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ORIGINAL CONTRIBUTION

Change in maternal body mass index is associated with offspring body mass index: a 21-year prospective study

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Abstract
Purpose To examine whether changes in maternal overweight and obesity from pre-pregnancy to two decades postpartum predict the body mass index (BMI) of adult offspring.
Methods We used a subsample of 1997 mother–offspring pairs from the 7,223 original cohorts of women who gave birth in Brisbane, Australia, between 1981 and 1984. Multiple linear regression and multinomial logistic regression were used to examine the relationship between change in maternal BMI from pre-pregnancy to 21-year postpartum, and offspring BMI at 21-year, adjusting for potential confounding factors.
Results At 21-year postpartum, 31.15 % mothers were overweight and a further 30.80 % were obese. Mothers gained a mean weight of 16.07 kg over the 21 year. We found that the offspring of mothers who became overweight or remained overweight at 21-year postpartum were at greater risk of being overweight and obese at 21 years. In the adjusted model, offspring of mothers who had normal BMI before pregnancy but became overweight by 21-year postpartum were (odds ratio) 1.72 (95 % CI = 1.20, 2.47) times more likely to be overweight. Compared to offspring of mothers who maintained normal weight over two decades, offspring of mothers who remained persistently overweight were (odds ratio) 5.39 (95 % CI = 3.50, 8.30) times more likely to be obese by age 21 year.
Conclusions The findings of this study suggest that long-term changes in maternal BMI from pre-pregnancy to 21-year postpartum are independently associated with BMI in their young adult offspring.

Keywords Maternal overweight · Offspring obesity · BMI change · Confounders

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Introduction

Emerging evidence suggests that parental obesity is an important risk factor for an increased risk of obesity in childhood and adulthood [1–4]. Recent prospective studies have reported that children of obese mothers are more likely to be overweight and obese [5, 6] and that maternal body mass index (BMI) is an important risk factor for youth overweight and obesity [7]. Pre-pregnancy maternal obesity is also a predictor of obesity in preschool children [3]. Mothers who are overweight/obese 36 months after the birth of their offspring tend to be more likely to have a 3-year-old child who is overweight [8]. A 3-year follow-up study of 605 children who were 9–10 years old has suggested that reducing parental weight may lead to a reduction in offspring adiposity [9]. The results from a randomized controlled trial of 8- to 12-year-old children and their parents from 142 families have found that change in parental BMI is a significant predictor of change in child BMI over 6 and 24 months [10].

Changes in parent behavior have been found to impact on the child's weight-related behaviors [11]. However, whether it would be useful to advocate family-based strategies for reducing the BMI of obese children is not yet clear, partly because the effect of change in maternal BMI on the weight status of children is not well documented. It has been suggested that changes in maternal BMI, even over a short period of time, may have a role in determining BMI in the offspring. However, it is unknown whether changes in maternal BMI over a longer period of time, for example from pre-pregnancy to two decades postpartum, have an impact on their young adult's offspring BMI.

The aim of this study is to examine whether changes in maternal BMI from pre-pregnancy to two decades postpartum predict offspring BMI and its categories at 21 years; specifically to prospectively determine whether maternal weight gain is associated with changes in offspring's BMI.

Materials and methods

Study design and participants

Data used are from the Mater-University of Queensland Study of Pregnancy (MUSP) cohort, a mother–offspring pair cohort that began during 1981–1984, when mothers were on average 18 weeks of gestation during their first clinic visit (FCV) at the Mater Mothers Hospital in Brisbane, Australia [12, 13]. The birth cohort comprised 7,223 women who had singleton births at the study hospital and these mothers and their offspring have been followed up, with assessments at 6 month and at 5, 14 and 21 years after the birth. The main analyses are conducted for a subsample of 1997 mothers for whom complete data were available on their pre-pregnancy BMI, BMI at 21-year postpartum and their offspring's BMI at the 21-year follow-up. Informed consent from the mothers was obtained for at phases of data collection. Ethics Committees at the Mater Hospital and the University of Queensland approved each phase of the study. Full details of the study participants and measurements have been previously reported [12, 13].

