

Early overweight and pubertal maturation—pathways of association with young adults' overweight: a longitudinal study

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ABSTRACT

Objective: Objectives of this study were to examine the prospective association of childhood body mass index (BMI) and overweight and pubertal stages with BMI and overweight in early adulthood independent of each other.

Design: A population-based prospective birth cohort.

Subjects: We used a population-based prospective birth cohort of 2897 (52% men) young adults who were born during 1981–1983 in Brisbane, Australia, and for whom we had puberty stages using Tanner scale at 14 years and measured BMI at 5 years of age.

Main outcome measures: Pubertal stages at adolescent and BMI and its categories at 21 years.

Results: We found that increasing BMI and overweight at 5 years of age predict the advanced stages of puberty. An advanced stage of puberty predicts young adults' BMI and overweight status at 21 years. When taking both childhood BMI and pubertal status into consideration, we found that being overweight at 5 years substantively increases BMI at 21 years, regardless of the stage of puberty reported at 14 years. We also found that subjects with normal BMI at 5 years but with higher stages of puberty at 14 years had threefolds greater risk to be overweight at 21 years compared with their counterparts. All associations remained consistent after controlling for potential confounders.

Conclusions: Although this study underscores the impact of both child overweight and pubertal development on young adults' obesity, the mechanism that further explains the impact of puberty needs to be identified.

Keywords: overweight, body mass index, puberty, childhood and adolescence

Introduction

Although numerous studies have found that pregnancy or intrauterine growth and early childhood growth^{1,2} are two important stages in the development of adult obesity, there is paucity of information about the impact of pubertal maturation on adult obesity independent of childhood obesity and other confounding factors. Understanding the factors that are associated with obesity in childhood and adolescence may help identify pathways leading to this widespread problem and to refine causal hypotheses concerning the developmental origins of obesity.

Two hypotheses are advanced to explain the relation between onset of puberty and obesity in adolescents and young adults. First, the association may be due to common biological and/or environmental etiologies. In this model, early puberty and obesity share relationships with some other factors, rather than being independently associated. These common factors include intrauterine factors such as exposure to cigarette smoking,³ malnutrition at a critical growth period⁴ or poor gestational growth^{5, 6} and timing of puberty and maturation. There is also evidence suggesting that children from higher socioeconomic groups or those who are overweight or obese throughout childhood experience puberty earlier,^{7, 8, 9, 10, 11, 12, 13, 14} although this is contested.^{15, 16} Other investigations have found a similar association with parental sociodemographic background,^{17, 18} maternal smoking during pregnancy¹⁹ and intrauterine growth.²⁰ More importantly, childhood body mass index (BMI), which is related to obesity in early adulthood,²¹ is associated with the timing of puberty.²² Therefore, any study that examines the association between puberty and adult obesity should take into account those background characteristics as potential confounding factors. To our knowledge, no studies of the association of pubertal development with obesity in young adult age have taken all of these factors simultaneously into consideration.

An alternative hypothesis proposes that the timing of puberty influences young adults' overweight and obesity, independent of childhood background. Despite uncertainty about biological mechanisms, it has been suggested that early maturation, in particular in women, may provide a longer duration of positive energy balance²³ or that the presence of endocrine factors during reproductive maturation enforces the accumulation of body fat.²⁴ Longitudinal data on this model of association are not conclusive, with some longitudinal studies suggesting stronger association of earlier puberty,^{25, 26, 27, 28} and others childhood BMI^{21, 22} and adult obesity. Other studies that have found an association between puberty and adult BMI did not examine childhood BMI,^{23, 24, 29} or found both childhood weight and early menarche as important predictors of adult obesity.^{30, 31} However, most of these studies have examined only women,^{21, 22, 23, 25, 26, 28, 29} and different classifications are used for puberty and early onset. There remains a need for prospective studies that examine the effect of both childhood BMI and pubertal maturation on adult obesity in both men and women.

The aims of this study were (i) to prospectively examine the association between BMI score and categories of BMI at childhood with the pubertal stages at adolescent; (ii) to study the prospective relationship between pubertal stages at 14 years and BMI score and its categories at 21 years; and (iii) to investigate whether childhood overweight or stage of puberty or both independently predict BMI and its categories at 21 years using a community-based birth cohort study.

