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Longitudinal effect of sexual maturation on weight status in children aged 9 to 12 years

Efeito longitudinal da maturação sexual no estado nutricional em crianças de 9 a 12 anos de idade

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ABSTRACT

Determining the stages of sexual maturation is important for observing the relationship with different factors associated with negative outcomes for the child throughout life. In this study we investigated the longitudinal effect of sexual maturation on excess body weight in children aged 9 to 12 years. This study is part of a larger study, named the Predictors of Maternal and Infant Excess Body Weight (PREDI) Study, and used data from mother-child pairs obtained at baseline and 1st, 4th and 5th follow-ups. Child sexual maturation was assessed according to Tanner stages. Descriptive analysis and Poisson regression models adjusted for important covariates were used to examine the effect of sexual maturation on the child's weight status at 9 and 12 years of age. Being large for gestational age (42.4%) and an excessive pre-pregnancy body mass index (BMI) of the mother (42.3%) were significantly associated ($p<0.05$) with excess body weight in children at 9 years of age. However, no longitudinal effect of sexual maturation on weight status was found in children from 9 to 12 years of age. Pre-pregnancy BMI and weight status at birth continue to be important predictors of excess body weight in children over the years. Primary health care that follows the mother from prenatal care through the early stages of the child's development is the best strategy to prevent excess weight in both the mother and the child over the years.

Keywords: puberty; sexual development; body mass index; children; longitudinal study.

RESUMO

Determinar os estágios de maturação sexual é importante para observar a relação com diferentes fatores associados a resultados negativos para a criança ao longo da vida. Neste estudo, nós investigamos o efeito longitudinal da maturação sexual no excesso de peso corporal em crianças de 9 a 12 anos de idade. Este estudo faz parte de um estudo maior denominado "Preditores do Excesso de Peso Corporal Materno-Infantil", e utilizou dados de pares de mães-filhos obtidos nos segmentos de base, 1º, 4º e 5º seguimentos. A maturação sexual da criança foi avaliada segundo os estágios de Tanner. Análise descritiva e modelos de regressão de Poisson ajustados para importantes covariáveis foram utilizados para examinar o efeito da maturação sexual no estado nutricional da criança aos 9 e 12 anos de idade. Crianças grandes para a idade gestacional (42,4%) e Índice de Massa Corporal (IMC) pré-gestacional excessivo (42,3%) foram significativamente ($p<0.05$) associados ao excesso de peso corporal aos 9 anos de idade. No entanto, nossos achados não revelaram efeito longitudinal da maturação sexual sobre o estado nutricional em crianças dos 9 aos 12 anos de idade. IMC pré-gestacional e estado nutricional ao nascer continuam sendo importantes preditores do excesso de peso corporal da criança ao longo dos anos. A atenção primária à saúde e que acompanha a mãe desde o pré-natal até as primeiras fases de desenvolvimento da criança constituem a melhor forma de prevenir o excesso de peso do para mãe-criança ao longo dos anos.

Palavras-chave: puberdade; desenvolvimento sexual; índice de massa corporal; crianças. estudo longitudinal.

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INTRODUCTION

Puberty is a significant period in a child's life, which is characterized by the emergence of male and female sexual characteristics (Suutela *et al.*, 2024). It is during the developmental stages of puberty that the child reaches sexual maturation (Deardorff *et al.*, 2022). The changes induced by this process occur rapidly and alter not only children's physical features but also their behavioral and psychological characteristics (Dorn *et al.*, 2019). In girls, the development of the breast bud is the first sign of pubertal development; in boys, the onset is characterized by enlargement of the testicles (Du *et al.*, 2024; Vijayakumar *et al.*, 2024).

Puberty begins between 8 and 13 years of age in girls and between 9 and 14 years of age in boys (Deardorff *et al.*, 2022). However, studies have demonstrated a trend towards a reduction in the age of puberty onset (Bigambo *et al.*, 2023; Kang *et al.*, 2023; Lunddorf *et al.*, 2024). This downward trend has been described for both sexes in some countries (Chow *et al.*, 2020; Ohlsson *et al.*, 2019; Shu; Zong; Li, 2022). In Brazil, some authors also reported a decline in the median age of Tanner stages in both sexes, which was more pronounced among overweight girls (Matsuo *et al.*, 2022). In other words, the trend of declining pubertal age seems to be a global phenomenon and of great relevance for public health.

