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

Abdullah A Mamun[1], Michael J O'Callaghan[2,3], Gail M Williams[1], Jake M Najman[1]

[1] School of Population Health, University of Queensland, Brisbane, Australia,

[2] Mater Children's Hospital, and University of Queensland, Brisbane Australia

[3] School of Medicine, University of Queensland, Brisbane, Australia

Running title: Maternal and offspring overweight status

Funding: The core study was funded by the National Health and Medical Research Council (NHMRC) of Australia. AAM is supported by a Career Development Awards from the NHMRC (ID 519756). For the work in this paper, AAM has a grant from the National Heart Foundation of Australia (ID G07B3135). The views expressed in the paper are those of the authors and not necessarily those of any funding body and no funding body influenced the way in which the data were analysed and presented.

Conflict of interest: Authors have no conflict of interest.

Corresponding author:

Abdullah Al Mamun

School of Population Health, University of Queensland

Herston Rd, Herston, QLD 4006, Australia

Tel: +61 7 33464689; Fax: +61 7 33655599; e-mail: mamun@sph.uq.edu.au

Mamun, AA, O'Callaghan, MJ, Williams, GM, Najman, JM

Word count: 4986 (including references and tables)

The number of figure: None

The number of tables: four

[1]Supplemental table 1 is available from the "Online Supporting Material" link in the online posting of the article and from the same link in the online table of contents at http://jn.nutrition.org.

Author defined abbreviations:

FCV First Clinic Visit

MUSP Mater-University of Queensland Study of Pregnancy

ABSTRACT

It is relatively less known whether changes in maternal overweight and obesity from pre-pregnancy to two decades postpartum predict the body mass index (BMI) of adult offspring . We have examined whether long-term changes in maternal BMI are associated with offspring BMI using a subsample of 1997 mother-offspring pairs from the 7223 original cohort 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 y postpartum and offspring BMI at 21 y, adjusting for potential confounding factors. At 21 y postpartum, 31.15% mothers were overweight and a further 30.80% were obese. Mothers gained a mean weight of 16.07 kg over 21y. We found that the offspring of mothers who became overweight, or remained overweight at 21 y 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 y postpartum were 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 5.39 (95%CI= 3.50,8.30) times more likely to be obese by age 21 y. The findings of this study suggest that long-term changes in maternal BMI from pre-pregnancy to 21 y postpartum are independently associated with BMI in their young adult offspring.

Key words: maternal overweight, offspring obesity, BMI change

This is a post-print version of the following article: Mamun, Abdullah A., O'Callaghan, Michael J., Williams, Gail M. and Najman, Jake M. (2012) Change in maternal body mass index is associated with offspring body mass index: a 21-year prospective study. *European Journal of Nutrition*, *52* 6: 1597-1606.

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 BMI is an important risk factor for youth overweight and obesity [7]. Also, the role of pre-pregnancy maternal obesity as a predictor of obesity in preschool children has been identified [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 three year follow-up study has suggested that reducing parental weight may lead to a reduction in offspring adiposity [9]. The results from a randomized controlled trial have also found that changes in parental BMI are 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 any 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 similar changes in offspring's BMI.

MATERIALS AND METHODS

Study Design and Participants

Data used are from the MUSP, a mother-offspring pair cohort that began during 1981-1984, when mothers were on average 18 weeks of gestation during their FCV at the Mater Mothers Hospital in Brisbane, Australia [12 13]. The birth cohort comprised 7223 women who had singleton births at the study hospital and these mothers and their offspring have been followed-up prospectively, with assessments at 6 mo and at 5, 14 and 21 y after the birth. The present analyses are limited to 1997 mothers for whom complete data was available on their pre-pregnancy BMI, BMI at 21 y postpartum and their offspring's BMI at the 21 y follow-up. Informed consent from the mothers was obtained for all 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 y postpartum (including absolute change as well as change of maternal BMI categories), while offspring BMI and its categories at 21 y are outcomes.