Methods

Participants

The study population was from the Mater-University Study of Pregnancy and its Outcomes. This is a prospective study of 7223 women, and their offspring, who received antenatal care at a major public hospital in Brisbane between 1981 and 1983 and delivered a live singleton child who was not adopted before leaving the hospital.³² The mothers and children have been followed up with maternal questionnaires being administered at 3–5 days, 6 months, 5 and 14 years after pregnancy. At 14 and 21 years, the offspring were administered a health, sociodemographic and lifestyle questionnaire. At 5, 14 and 21 years follow-up, offspring were on average 5.51 (range: 4.50, 6.85), 13.91 (range: 12.48, 15.14) and 20.65 (range: 18.17, 23.53) years old, respectively. For the examination of the link between overweight/obesity at 5 years and stages of puberty, this study was restricted to 2897 offspring for whom we had measured both overweight/obesity at 5 years and puberty at 14 years. To examine the prospective association between puberty and overweight/obesity at 21 years, we had 2105 offspring for whom we had puberty at 14 years and measured overweight/obesity at 21 years.

Although the Mater-University Study of Pregnancy and its Outcomes mother cohort is not representative of the total population of women giving birth, it is likely to be a reasonable sample of lower-to-middle socioeconomic status women giving birth.³³ About 90% of the mothers were Caucasian, only 4% were Asian and the rest were Aboriginal Islander. Children who could not participate were more likely to be from families with low income at birth, who have mothers who smoked throughout their pregnancy, and mothers and fathers with lower educational attainments.^{32, 33} Participants gave signed informed consent for their participation and that of their children. Full details of the study participants and measurements have been reported earlier.^{32, 33}

Measures

Puberty

We obtained self-reported data on pubertal development using Tanner drawings of the five stages of pubertal development, which for men involve the development of genitalia and pubic hair and for women, breasts and pubic hair.^{34, 35} Validation of the drawings has involved samples of men and women who completed the questionnaire and were examined by physician blind to their questionnaire responses. There were moderate-to-strong correlations between self-reports and physician assessments.³⁴ More recent validations have confirmed that child/youth self-reports of pubertal development are in good agreement with independent ratings.^{36, 37}

Body mass index

Body mass index at age 5 and 21 years follow-up was calculated from the measured weights and heights. In all assessments, the average of two measures of the participant's weight, lightly clothed with a scale accurate to 0.2 kg, was used. A portable stadiometer was used to measure height. Overweight or obesity was defined according to standard definitions derived from international surveys by Cole *et al.*³⁸ BMI at 21 years was categorized into normal (BMI < 25 kg/m²), overweight (BMI = 25–29 kg/m²) and obese (BMI ≥ 30 kg/m²) using the WHO classification of BMI cutoffs.³⁹ To increase the statistical precision, we combined overweight and obese categories as overweight.

Combined measures of BMI at age 5 and puberty at 14 years

Combining four categories of pubertal stages with two categories of BMI (normal and overweight) at 5 years of age, we derived a composite indicator of pubertal stages and overweight status: normal BMI at age 5 years and pubertal stage 1 or 2, normal BMI at 5 years and pubertal stage 3, normal BMI at 5 years and pubertal stage 4, normal BMI at 5 years and pubertal stage 5, overweight at 5 years and pubertal stage 1/2, overweight at 5 years and pubertal stage 3, overweight at 5 years and pubertal stage 4 and overweight at 5 years and pubertal stage 5. Using these mutually exclusive categories, we aim to determine whether childhood overweight or early stages of puberty or their combination prospectively predicts young adults' BMI and overweight status.

Confounders or mediators

The potential confounding factors are selected on the basis of *a priori* knowledge⁴⁰ of their association with exposure and outcome. The main confounders we considered in this study were maternal age at index pregnancy (in years), maternal educational attainment (did not complete secondary school, completed secondary school, completed further/higher education), offspring birth weight (in g), maternal pre-pregnancy BMI (based on measured height at index pregnancy and self-reported pre-pregnancy weight), maternal tobacco consumption during pregnancy and breast-feeding. These data were obtained from questionnaires at the first clinic visit and obstetric records. Maternal tobacco consumption during the last

trimester of pregnancy (non-smoker, one to nine cigarettes per day and 10 or more cigarettes per day) was recorded at 3–5 days after delivery. Breast-feeding was reported at 6-month follow-up and for the purpose of this study, it was categorized as never breast-fed, <4 months and \geq 4 months.