A lower age of puberty onset can anticipate the development of characteristics inherent to this phase of life such as intense hormone production, with negative outcomes throughout an individual's life, including mental health problems, breast cancer, gynecological, obstetric and neurocognitive problems, and excess body weight (Goldberg *et al.*, 2020; Ho *et al.*, 2024; Moodie *et al.*, 2020). In addition to behavioral changes, the body accumulates fat for the development of gonads, promoting excess body weight (Spaziani *et al.*, 2021). Indeed, excess body weight is currently a serious global public health problem, especially among children and adolescents (Zhang *et al.*, 2024). The consequences of children being overweight range from psychological disorders, social isolation, associated chronic non-communicable diseases, and even the maintenance of a vicious cycle of excess weight across generations, especially among girls (Ciężki *et al.*, 2024; Codazzi *et al.*, 2024; Iversen *et al.*, 2024).

The exact mechanisms underlying the complex relationship between adiposity and sexual maturation need to be further investigated. Basically, excess adiposity accelerates sexual maturation by leptin-driven neuroendocrine activation of gonadotropin-releasing hormone, insulin resistance, peripheral conversion of androgens to estrogens by adipose tissue, and hypothalamic inflammation. While overweight girls tend to mature earlier, the effects in overweight boys are more variable and include delayed puberty in some cases. Since excess body weight is associated with sexual maturation, especially in girls (Abou El Ella *et al.*, 2020; Corrêa *et al.*, 2024; Eckert-Lind *et al.*, 2020), and can have negative outcomes throughout an individual's life, longitudinal studies that allow to estimate causality are essential to better understand the relationship between sexual maturation and excess weight.

Therefore, the present study aimed to evaluate the longitudinal effect of sexual maturation on excess body weight in children from 9 to 12 years of age. Our hypothesis is that more advanced stages of sexual maturation are more prevalent among children with excess body weight. The results obtained will be useful for supporting actions aimed at monitoring excess body weight and, consequently, preventing the anticipation of sexual maturation stages in children at this stage of development.

MATERIALS AND METHODS

Study design and participants

This is a longitudinal study that is part of a larger study, named the Predictors of Maternal and Infant Excess Body Weight (PREDI) Study. The PREDI Study was started in 2012 in a public maternity hospital in Joinville, State of Santa Catarina, Brazil.

Information on the PREDI Study enrollment process has been published previously (Corrêa *et al.*, 2024; Czarnobay *et al.*, 2023; Mastroeni *et al.*, 2017). Considering a prevalence of macrosomic infants of 6%, a 95% confidence interval (CI), an absolute precision of 2.5%, and a population of 7,200 neonates, the estimated sample size was 331 individuals (Corrêa *et al.*, 2024; Mastroeni *et al.*, 2017). Adding 20% for losses, a minimum of 397 participants were required. All women over the age of 18 years, who gave birth to a full-term singleton (37-42 weeks of gestation), were asked to participate in the study at baseline. Exclusion criteria included plans for adoption immediately after delivery and the presence of an infectious contagious disease (acquired immune deficiency syndrome, hepatitis, syphilis, and toxoplasmosis), preeclampsia, Down syndrome, and birth defects. Of the 529 eligible mother-child pairs, 435 joined at baseline in 2012, 315 at 1st follow-up (2013-14), 221 at 2nd follow-up (2016-17), 187 at 3rd follow-up (2018), 144 at 4th follow-up (2021), and 100 at 5th follow-up (2024) (Figure 1).

This study was approved by the Review and Ethics Committee of the University of Joinville Region (CAAE 40242620.4.0000.5366). Written informed consent was obtained from all participants included in the study.

Data collection

Details of the data collection tools have been published previously (Corrêa *et al.*, 2024; Czarnobay *et al.*, 2023; Mastroeni *et al.*, 2017). Except for the baseline assessment that was conducted at the maternity hospital, all follow-ups were performed in the homes of the participants and all mother-child pairs of the previous follow-up were encouraged to participate in the subsequent follow-ups. All members of the health team involved in data collection received prior training. A pre-test of the study was conducted to test the equipment and improve the quality of the instrument. For this study, baseline data (birth weight, sex, type of delivery, pre-pregnancy body mass index - BMI, mother's age at menarche, and gestational weight gain - GWG) and data from the 1st (duration of breastfeeding and age at menarche), 4th and 5th follow-ups (child's BMI, maternal age, maternal education, marital status, monthly household income, and Tanner stage) were used.

Baseline

At the maternity hospital, the mothers received information about the study within 24-48 hours after the child's birth. When both the mother and child met the inclusion criteria, the mother was asked to participate by providing informed consent in accordance with the Ethics Committee of the University of Joinville Region. Once enrolled in the study, the mothers completed a structured questionnaire that included anthropometric measurements and clinical, biological, demographic, and socioeconomic data. The questionnaire was administered in a private room of the maternity hospital within 24-48 hours after delivery, when immediate maternal postpartum height and weight were measured. Postpartum height was measured to the nearest 0.1 cm using a portable stadiometer (WCS®, Compact Model, Curitiba, Brazil) on a wall without skirting (Czarnobay *et al.*, 2023).