Offspring body mass index

This is a post-print version of the following article: Mamun, Abdullah A., O'Callaghan, Michael J., Williams, Gail M. and Najman, Jake M. (2012) Change in maternal body mass index is associated with offspring body mass index: a 21-year prospective study. *European Journal of Nutrition*, *52* 6: 1597-1606.

Young adult's height at 21 y was measured without shoes using a portable stadiometer to the nearest 0.1 cm. Respondent weight was measured in light clothing with a scale accurate to 0.2 kg. Two measures of weight and height were taken 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<25kg/m^2), overweight (BMI=25-29 kg/m^2) and obese (BMI≥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 0.1cm. Weight was measured in light clothing with a scale accurate to 0.2 kg. Two measures of weight and height were taken with a five minute 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 and to increase statistical precision, maternal BMI was dichotomized as normal or overweight (including obese category). Change in maternal BMI from FCV to 21 y postpartum was calculated by subtracting FCV BMI from 21 y BMI. Similarly, change in maternal BMI from pre-pregnancy to 21 y postpartum was calculated by subtracting pre-pregnancy BMI from 21 y BMI. Combining pre-pregnancy and 21 y postpartum BMI categories, four possible patterns are considered: (a) Normal BMI before pregnancy and 21 y postpartum; (b) Normal BMI before pregnancy but overweight at 21 y postpartum; (c) overweight before pregnancy but normal at 21 y 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) and maternal pre-pregnancy consumption of cigarettes. At the FCV, the mean age of mothers was 25 (range: 13 to 47) y. Mothers were asked, "How many cigarettes did you usually smoke per day before you became pregnant?" For the analysis purpose, we categorized their response as none, 1-19, or 20 or more per day.

Birth weight, duration of breastfeeding, TV watching, sports participation and family attitude to eating together were considered as possibly confounding factors for the association between maternal BMI change and offspring BMI. Child birth weight (in grams) was as recorded in the obstetric record of the birth. Duration of breastfeeding was obtained at the 6 mo postpartum and was categorized as never, <4 mo or 4 months or more. Child TV watching and sports participation data were obtained from the maternal report at the 14 y 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 h per day) and the amount of time children spent on sports

This is a post-print version of the following article: Mamun, Abdullah A., O'Callaghan, Michael J., Williams, Gail M. and Najman, Jake M. (2012) Change in maternal body mass index is associated with offspring body mass index: a 21-year prospective study. *European Journal of Nutrition*, *52* 6: 1597-1606.

or exercise (d 4-7 per w; d 0-3 per w). At the 14 year follow-up, the mothers were asked how important it was that the family ate together and was given the response options: very important, quite important and not really important. We used this as a measure of shared family meals [16].

Statistical analyses

We compared both the sub-sample of respondents who were followed-up using a questionnaire (N=3775) to those not followed-up at 21 y and those completed physical assessments (N=2181) to those not followed-up at 21 y who had BMI and socio-demographic information at the first clinic visit. Adjusted odds ratios of not being followed up at 21 y were estimated using multiple logistic regression.

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 y 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 y 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.

Based on the scatter plot of maternal BMI change and offspring BMI at 21 y, we found the association approximated a linear relationship. We also examined the non-linearity of the association using restricted cubic spline regression models including potential confounders and found no non-linear relationships (*P*>0.20).

Multiple linear regressions are used to examine the association of change in maternal BMI (absolute change and overweight patterns) from pre-pregnancy to 21 y postpartum with offspring BMI at 21 y. 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 y. Similarly, multinomial logistic regressions are used to estimate the unadjusted and adjusted odds of being overweight and obese at 21 y with the change in maternal BMI and its categories from pregnancy to 21 y postpartum.

We have presented significant *P* values to three decimal places and non-significant *P* values are reported to two digits past the decimal.

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

Results

We found that offspring who were not followed-up at 21 years either using a questionnaire or by conducting physical assessments including BMI, were more like to have younger mothers, with less education and lower income, to have had marital break-downs 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 (supplementary Table 1).