The mediating factors we considered to examine the association of composite indicator of BMI at 5 years of age with puberty at 14 years with BMI at 21 years were child diets, family meal patterns, TV watching and sports involvement at the 14-year follow-up. At the 14-year follow-up, mothers were asked to report the frequency of their child's consumption of fast food, salad, soft drinks and red meat (all with response options of rarely or never, at least two or three times a week, most days), family attitude to having meals together (at least once a day, few times/once/less than once a week) and to report the amount of time her child spent watching television (<1 h per day, 1–<3 h per day, 3–<5 h per day and \geq 5 h per day). Details were also obtained about the amount of time children spent on sports or exercise (4–7 days per week and 0–3 days per week). Young adults' weight was measured as the average of two measures of weight, lightly clothed with a scale accurate to 0.2 kg.

Statistical analyses

The mean height, weight and BMI scores at 5 and 21 years by pubertal stages at 14 years are presented in [Table 1](#). We used analysis of variance and F test to compare mean values ([Table 1](#)). We undertook all main analyses based on internally age- and sex-standardized BMI z-scores (BMI-ZS) at 5 and 21 years. The association between BMI-ZS and BMI categories (normal vs overweight) at 5 years with pubertal stages at 14 years was estimated in terms of odds ratio (OR) with 95% confidence interval (CI) using a series of multinomial logistic regressions, adjusting for potential confounders and mediators. Similarly, we used a series of multiple regression models to calculate whether pubertal stages independently predict BMI-ZS at 21 years. A series of multiple regressions were used to examine the prospective association between combined categories of childhood BMI and adolescents' puberty stages with BMI-ZS at 21 years (see footnote of [Table 2](#) for details). Similarly, a series of multiple logistic regressions were applied to predict young adults' BMI categories ([Table 3](#)).

Table 1 - Mean (s.d.) height, weight and BMI scores at age 5 and 21 years by pubertal stage.

At age 5 years (mean, s.d.)	N	Pubertal stages				P-value
		Stage 1 or 2 (n=265)	Stage 3 (n=1179)	Stage 4 (n=1233)	Stage 5 (n=220)	
Height (m)	2897	1.11 (0.06)	1.12 (0.05)	1.14 (0.05)	1.14 (0.06)	<0.001
Weight (kg)	2897	19.14 (2.49)	20.15 (2.98)	20.89 (2.92)	21.57 (3.62)	<0.001
BMI (kg/m ²)	2897	15.62 (1.37)	15.93 (1.58)	16.13 (1.56)	16.50 (1.82)	<0.001
BMI z-score	2897	-0.26 (0.89)	-0.05 (0.98)	0.08 (0.96)	0.29 (1.10)	<0.001
At age 21 years (mean, s.d.)	N	Stage 1 or 2 (n=160)	Stage 3 (n=857)	Stage 4 (n=919)	Stage 5 (n=169)	
Height (m)	2105	1.74 (0.08)	1.73 (0.09)	1.71 (0.09)	1.70 (0.10)	<0.001
Weight (kg)	2105	70.87 (15.57)	70.57 (15.69)	72.44 (16.15)	75.26 (17.99)	<0.001
BMI (kg/m ²)	2105	23.19 (4.47)	23.60 (4.53)	24.73 (4.92)	25.95 (5.72)	<0.001
BMI z-score	2105	-0.21 (0.94)	-0.12 (0.92)	0.10 (0.97)	0.29 (1.04)	<0.001

Abbreviation: BMI, body mass index.

Table 2 - Prospective association between combined categories of BMI at 5 years and pubertal stages at 14 years with BMI z-score at 21 years, estimated in terms of regression coefficient adjusting for potential confounders and mediators (N=1507).