The main predictor in this study is maternal BMI change from pre-pregnancy to 21-year postpartum (including absolute change as well as change of maternal BMI categories), while offspring BMI and its categories at 21 year are the outcomes.

Offspring body mass index

Young adult's height at 21 years was measured without shoes using a portable stadiometer (no. 214 Road Rod Portable Stadiometer, USA) to the nearest 0.1 cm. Respondent weight was measured in light clothing with a scale (*Wedderburn Scales, Japan)* accurate to 0.2 kg. Two measures of weight and height were taken with a 5-min interval, and the mean of these two measures was used in all analyses. BMI (weight in kilograms divided by the square of height in meters, i.e. kg/m^2) was categorized into normal (BMI $<$ 25 kg/m^2), overweight (BMI $=$ 25–29 kg/m^2) and obese (BMI $\geq$ 30 kg/m^2) using the WHO classification of BMI cut-offs [14].

Maternal body mass index

Maternal pre-pregnancy BMI was calculated based on maternal measured height at the FCV of pregnancy and self-reported pre-pregnancy weight, which was recorded at the study initiation from maternal questionnaires. Maternal BMI at FCV was calculated based on the measured height and weight at that visit. There was a high correlation between maternal estimate of pre-pregnancy weight and measured weight on the FCV (Pearson's correlation coefficient $=$ 0.95). The mother's height was measured without shoes using a portable stadiometer to the nearest 0.1 cm. Weight was measured in light clothing with a scale accurate to 0.2 kg. Two measures of weight and height were taken with a 5-min interval, and the mean of these two measures was used in all analyses. Like offspring BMI, maternal BMI was categorized into normal, overweight and obese using the WHO classification of BMI cut-offs [14]. However, for the purpose of the main analyses, maternal BMI was dichotomized as normal or overweight (including obese category). Change in maternal BMI from pre-pregnancy to 21-year postpartum was calculated by subtracting pre-pregnancy BMI from 21-year BMI. Similarly, the change in maternal BMI from FCV to 21-year postpartum was calculated by subtracting FCV BMI from 21-year BMI. Combining pre-pregnancy and 21-year postpartum BMI categories, four possible patterns are considered: (a) normal BMI before pregnancy and 21-year postpartum; (b) normal BMI before pregnancy but overweight at 21-year postpartum; (c) overweight before pregnancy but normal at 21-year postpartum and (d) overweight at both times.

Confounding factors

The following maternal and child characteristics were considered to be potential confounding factors on the basis of a priori knowledge [15] and their association with maternal BMI change and offspring BMI. Available potential confounders were maternal age at birth (in years), offspring sex, maternal educational attainment (did not complete secondary school, completed secondary school, completed further/higher education), maternal pre-pregnancy consumption of cigarettes, maternal stress, depression during pregnancy, birth weight, breastfeeding, offspring TV watching, sports participation and family attitude to eating together. At the FCV, the mean age of mothers was 25 (range: 13–47) years. Mothers were asked, "How many cigarettes did you usually smoke per day before you became pregnant?" For analysis, we categorized the responses as none, 1–19, or 20 or more cigarettes per day. Maternal stress was measured using the Los Angeles Stress Scale [16], and maternal depression was measured using the Delusions-Symptoms-States-Inventory (DSSI) [17]. The Cronbach's alpha for both scales was 0.80. In the present study, the DSSI responses were dichotomized. Those people reporting experiencing a symptom 'all the time', 'most of the time' or 'some of the time' were considered to be experiencing a symptom of depression. There were seven symptoms in all. We have defined maternal stress in a similar manner. Child birth weight (in grams) was as recorded in the obstetric record of the birth. Duration of breastfeeding was obtained at the 6-month postpartum and was categorized as never, <4 or 4 months or more. Child TV watching and sports participation data were obtained from the maternal report at the 14-year follow-up. Mothers reported the amount of time their child spent watching television (<1 h per day, 1 to <3 h per day, 3 to <5 h per day and 5 or more hour per day) and the amount of time children spent on sports or exercise (4–7 days per week; 0–3 days per week). At the 14-year follow-up, the mothers were asked how important it was that the family had meals together. The response options were very important, quite important and not really important. We used this as a measure of shared family meals [18].