Of 1997 women, 11.02% were overweight and 3.91% were obese before pregnancy. At 21 y postpartum, 31.15% mothers were overweight and a further 30.80% were obese. Mothers gained a mean of 16.07 ±11.79 kg over 21 y and their mean BMI changed from 21.82 kg/m^2 before pregnancy to 27.89 kg/m^2 at 21 y postpartum. At 21 y, overall, 21.38% of offspring were overweight and a further 11.52% were obese.

Maternal anthropometric measures including pre-pregnancy, FCV and 21 years postpartum weight, BMI and change in BMI were associated with the change in maternal BMI categories (all $P<0.01$) (Table 1 and Table 2**)**. Maternal age at FCV, education level, smoking cigarettes before pregnancy, and breastfeeding were associated with maternal BMI categories change (Table 1). Offspring birth weight and their TV watching at adolescence were associated with maternal BMI change (Table 2).

The association of changes in maternal BMI and its categories from pre-pregnancy or pregnancy to 21 y postpartum of the index pregnancy with mean difference in offspring BMI at 21 y is presented in Table 3. Mean differences or regression coefficients (with 95% confidence interval) are presented for 1809 offspring for whom we have available data for all variables included in the adjusted model. In the unadjusted model, for one unit increase in absolute mean difference of maternal BMI over 21 y, offspring BMI increased by 0.12 (95%CI=0.07,0.17) kg/m^2 at 21 y. Similarly, when we considered the maternal BMI change from FCV to 21 y postpartum, the offspring BMI increased at the same rate. For mothers who became overweight and remained overweight at 21 y 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 y 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 or FCV to 21 y postpartum of the index pregnancy with offspring overweight and obesity at 21 y is presented in Table 4. The odds 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 y 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 21 y compared to women who maintained normal weight postpartum. These associations are independent of a range of potential confounding factors.

Discussion

Using a 21 y 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 are more likely to become overweight by age 21 y. We also found that an increased in BMI for a mother from pregnancy to 21 y postpartum is associated with her offspring having increased BMI by 21 y of age. These prospective associations are not explained by the 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 y.

Our results are in broad agreement with past research that maternal BMI is an important predictor of offspring BMI [3 4 7 17 18]. In addition our study found that not only does maternal BMI before the index pregnancy predicts offspring BMI but that maternal BMI change over two decades is associated with offspring BMI. 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, their age and tobacco consumption, birth weight of the children, sex, breastfeeding, children TV watching and their sports participation and family meal patterns when children were adolescents.

There may be many factors which affect the child's weight outcome. Both genetic and environmental factors may promote behaviors associated with weight change in children [19-22]. Familial aggregation of certain behaviors including diet and physical activity have been attributed to genetic (as well as environmental) influences [23]. It may be possible that overweight mothers put their children at risk of overweight partly by passing on their genetic propensity to gain weight.

Previous research has identified similarities in parents' and children's dietary practices [24], food preferences [25] and physical activity [26]. The role of the mother in determining lifestyle at home may also explain why more often 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 [22]. 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 y old demonstrate increased preferences for high fat foods if their parents are obese [27]. There is also some evidence that disinhibited overeating has a genetic basis [28] 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. It is possible that higher BMI values are due to 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 y, we found the associations between change in maternal BMI from pregnancy to 21 y postpartum and offspring BMI at 21 y remain robust. Research points to the contribution of both genetic factors and similarities in parents' and children's dietary and lifestyle which are likely to account for mother-offspring correlation in high BMI or obesity risk. However, it is currently not possible to determine whether genetic or environmental factors play a major role in explaining the associations observed in the present study. A large study with better biological 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 of 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 imputation resulting in only marginal changes in our findings. Secondly, we have undertaken sensitivity analyses modelling a wide variety of associations about the impact of those lost to follow-up [13]. These have provided findings which do not differ substantially. Finally, we have undertaken comparative analyses using data from different cohort studies with different levels of attrition, with the conclusion that substantial variations in loss to follow-up generally have very little impact on the findings [29] .

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 14 y 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 [30-32]. 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 y 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 21 y postpartum their children are more likely to avoid becoming overweight or obese when they grown 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.