BMI categories at 5 and puberty stage at 14 years	N	Model 1	Model 2	Model 3	Model 4	Model 5
Normal at 5 and stage 1/2	100	0.00	0.00	0.00	0.00	0.00
Normal at 5 and stage 3	526	0.08 (-0.10, 0.27)	0.09 (-0.10, 0.26)	0.03 (-0.16, 0.21)	0.09 (-0.10, 0.28)	0.03 (-0.15, 0.21)
Normal at 5 and stage 4	550	0.33 (0.14, 0.52)	0.33 (0.14, 0.52)	0.28 (0.09, 0.46)	0.34 (0.15, 0.53)	0.28 (0.10, 0.47)
Normal at 5 and stage 5	95	0.45 (0.20, 0.70)	0.44 (0.19, 0.69)	0.39 (0.14, 0.63)	0.47 (0.22, 0.72)	0.40 (0.15, 0.64)
Overweight at 5 and stage 1/2	8	1.08 (0.44, 1.71)	1.07 (0.44, 1.71)	0.95 (0.33, 1.57)	1.08 (0.45, 1.71)	0.95 (0.34, 1.56)
Overweight at 5 and stage 3	81	1.02 (0.76, 1.28)	1.02 (0.76, 1.28)	0.89 (0.64, 1.14)	1.04 (0.78, 1.29)	0.89 (0.64, 1.14)
Overweight at 5 and stage 4	115	1.20 (0.97, 1.44)	1.19 (0.95, 1.43)	1.07 (0.83, 1.30)	1.24 (1.00, 1.48)	1.09 (0.85, 1.32)
Overweight at 5 and stage 5	27	1.09 (0.71, 1.46)	1.09 (0.71, 1.46)	0.87 (0.51, 1.24)	1.07 (0.70, 1.45)	0.86 (0.49, 1.23)

Abbreviation: BMI, body mass index. Model 1 adjusted by age at 5 years, age and sex at 14 years; model 2 adjusted by age at 5 years, age and sex at 14 years, maternal age, their education and cigarette smoking during pregnancy; model 3 adjusted by age at 5 years, age and sex at 14 years, birth weight, maternal pre-pregnancy BMI and breastfeeding; model 4 adjusted by age at 5 years, age and sex at 14 years, adolescents' TV watching, their sport participation, fast food, family meals, soft drinks and salad; model 5 adjusted by all factors mentioned above.

Table 3 - Prospective association between combined categories of BMI at 5 years and pubertal stages at 14 years with BMI categories at 21 years, estimated in terms of OR adjusting for potential confounders and mediators (N=1507).

BMI categories at 5 and puberty stage at 14 years		Model 1	Model 2	Model 3	Model 4	Model 5
Normal at 5 and stage 1/2	100	1.00	1.00	1.00	1.00	1.00
Normal at 5 and stage 3	526	1.47 (0.84, 2.58)	1.49 (0.84, 2.62)	1.31 (0.74, 2.33)	1.49 (0.84, 2.63)	1.32 (0.74, 2.36)
Normal at 5 and stage 4	550	2.53 (1.44, 4.43)	2.58 (1.47, 4.52)	2.34 (1.32, 4.13)	2.62 (1.49, 4.60)	2.42 (1.36, 4.30)
Normal at 5 and stage 5	95	3.03 (1.53, 5.97)	3.00 (1.51, 5.93)	2.79 (1.39, 5.53)	3.26 (1.64, 6.47)	2.85 (1.41, 5.76)
Overweight at 5 and stage 1/2	8	7.62 (1.66, 35.03)	7.76 (1.68, 35.91)	6.90 (1.40, 33.97)	7.60 (1.65, 35.13)	7.25 (1.46, 36.02)
Overweight at 5 and stage 3	81	9.04 (4.51, 18.09)	9.23 (4.59, 18.55)	7.48 (3.68, 15.23)	9.29 (4.61, 18.71)	7.48 (3.64, 15.35)
Overweight at 5 and stage 4	115	14.39 (7.34, 28.21)	14.31 (7.28, 28.16)	12.08 (6.07, 24.03)	15.95 (8.05, 31.58)	13.01 (6.45, 26.25)
Overweight at 5 and stage 5	27	15.97 (5.77, 44.18)	16.45 (5.92, 45.72)	11.71 (4.09, 33.52)	15.39 (5.52, 42.95)	11.23 (3.87, 32.56)

Abbreviations: BMI, body mass index; OR, odds ratio. Model 1 adjusted by age and sex at 14 years; model 2 adjusted by age and sex at 14 years, maternal age, their education and cigarette smoking during pregnancy; model 3 adjusted by age and sex at 14 years, birth weight, maternal pre-pregnancy BMI and breastfeeding; model 4 adjusted by age and sex at 14 years, adolescents' TV watching, their sport participation, fast food, family meals, soft drinks and salad; model 5 adjusted by all factors mentioned above.