Statistical analyses

We compared the characteristics of women who provided information on pre-pregnancy BMI, BMI at 21-year postpartum and their offspring's BMI at 21 year, with the women who did not have these information but did provide other socio-demographic information at the FCV. The characteristics we considered at the FCV are maternal age, education, family income, marital status, depression, stress, racial origin and pre-pregnancy BMI. We used Chi square test for this comparison.

Descriptive analyses (% for categorical data; mean ± SD for continuous data) of the maternal and offspring characteristics (as described before) are presented by maternal body mass index change categories from (pre) pregnancy to 21-year postpartum. Any statistically significant differences of these characteristics by offspring BMI are tested using F-tests for continuous variables and Chi square tests for categorical variables. Because few women (only 5) were in the category of overweight before pregnancy but normal at 21-year postpartum, we have excluded them from the analyses.

Statistical evidence for a difference in effect between males and females was assessed by computing a likelihood ratio test of the interaction with sex. As we found no statistical evidence that the effect differed between the sexes, results are presented for males and females combined. Similarly, we have assessed the interaction effects for maternal age and education.

Based on the scatter plot of maternal BMI change and offspring BMI at 21 year, we found the association approximated a linear relationship. We also examined the nonlinearity of the association using restricted cubic spline regression models including potential confounders and found no nonlinear relationships ($P > 0.20$). To increase statistical precision, maternal BMI was dichotomized as normal or overweight (including obese category) before pregnancy and 21-year postpartum.

Multiple linear regressions are used to examine the association of change in maternal BMI (absolute change and overweight patterns) from pre-pregnancy to 21-year postpartum with offspring BMI at 21 year. Results are presented for unadjusted and adjusted for potential confounding factors. Results are presented as regression coefficients or mean difference (with 95 % Confidence Interval) in offspring BMI at 21 year. Similarly, multinomial logistic regressions are used to estimate the unadjusted and adjusted odds ratio (OR) of being overweight and obese at 21 year with the change in maternal BMI and its categories from pregnancy to 21-year postpartum.

We have added an analysis stratified by the maternal pre-pregnancy BMI < 25 kg/m^2 and BMI ≥ 25 kg/m^2 to determine whether a change in the mother's BMI by their pre-pregnancy BMI status differentially predicted children's BMI at age 21. A test of interaction between pre-pregnancy BMI and change in BMI to predict offspring BMI was performed.

All analyses were carried out using Stata version 11.0 (Stata inc., Texas).

Results

We found that offspring who were not followed up at 21 years were more like to have younger mothers, with less education and lower income, to have more often had marital breakdowns and be depressed as well as having Asian or Aboriginal-Islander background (all $P < 0.05$). The loss to follow-up was not associated with maternal pre-pregnancy BMI (Table 1).

Of 1997 women, 11.02 % were overweight and 3.91 % were obese before pregnancy. At 21-year postpartum, 31.15 % mothers were overweight and a further 30.80 % were obese. Mothers gained a mean of 16.07 ± 11.79 kg over the 21 years of follow-up period, and their mean BMI changed from 21.82 kg/m^2 before pregnancy to 27.89 kg/m^2

Table 1 Comparison of the characteristics of women those who did have information on pre-pregnancy BMI, BMI at 21-year postpartum and their offspring's BMI at 21 year with the women who did not have these information but socio-demographic information at the first clinic visit (FCV)