Acknowledgements: The authors thank the Mater-University of Queensland Study of Pregnancy team, the Mater Misericordiae Hospital, and the Schools of Social Science and Population Health at the University of Queensland for their support. They specifically thank members of the Mater-University of Queensland Study of Pregnancy 21-Year Follow-up team, including Rosemary Aird, Stacey Allerton, Ruth Armstrong, Samantha Batchelor, Pauline Bonnici, Rachael Bor, Emma Brown, Justine Butcher, Fiona Cameron, Narelle Constantine, Sophie Gudgeon, Jatinder Kaur, Jane Maclean, Amanda Margerison, Kobie Mulligan, Kelly Quinlan, Marie Seeman, and Jennifer Winn. There is no conflict of interest

Author's contributions: AAM did the literature review, performed overall analyses and wrote initial draft of the MS. MO'C, GW and JN made a critical revision and extended the discussion of the findings of this study.

References

1. Lake JK, Power C, Cole TJ. Child to adult body mass index in the 1958 British birth cohort: associations with parental obesity. Arch Dis Child 1997;77(5):376-81.

2. Mamun AA, Lawlor DA, O'Callaghan M, Williams GM, Najman JM. Family and early life factors associated with changes in overweight status between ages 5 and 14: findings from the Mater University Study of Pregnancy and its outcomes. Int Journal of Obesity 2005;29:475-482.

3. Whitaker RC. Predicting preschooler obesity at birth: the role of maternal obesity in early pregnancy. Pediatrics 2004;114(1):e29-36.

4. Whitaker RC, Wright JA, Pepe MS, Seidel KD, Dietz WH. Predicting obesity in young adulthood from childhood and parental obesity. N Engl J Med 1997;337(13):869-73.

5. Salsberry PJ, Reagan PB. Dynamics of early childhood overweight. Pediatrics 2005;116(6):1329-1338.

6. Strauss RS, Knight J. Influence of the home environment on the development of obesity in children. Pediatrics 1999;103(6).

7. Kowaleski-Jones L. Are You What Your Mother Weighs? Evaluating the Impact of Maternal Weight Trajectories on Youth Overweight. Maternal and child health journal 2009.

8. Lemay CA, Elfenbein DS, Cashman SB, Felice ME. The body mass index of teen mothers and their toddler children. Maternal and child health journal 2008;12(1):112-118.

9. Kanda A, Kamiyama Y, Kawaguchi T. Association of reduction in parental overweight with reduction in children's overweight with a 3-year follow-up. Preventive Medicine 2004;39(2):369-372.

10. Wrotniak BH, Epstein LH, Paluch RA, Roemmich JN. Parent weight change as a predictor of child weight change in family-based behavioral obesity treatment. Archives of Pediatrics & Adolescent Medicine 2004;158(4):342-347.

11. Golan M, Weizman A, Apter A, Fainaru M. Parents as the exclusive agents of change in the treatment of childhood obesity. American Journal of Clinical Nutrition 1998;67(6):1130-1135.

12. Keeping JD, Najman JM, Morrison J, Western JS, Andersen MJ, Williams GM. A prospective longitudinal study of social, psychological and obstetric factors in pregnancy: response rates and demographic characteristics of the 8556 respondents. Br J Obstet Gynaecol 1989;96(3):289-97.

13. Najman JM, Bor W, O'Callaghan M, Williams GM, Aird R, Shuttlewood G. . Cohort Profile: The Mater-University of Queensland Study of Pregnancy (MUSP). International Journal of Epidemiology 2005;34(5):992-997.

14. World Health Organization. Obesity. Preventing and Managing the Global Epidemic. Report of a WHO Consultation on Obesity, 3-5 June 1997. Geneva, Switzerland.: World health Organization, 1998.

15. Hernan MA, Hernandez-Diaz S, Werler MM, Mitchell AA. Causal knowledge as a prerequisite for confounding evaluation: an application to birth defects epidemiology. Am J Epidemiol 2002;155(2):176-84.

