[4] showed a potential role for genetics for the association between GWG and offspring BMI change. The association between GWG and offspring BMI change attenuated with 28% when a genetic score was added, but offspring genetic variation did not play a role in the association. The authors speculate that epigenetics may underlie this finding. However, shared lifestyle was found to be important as well: A meta-analysis reported that excessive GWG according to the IOM criteria is associated with larger postpartum weight retention,[18,19] and because postpartum weight retention was found to be associated with lifestyle characteristics,[20] GWG may also reflect underlying health behaviors present after delivery. A few studies have used a between-sibling design to unravel intrauterine effects from genetic and lifestyle influences, with conflicting results.[21–23] One study reported that the GWG–childhood overweight associations are completely explained by behavioral and environmental factors,[21] and another study concluded that GWG is associated with child's weight, independent of behavioral and environmental factors.[22] Besides differences in age of outcome between the 2 studies, the conclusion may also differ according to maternal prepregnancy BMI: 1 study concluded that most of the GWG–offspring overweight association was explained by lifestyle and genetic factors in normal weight mothers, and there was a contribution of intrauterine programming in overweight mothers.[23] Studies reporting associations between GWG and childhood obesity adjusted for birth weight, and most concluded that the association is not explained by tracking of birth size, although associations attenuate. Based on the literature and our results, we hypothesize that postdelivery weight change in mothers, reflecting underlying family lifestyle, is associated with childhood overweight, in addition to intrauterine effects, which only puts children on a higher starting BMI track.

CONCLUSIONS

The aim of the IOM GWG recommendations is based on achieving a healthy birth weight and preventing maternal overweight. The IOM did not have sufficient evidence to use the GWG recommendations for long-term health, particularly

offspring overweight development.[24] Based on our study, we conclude that excessive GWG puts children on a BMI track that easily exceeds the limits of a healthy BMI. This study reinforces the importance of maintaining a healthy weight in pregnancy. However, maternal postdelivery weight gain is associated with the development of childhood overweight, which probably reflects underlying shared familial factors, including health behaviors. Therefore, family interventions at any stage during the child's life may facilitate reaching a healthy BMI in the child. Also, interventions before pregnancy remain important, because maternal prepregnancy BMI may be even more strongly related to childhood BMI than GWG.[25,26] Because childhood BMI is known to track into adulthood,[27] and the cardiovascular consequences of adult overweight are clear,[28] GWG may have important implications for future cardiovascular health.

ABBREVIATIONS

CI: confidence interval
GWG: gestational weight gain
IOM: Institute of Medicine
OR: odds ratio

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