Background factors	Had information on pre-pregnancy BMI, BMI at 21-year postpartum and their offspring's BMI at 21 years (n = 1997)	Had no information on gestational weight gain, pre-pregnancy BMI and diabetes mellitus at 21 years but at pregnancy (n = 5,226)	P*
Maternal age at FCV			
13–19	197 (9.86)	799 (15.29)	
20–34	1,691 (84.68)	4,179 (79.97)	
34+	109 (5.46)	248 (4.75)	<0.001
Maternal education at FCV			
Did not complete secondary education	313 (15.79)	992 (19.14)	
Completed secondary education	1,280 (64.45)	3,329 (64.22)	
Completed further or higher education	393 (19.79)	863 (16.65)	<0.001
Income at first clinic visit (FCV)			
AUS $10400 or more	1,362 (71.50)	3,079 (63.56)	
$10400 or less	543 (28.50)	1,765 (36.44)	<0.001
Marital status at FCV			
Married	1,652 (83.22)	3,734 (72.15)	
Living together	161 (8.11)	683 (13.20)	
Single	139 (7.00)	597 (11.54)	
Separated/divorced/widowed	33 (1.66)	161 (6.11)	<0.001
Maternal depression at FCV			
Not depressed	1,908 (96.95)	4,765 (93.12)	
Depressed	60 (3.05)	352 (6.88)	<0.001
Maternal stress			
Not stressed	1,839 (93.30)	4,636 (90.64)	
Stressed	132 (6.70)	479 (9.36)	<0.001
Maternal smoking status at FCV			
None smoker	1,297 (65.44)	3,125 (60.40)	
1–20 cigarettes per day	543 (27.40)	1,574 (30.42)	
20 + cigarettes per day	142 (7.16)	475 (9.18)	<0.001
Racial origin			
White	1,810 (93.06)	4,449 (87.84)	
Asian	69 (3.55)	238 (4.70)	
Aboriginal-Islander	66 (3.39)	378 (7.46)	<0.001
Pre-pregnancy BMI			
Normal	1,699 (85.08)	3,900 (83.07)	
Overweight	220 (11.02)	566 (12.06)	
Obese	78 (3.91)	229 (4.88)	0.09

* P indicates the significance level of the difference by characteristics of women those who did and did not have information on pre-pregnancy BMI, BMI at 21-year postpartum and offspring's BMI at 21 year. We used a Chi square test for categorical data

at 21-year postpartum. At 21 year, overall, 21.38 % of offspring were overweight and a further 11.52 % were obese.

Maternal anthropometric measures including pre-pregnancy, FCV and 21-year postpartum weight, BMI and change in BMI were associated with the change in maternal BMI categories (all $P < 0.01$) (Tables 2, 3). Maternal age at FCV, education level, smoking cigarettes before pregnancy and breastfeeding were associated with maternal BMI categories change (Table 2). Offspring birth weight and their TV watching at adolescence were associated with maternal BMI change (Table 3).

The association of changes in maternal BMI and its categories from pre-pregnancy or pregnancy to 21-year postpartum of the index pregnancy with mean difference in offspring BMI at 21 year is presented in Table 4. Mean differences or regression coefficients (with 95 % confidence interval) are presented for 1807 offspring for whom we have available data for all variables included in the

Table 2 Maternal characteristics (mean ± SD for continuous variables and % for categorical variables) by maternal body mass index categories change from pregnancy to 21-year postpartum