16. Mamun AA, Lawlor DA, O'Callaghan MJ, Williams GM, Najman JM. Positive maternal attitude to the family eating together decreases the risk of adolescent overweight. Obes Res 2005;13(8):1422-30.

17. Heude B, Kettaneh A, Rakotovao R, Bresson JL, Borys JM, Ducimetiere P, et al. Anthropometric relationships between parents and children throughout childhood: the Fleurbaix-Laventie Ville Sante Study. International Journal of Obesity 2005;29(10):1222-1229.

18. Whitaker R, Dietz WH. Role of the prenatal environment in the development of obesity. J Pediatr 1998;132(5):768-76.

19. Wardle J, Guthrie C, Sanderson S, Birch L, Plomin R. Food and activity preferences in children of lean and obese parents. International Journal of Obesity 2001;25(7):971-977.

20. Maes HHM, Neale MC, Eaves LJ. Genetic and environmental factors in relative body weight and human adiposity. Behavior Genetics 1997;27(4):325-351.

21. Davison KK, Birch LL. Obesigenic families: parents' physical activity and dietary intake patterns predict girls' risk of overweight. International Journal of Obesity 2002;26(9):1186-1193.

22. Davison KK, Birch LL. Child and parent characteristics as predictors of change in girls' body mass index. International Journal of Obesity 2001;25(12):1834-1842.

23. Mitchell BD, Rainwater DL, Hsueh WC, Kennedy AJ, Stern MP, Maccluer JW. Familial aggregation of nutrient intake and physical activity: Results from the San Antonio Family Heart Study. Annals of Epidemiology 2003;13(2):128-135.

24. Oliveria SA, Ellison RC, Moore LL, Gillman MW, Garrahie EJ, Singer MR. Parent-child relationships in nutrient intake - The Framingham Childrens Study. American Journal of Clinical Nutrition 1992;56(3):593-598.

25. Borahgiddens J, Falciglia GA. A metaanalysis of the relationship in food preferences between parents and children. Journal of Nutrition Education 1993;25(3):102-107.

26. Anderssen N, Wold B. Parental and peer influences on leisure-time physical-activity in young adolescents. Research Quarterly for Exercise and Sport 1992;63(4):341-348.

27. Fisher JO, Birch LL. Fat preferences and fat consumption of 3-year-old to 5-year-old children are related to parental adiposity. Journal of the American Dietetic Association 1995;95(7):759-764.

28. Provencher V, Perusse L, Bouchard L, Drapeau V, Bouchard C, Rice T, et al. Familial resemblance in eating behaviors in men and women from the Quebec Family Study. Obesity Research 2005;13(9):1624-1629.

29. Horwood LJ, Fergusson DM, Hayatbakhsh MR, Najman JM, Coffey C, Patton GC, et al. Cannabis use and educational achievement: Findings from three Australasian cohort studies. Drug and Alcohol Dependence 2010;110(3):247-253.

30. Videon TM, Manning CK. Influences on adolescent eating patterns: The importance of family meals. Journal of Adolescent Health 2003;32(5):365-373.

31. Stockmyer C. Remember when mom wanted you home for dinner? Nutrition Reviews 2001;59(2):57-60.

32. Neumark-Sztainer D, Hannan PJ, Story M, Croll J, Perry C. Family meal patterns: associations with sociodemographic characteristics and improved dietary intake among adolescents. J Am Diet Assoc 2003;103(3):317-22.

TABLE 1: Maternal characteristics by maternal body mass index categories change from pregnancy to 21 y post-partum

	N	Maternal BMI categories change from pregnancy to 21 y postpartum			*P*
		Normal before and at 21 y	Normal before but overweight at 21 y	Overweight at both time	
Total sample (%)	1992	37.90	47.39	14.71	
Maternal characteristics					
Maternal age at first clinic visit in years: mean±SD	1992	25.60± 4.86	25.28± 4.90	27.09± 5.23	<0.001
Maternal pre-pregnancy weight (kg): : mean±SD	1992	52.25± 6.34	56.86± 6.52	75.32± 11.19	<0.001
Maternal weight (kg) at first clinic visit (kg): : mean±SD	1992	56.87± 7.20	62.19± 7.68	78.80± 11.08	<0.001
Maternal weight (kg) at 21 y postpartum: : mean±SD	1992	59.73± 6.76	78.99± 11.65	94.59±16.95	<0.001
Maternal pre-pregnancy BMI (kg/m^2): : mean±SD	1992	19.56± 1.89	21.45± 1.92	28.70± 3.86	<0.001