Results

Of the 2897 offspring, 9.15% (men, 13.45% and women, 4.46%) were on pubertal stage 1 or 2, 40.70% (men, 44.69% and women, 36.36%) on stage 3, 42.56% (men, 35.08% and women, 50.68%) on stage 4 and 7.59% (6.76% men and 8.50% women) on stage 5. The mean BMI of the offspring at 5 years of age was 16.03 kg/m² (s.d.=1.58) and 16.53% were overweight at that age. The mean BMI of young adults were 24.25 kg/m² (s.d.=4.86) and 34.39% were overweight at 21 years. Those offspring who reported more advanced stages of puberty at the 14-year follow-up had greater height, weight and BMI scores at 5 years (all *P*-values <0.001) (Table 1). The same direction of association was found between stage of puberty at 14 years and height, weight and BMI scores at 21 years.

Association between BMI at 5 years and pubertal stages

We examined the association between BMI at 5 years and stages of puberty reported by adolescent at the 14-year follow-up, adjusting for potential confounders and mediators. In a series of multinomial regression models, we found that BMI-ZS at 5 years of age were positively associated with stages of puberty. For instance, for 1 s.d. increase in BMI-ZS at 5 years, the offspring had nearly twofolds greater odds (OR 1.88; 95% CI: 1.53, 2.31) to be on pubertal stage 5 (in the age- and sex-adjusted model). Similarly, when 5-year-old children were categorized into two groups (normal and overweight/obese), those who were overweight at 5 years had nearly twofolds greater odds (OR 1.90; 1.20, 3.01) to be on stage 4 and more than twofolds (OR 2.32; 1.32, 4.05) greater odds to be on stage 5 as compared with normal-weight offspring (in the age- and sex-adjusted model). Adjustment for potential factors did not substantively alter these associations (the full set of multivariable results available from authors on request).

Association between pubertal stages and BMI at 21 years

We further examined whether pubertal stages at 14 years of age would prospectively predict BMI-ZS at 21 years after controlling for potential confounders. Those offspring who were on stage 4 or 5 at the 14-year follow-up had greater BMI-ZS at 21 years of age compared with the offspring who had normal BMI at that age. Similarly, young adults who were on stage 4 pubertal status at 14 years had 2.53 times increased odds (95% CI: 1.60, 4.00) and those who were on stage 5 had 3.41 times (95% CI: 1.96, 5.93) greater risk of being overweight at 21 years of age compared with stage 1 or 2 (in the age- and sex-adjusted model). The associations remain independent of potential factors (the full set of multivariable results available from authors on request).

Association of childhood overweight and pubertal stages with young adults' BMI

To examine the link between childhood BMI and pubertal status, and young adults' BMI independent of each other, we created a composite variable with eight categories. We then analyzed BMI at 21 years of age against categories of childhood BMI and puberty with the normal BMI at 5 and stage 1/2 of puberty being the reference group (Table 2). Data show that individuals with normal BMI at 5 years and pubertal stage 4 or 5 at 14 years had greater BMI-ZS at 21 years of age compared with the reference category. The most striking is the finding that being overweight at 5 years substantively increases BMI-ZS at 21 years, regardless of the stage of puberty reported at 14 years. A more surprising pattern of association is noted when dichotomous BMI at 21 years was regressed against the same independent variable (Table 3). In the age- and sex-adjusted model, subjects with normal BMI at 5 years who were categorized at stage 4 or 5 puberty at 14 years were threefolds more likely to be overweight at 21 years compared with their counterparts. The point estimate of association more than doubled (OR=7.6; 95% CI: 1.7, 35.0) when risk of overweight at 21 years was examined for overweight children with stage 4 or 5 puberty. All associations remained significant and consistent after controlling for potential confounders or mediators, although some of the point estimates were slightly attenuated.