	N	Maternal BMI categories change from pregnancy to 21-year postpartum			*P**
		Normal before and at 21 year	Normal before but overweight at 21 year	Overweight at both time	
Total sample (%)	1,992	37.90	47.39	14.71	
Maternal characteristics					
Maternal age at first clinic visit in years	1,992	25.60 ± 4.86	25.28 ± 4.90	27.09 ± 5.23	<0.001
Maternal pre-pregnancy weight (kg)	1,992	52.25 ± 6.34	56.86 ± 6.52	75.32 ± 11.19	<0.001
Maternal weight (kg) at first clinic visit (kg)	1,992	56.87 ± 7.20	62.19 ± 7.68	78.80 ± 11.08	<0.001
Maternal weight (kg) at 21-year postpartum	1,992	59.73 ± 6.76	78.99 ± 11.65	94.59 ± 16.95	<0.001
Maternal pre-pregnancy BMI (kg/m^2)	1,992	19.56 ± 1.89	21.45 ± 1.92	28.70 ± 3.86	<0.001
Maternal BMI at first clinic visit (kg/m^2)	1,992	18.32 ± 2.61	20.11 ± 2.93	25.34 ± 4.07	<0.001
Maternal BMI (kg/m^2) at 21-year postpartum	1,992	22.35 ± 1.84	29.81 ± 3.91	36.05 ± 6.09	<0.001
Change in maternal BMI from pre-pregnancy to 21-year FU	1,992	2.79 ± 2.03	8.35 ± 3.68	7.35 ± 5.58	<0.001
Change in maternal BMI from first clinic visit to 21-year FU	1,992	4.05 ± 2.75	9.63 ± 4.16	10.63 ± 6.06	<0.001
Maternal smoking cigarettes before pregnancy					
None	1,084	35.33	47.51	17.16	0.004
1–20 Cigarettes per day	550	42.36	46.73	10.91	
20 or more cigarettes per day	345	38.84	47.83	13.33	
Maternal education					
Did not complete secondary education	312	30.13	50.00	19.87	0.005
Completed secondary education	1,276	38.79	47.02	14.18	
Completed further or higher education	393	41.48	46.31	12.21	
Breastfeeding					
Never	339	35.10	44.84	20.06	
Less than 4 months	716	36.03	49.72	14.25	
4 months and more	874	40.73	45.88	13.39	0.014

* *P* indicates the significance level of the difference by offspring body mass index categories. We used an F test for a continuous data and a Chi square test for categorical data

adjusted model. In the unadjusted model, for one unit increase in absolute mean difference of maternal BMI over 21 year, offspring BMI increased by 0.12 (95 % CI = 0.07, 0.17) kg/m^2 at 21 year. Similarly, when we considered the maternal BMI change from FCV to 21-year postpartum, the offspring BMI increased at the same rate (results are not presented). For mothers who became overweight and remained overweight at 21-year postpartum, their offspring have 1.28 (95 % CI = 0.83, 1.74) and 3.43 (95 % CI = 2.80, 4.06) units higher BMI at 21-year follow-up compared to the offspring of those women who maintained normal weight. All these associations remained robust and statistically significant after adjusting for potential confounding factors.

The association of the change in maternal BMI and its categories from pre-pregnancy to 21-year postpartum with offspring overweight and obesity at 21 year is presented in Table 5. The odds ratio (OR) of being overweight and obese are 1.04 (95 % CI = 1.02, 1.07) and 1.05 (95 % CI = 1.01, 1.08), respectively, for one unit increase in maternal BMI change over 21-year postpartum. Offspring of mothers who become overweight are 1.74 (95 % CI = 1.33, 2.26) times more likely to be overweight and offspring of mothers who persistently remain overweight are nearly three times more likely to be overweight and five times more likely to be obese at the 21-year follow-up compared to women who maintained normal weight post-partum. A similar strength of associations is observed for the change in maternal BMI from FCV to 21-year post-partum (results are not presented). These associations are independent of a range of potential confounding factors.

When we repeated the analyses stratifying by the maternal pre-pregnancy BMI < 25 kg/m^2 and BMI ≥ 25 kg/m^2, the

Table 3 Offspring characteristics around birth and at 14-year follow-up maternal body mass index categories change from pregnancy to 21-year postpartum