Maternal BMI at first clinic visit (kg/m^2): mean±SD	1992	18.32± 2.61	20.11± 2.93	25.34± 4.07	<0.001
Maternal BMI (kg/m^2) at 21 y postpartum: mean±SD	1992	22.35± 1.84	29.81± 3.91	36.05± 6.09	<0.001
Change in maternal BMI from pre-pregnancy to 21yr FU : mean±SD	1992	2.79± 2.03	8.35± 3.68	7.35± 5.58	<0.001
Change in maternal BMI from first clinic visit to 21 y FU : mean±SD	1878	4.05± 2.75	9.63±4.16	10.63± 6.06	<0.001
Maternal smoking cigarettes before pregnancy					
None	1084	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	1276	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 mo	716	36.03	49.72	14.25	
4 mon 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-squared test for categorical data.

TABLE 2: Offspring characteristics around birth and at 14 y follow-up maternal body mass index categories change from pregnancy to 21 y post-partum

	N	Maternal BMI categories change from pregnancy to 21 y postpartum			*P*
		Normal before and at 21 y	Normal before but overweight at 21 y	Overweight at both time	
Offspring characteristics					
Sex					
Male	1015	36.26	48.87	14.88	
Female	977	39.61	45.85	14.53	0.29
Birth weight (kg): mean±SD	1991	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-squared test for categorical data.

TABLE 3: Mean difference in offspring body mass index by the change in maternal body mass index from pre-pregnancy to 21 y post partum (N=1807)

Change in maternal BMI from pre-pregnancy to 21 y FU	Mean difference or regression coefficient	
	Unadjusted (95% CI)	Adjusted (95% CI)
Mean difference in maternal BMI (kg/m^2) change from pre-pregnancy to 21y	0.12(0.07,0.17)	0.11(0.06,0.15)
Mean difference in maternal BMI (kg/m^2) change from first clinic visit to 21y	0.12(0.07,0.17)	0.12(0.07,0.17)
Overweight/obesity pattern		
Normal before pregnancy and at 21 y postpartum (ref. category)	0	0
Normal before pregnancy but overweight at 21 y postpartum	1.28(0.83,1.74)	1.25(0.79,1.71)
Overweight before pregnancy and at 21 y 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 y.

TABLE 4: Unadjusted and adjusted odds (multinomial logistic regression, normal BMI at 21 y as reference) of being overweight and obese at 21 y by the change in maternal BMI from pre-pregnancy to 21 y postpartum (N =1807)

Change in maternal BMI from pre-pregnancy to 21 years FU	Unadjusted Odds ratio (95% CI)			Adjusted Odds ratio (95% CI)		
	Normal	Overweight	Obese	Normal	Overweight	Obese
Mean difference in maternal BMI change from pre-pregnancy to 21 y	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)
Mean difference in maternal BMI change from first clinic visit to 21 y	1.00	1.04 (1.02,1.07)	1.06 (1.02,1.10)	1.00	1.04 (1.01,1.06)	1.06 (1.02,1.09)
Overweight/obesity pattern						
Normal before pregnancy and at 21 y postpartum (ref. category)	1.00	1.00	1.00	1.00	1.00	1.00
Normal before pregnancy but overweight at 21y 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 y postpartum	1.00	2.92 (2.05,4.14)	5.20 (1.96,4.11)	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 y.

File name: Additional file 1

File format: PDF

Title of data: Supplemental table 1

Description of data: Comparison of respondents who were followed-up using a questionnaire vs. not followed-up at 21yr, followed-up conducting physical assessments vs. not followed-up at 21yr but had BMI and socio-demographic information at first clinic visit