Discussion

Using a 21-year follow-up of a pre-birth cohort study, we found that (i) increasing BMI and overweight at 5 years of age predict the advanced stages of puberty; (ii) the advanced stages of puberty predict young adults' BMI and overweight status at 21 years; and (iii) when taking both childhood BMI and pubertal status into consideration, we found that childhood overweight status was positively associated with young adults' BMI or overweight, irrespective of pubertal stages, and pubertal stage were positively associated with young adults' BMI or overweight status if the offspring had normal BMI at 5 years. This study suggests that childhood BMI and pubertal status at 14 years of age predict young adults' BMI. This association is independent of a range of potential confounders and mediators.

Our primary finding that childhood BMI is prospectively associated with stages of puberty is in agreement with earlier studies.^{7, 9, 11, 22, 28} Additional studies, retrospectively^{23, 29} or prospectively,^{22, 23, 28} have indicated that pubertal maturation is associated with young adults' BMI and height.

To our knowledge, very few studies have simultaneously examined the impact of childhood obesity and pubertal development on young adults' obesity.^{21, 22} In the two studies we were able to track, childhood obesity²² or pre-menarche weight²¹ and age at menarche were associated with adult obesity. However, they indicated that childhood weight was a stronger predictor of adult obesity. In accordance with these studies, our data suggest that both child BMI and pubertal progression associated with young adults' overweight/obesity. Although there appears to be a continuity in the pathway of child–adult overweight/obesity, this association is enforced when individuals show the advanced stages of puberty in early adolescence. Our study confirms that these associations are independent of a wide range of possible

confounders including maternal BMI, birthweight, maternal tobacco consumption during pregnancy and breast-feeding.

Although the biological mechanisms of the association between puberty development and obesity are uncertain, there might be several explanations for this relationship other than that child obesity directly influences puberty maturation. A possible mechanism is that early maturing adolescents (girls) appear to have increased blood concentrations of estrogen hormone at an earlier age.⁴¹ It has been found that a high circulating level of estrogen persists until the age of 25 years and leads to the accumulation of adipose tissues in the body⁴² or that a longer period of positive energy balance in early maturers leads to increased obesity.²³ However, because our study indicated higher BMI related to pubertal maturity in both boys and girls, this may explain only a part of the association between puberty and adult obesity.

Another possibility for the findings of our study might be a genetic basis that is related to early pubertal maturation and affect the development of obesity. This study does not have the capacity to examine this hypothesis. There is a need for further investigation to explore the role of genetic background and other potential mechanisms of the pathway between puberty and obesity.

There are several potential limitations to this study. First, this study defined pubertal status based on self-reported Tanner scores at the 14-year follow-up. We have not obtained any biological measures that are indicative of progression through puberty. Although there have been concerns expressed about the measurement of progression through the stages of puberty, the Tanner stages are commonly used and have been validated.^{34, 35, 36} However, the use of only a single measure on puberty, taken around 14 years of age, warrants caution when interpreting the results.

Second, because of resource constraints, the Tanner measure was not administered to all respondents. Of the 5172 adolescents who participated at the 14-year follow-up, 3748 (72.5%) completed the questionnaire about puberty. Of these, complete data on child and adult obesity were available for 2897 participants. This incompleteness and loss to follow-up might have affected the findings presented here. However, our findings would be biased if the associations we have assessed were non-existent or in the opposite direction in non-participants. We have compared our estimates of overweight or obese at 20–24 years of age with the Australian National Nutritional Survey (NNS) 1995 for similar age category and the results are comparable. At 21 years of age, the prevalence of overweight was 34% in Mater-University Study of Pregnancy and its Outcomes, which is similar to that of 20- to 24-year age groups in the National Nutritional Survey. Nevertheless, we cannot be certain that some bias has not occurred. In addition, due to small number in some of the categories, caution is warranted when interpreting the findings of this study.

Notwithstanding the limitation, this study confirms that both child obesity and pubertal maturation are important in the prediction of adult obesity. Overweight or obese child is at substantial risk to develop obesity in early adulthood, and this risk is magnified if that child experiences a more advanced stage of puberty in early adolescence. This study provides implications for the prevention of adult obesity. Effective interventions that tackle childhood obesity, in particular before the individual progresses through the stages of puberty, are expected to have a sustained impact in early adulthood. Although this study underscores the impact of both child obesity and pubertal development on adult obesity and other related outcomes, such as cardiovascular disease, the mechanism that further explains the impact of puberty needs to be identified.

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