	N	Maternal BMI categories change from pregnancy to 21-year postpartum			*P**
		Normal before and at 21 year	Normal before but overweight at 21 year	Overweight at both time	
Offspring characteristics					
Sex					
Male	1,015	36.26	48.87	14.88	
Female	977	39.61	45.85	14.53	0.29
Birth weight (kg): mean ± SD	1,991	3.34 ± 0.48	3.39 ± 0.52	3.52 ± 0.57	<0.001
TV watching					
<1 h per day	135	47.41	43.70	8.89	
1 to <3 h per day	531	40.87	47.08	12.05	
3 to <5 h per day	526	34.79	49.24	15.97	0.011
≥5 h per day	709	36.81	46.12	17.07	
Sports					
d 4–7 per week	957	36.68	47.65	15.67	0.34
d 0–3 per week	949	39.20	46.89	13.91	
Family attitude to having meals together					
Not really important	182	37.91	45.60	16.48	
Quite important	868	36.87	47.00	16.13	0.42
Very important	859	39.58	47.26	13.15	

* *P* indicates the significance level of the difference by offspring body mass index categories. We used an F test for a continuous data and a Chi square test for categorical data

Table 4 Mean difference in offspring body mass index (95 % confidence interval) by the change in maternal body mass index from pre-pregnancy to 21-year postpartum ($N = 1{,}807$)

Change in maternal BMI from pre-pregnancy to 21-year FU	Mean difference or regression coefficient	
	Unadjusted (95 % CI)	Adjusted (95 % CI)
Change in maternal BMI (kg/m^2) from pre-pregnancy to 21-year postpartum*	0.12 (0.07, 0.17)	0.11 (0.06, 0.15)
Pre-pregnancy BMI < 25 ($n = 1{,}535$)*	0.12 (0.07, 0.18)	0.12 (0.06, 0.17)
Change in maternal BMI (kg/m^2) from pre-pregnancy to 21-year postpartum		
Pre-pregnancy BMI ≥ 25 ($n = 274$)*	0.03 (−0.07, 0.14)	0.02 (−0.09, 0.13)
Change in maternal BMI (kg/m^2) from pre-pregnancy to 21-year postpartum		
*Maternal overweight/obesity patterns***		
Normal before pregnancy and at 21-year postpartum (ref. category)	0	0
Normal before pregnancy but overweight at 21-year postpartum	1.28 (0.83, 1.74)	1.25 (0.79, 1.71)
Overweight before pregnancy and at 21-year postpartum	3.43 (2.80, 4.06)	3.46 (2.81, 4.11)

Adjusted: Results adjusted for maternal age in FCV, offspring sex, maternal smoking before pregnancy, maternal education, birth weight (in gm), breastfeeding, offspring TV watching, sport participation and family meals at 14 year

* Regression coefficient

** Mean difference

association between the change in maternal BMI (kg/m^2) from pre-pregnancy to 21-year postpartum and offspring BMI was statistically significant mainly for the mothers who had normal BMI before pregnancy, and it was attenuated for the women who were overweight before pregnancy (Tables 4, 5). However, the interaction effect between pre-pregnancy BMI and change in BMI to predict offspring BMI was not significant (*P*-for interaction = 0.09).

When we additionally adjusted all the multivariable results for maternal depression and stress during pregnancy, the strength and direction of associations remain nearly unchanged. We have conducted further analyses testing for interactions between maternal weight gain and maternal age at pregnancy and also interactions between maternal weight gain and education to predict offspring BMI at 21 year. We found none of these interactions was statically significant (all *P* values >0.26).

Discussion

Using a 21-year prospective follow-up of mother–offspring pairs, we found that mothers who became overweight or remained overweight or obese over two decades postpartum have children who were more likely to become overweight by 21 years of age. We also found that an increase in BMI for a mother from pregnancy to 21-year postpartum is associated with her offspring having increased BMI by 21 year of age. These prospective associations are not explained by a range of potential confounding factors including maternal age, education and tobacco consumption during pregnancy, offspring birth weight, breastfeeding, adolescent TV watching, sports participation and family meals. The findings of this study suggest that if mothers maintain healthy weight or normal BMI over a long postpartum period, their offspring are more likely to have normal BMI and are at less risk of becoming overweight or obese by age 21 year.

Our results are in broad agreement with past research that maternal BMI is an important predictor of offspring BMI [3, 4, 7, 19, 20]. In addition, our study found that not only maternal BMI before the index pregnancy predicts offspring BMI, but also maternal BMI change over two decades is associated with offspring BMI change. We have also found that the association between the change in maternal BMI from pre-pregnancy to two decades postpartum and adult offspring BMI was mainly observed for mothers who had normal BMI before pregnancy. The strength of our study is its longitudinal design and follow-up till young adulthood. More importantly, we were able to adjust for potential confounding factors including maternal education, age and tobacco consumption, birth weight of the children, sex, breastfeeding, children TV watching, and sports participation, and family meal patterns when children were adolescents.

There may be many factors which affect the child's weight in young adulthood. Both genetic and environmental factors may promote behaviors associated with weight change in children [21–24]. Familial aggregation of certain behaviors including diet and physical activity has been attributed to genetic (as well as environmental) influences [25]. It is likely that overweight mothers have children at risk of overweight partly because they transmit their genetic propensity to gain weight.

A major factor that could be associated with both maternal and offspring weight gain is maternal history of diabetes, and especially gestational diabetes. In our study,

Table 5 Unadjusted and adjusted odds (multinomial logistic regression, offspring normal BMI at 21 year as reference) of being overweight and obese at 21 year by the change in maternal BMI from pre-pregnancy to 21-year postpartum ($N = 1{,}807$)

Change in maternal BMI from pre-pregnancy to 21-year FU	Unadjusted			Adjusted		
	Odds ratio (95 % CI)			Odds ratio (95 % CI)		
	Normal	Overweight	Obese	Normal	Overweight	Obese
Change in maternal BMI (kg/m^2) from pre-pregnancy to 21-year postpartum	1.00	1.04 (1.02, 1.07)	1.05 (1.01, 1.08)	1.00	1.04 (1.01, 1.07)	1.05 (1.01, 1.08)
Pre-pregnancy BMI < 25 ($n = 1{,}535$)	1.00	1.06 (1.02, 1.09)	1.06 (1.02, 1.10)	1.00	1.05 (1.02, 1.09)	1.06 (1.01, 1.10)
Change in maternal BMI (kg/m^2) from pre-pregnancy to 21-year postpartum						
Pre-pregnancy BMI ≥ 25 ($n = 274$)	1.00	0.99 (0.94, 1.04)	1.00 (0.95, 1.05)	1.00	0.97 (0.92, 1.03)	0.99 (0.94, 1.05)
Change in maternal BMI (kg/m^2) from pre-pregnancy to 21-year postpartum						
Maternal overweight/obesity pattern						
Normal before pregnancy and at 21-year postpartum (ref. category)	1.00	1.00	1.00	1.00	1.00	1.00
Normal before pregnancy but overweight at 21-year postpartum	1.00	1.74 (1.33, 2.26)	1.72 (1.20, 2.47)	1.00	1.72 (1.32, 2.25)	1.70 (1.18, 2.45)
Overweight before pregnancy and at 21-year postpartum	1.00	2.92 (2.05, 4.14)	5.20 (3.44, 7.88)	1.00	3.03 (2.11, 4.35)	5.39 (3.50, 8.30)

Adjusted: Results are adjusted for maternal age in FCV, offspring sex, maternal smoking before pregnancy, maternal education, birth weight (in gm), breastfeeding, offspring TV watching, sport participation and family meals at 14 year of 1,807 women, only 7 women reported gestational diabetes. This number may be an underestimate. The diagnostic and screening criteria for gestational diabetes were controversial in the early 1980s [26]. Therefore, according to current standards, some women might have had undiagnosed diabetes during the pregnancy at that time. If these women were excluded from the analyses, this might attenuate the association between maternal weight change and offspring BMI.

Previous research has identified similarities in parents' and children's dietary practices [27], food preferences [28] and physical activity [29]. The role of the mother in influencing the child's lifestyle at home may explain why maternal BMI is linked to the child's BMI. Mothers usually remain responsible for the bulk of child-rearing. Mothers usually serve as role models for children's eating and physical activity and influence children's access to food and opportunities for physical activity. It is noted that mothers with higher BMI participate in less activity, enjoy activity less, and consume a greater percentage of energy from fat [24]. Children may adopt their level of physical activity and food preferences from their overweight mothers. One study has suggested that children as young as 5 years old demonstrate increased preferences for high-fat foods if their parents are obese [30]. There is also some evidence that disinhibited overeating has a genetic basis [31], and hence, if overweight mothers are genetically predisposed to disinhibited eating, their children may share those genetic predispositions. This may influence the development of these eating behaviors in children. The increase in BMI is associated with increasing age of both mothers and offspring. In our study, adjusting for a range of confounding factors including breastfeeding, maternal smoking, offspring TV watching, sport participation and attitude to having family meals together at 14 year, we found the associations between change in maternal BMI from pregnancy to 21-year postpartum and offspring BMI at 21 year remain robust. While both genetic factors and similarities in parents' and children's dietary and lifestyle are likely to account for mother–offspring correlation in high BMI or obesity risk, which of these makes the greater contribution remains to be determined. A large study with better biological (e.g. genetics) and environmental (serial measures of diets and physical activities) measurements may help to resolve this uncertainty.

The loss to follow-up in the MUSP cohort was considerable. This loss to follow-up is discussed in detail elsewhere [13]. In general, participants lost to follow-up in the MUSP were disproportionately of lower socio-economic status. Mothers and offspring lost to follow-up were less likely to have completed high school, more likely to be in their teenage years at FCV, be single at FCV, be smokers and to have poorer mental health [13]. The disproportionate loss to follow-up may lead to underestimates of the strength of associations (that is the loss of higher BMI mothers and children). We have previously used three strategies to assess the impact of attrition on our estimates of association. Firstly, we have used multiple imputations resulting in only marginal changes in our findings. Secondly, we have undertaken sensitivity analyses modeling a wide variety of associations about the impact of those lost to follow-up [13]. These have provided findings which do not differ from those we have obtained. Finally, we have undertaken comparative analyses using data from different cohort studies with different levels of attrition, with the conclusion that even with substantial variations in loss to follow-up, there is little impact on the findings [32].

Mothers gained a good deal of weight (16 kg) over two decades postpartum. Direct comparison of this finding with those from other studies is not possible because there is no other study so far that has estimated postpartum weight gain over two decades. However, the recent overweight/obesity rate in Australian females in 2007–2008 in the 45–55 year group was 55 % [33], which is not substantially different from our estimate of 62 %. The 55 % estimate relied on self-reported height and weight, which is likely to be an under estimate. Compared with the general population, the MUSP sample is likely to be a sample of lower to middle socioeconomic status of Australian women [12, 13]. Therefore, it appears that our estimate of 16 kg over 21 years on average is realistic.

We do not have good nutritional data during and post-pregnancy. However, when we adjusted the associations for the maternal reported eating family meals together at the 14-year follow-up, the association remains consistent. Maternal reports of eating meals together are a proxy measure for better quality of overall family diets. For instance, several studies have found that children and adolescents who eat dinner with family members more often are more likely to eat fruit and vegetables and are less likely to eat high-fat foods, convenience foods, and sweets and to drink large amounts of carbonated drinks [34–36]. Further studies are required with good nutritional data for both mothers and offspring. Another limitation is that no serial measurements of maternal BMI were made in the postpartum period until the 21-year follow-up. With a serial measurement of maternal BMI, one can examine the changes in offspring BMI with the changes in maternal BMI over time with more precision utilizing generalized linear models.

The findings of this study suggest that if mothers maintain normal weight over the 21-year postpartum period, their children are more likely to avoid becoming overweight or obese when they grow up. To further prevent the development of overweight and obesity for young adults, intervention programs should consider the maintenance of normal weight or encouraging a reduced level of weight gain among mothers during their postnatal periods. However, further large scale studies with serial measures of maternal pre-pregnancy and postpartum weight and offspring weight over a long period of time are needed to confirm this finding.

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