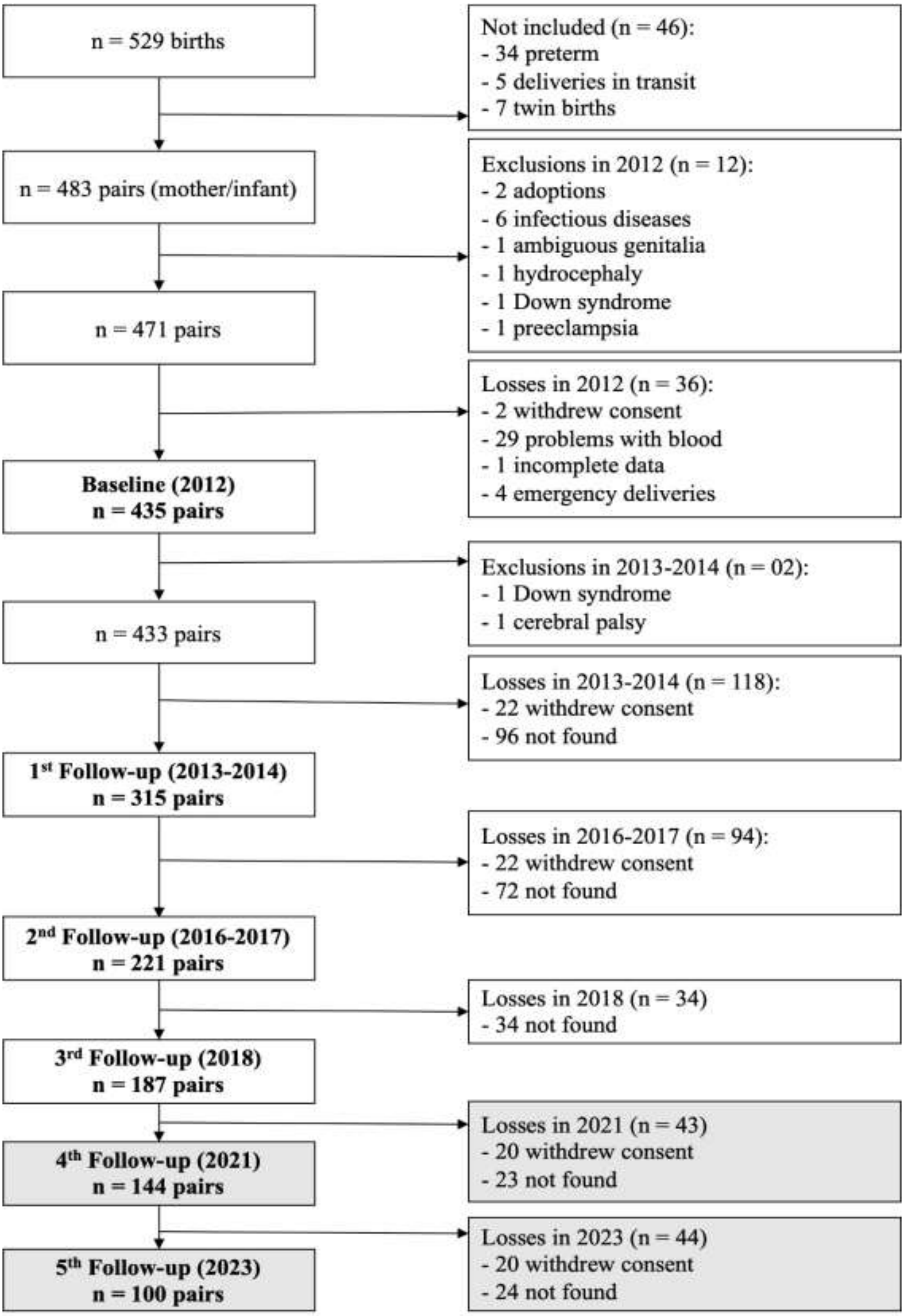
Pre-pregnancy BMI ([weight (kg)/height (m²)]) was calculated based on the mother's self-reported pre-pregnancy weight and immediate postpartum height. A pre-pregnancy BMI <18.5 kg/m2 was classified as underweight, between 18.5 and 24.9 kg/m2 as normal weight, between 25 and 29.9 kg/m2 as overweight, and ≥30.0 kg/m2 as obese (Who, 2000). The GWG was obtained by subtracting pre-pregnancy weight from the weight at delivery (measured on the day before delivery in the maternity hospital). The adequacy of GWG was evaluated according to the new Brazilian gestational weight gain recommendations (Carrilho *et al.*, 2023).

The child's birth weight and length were collected from the hospital records (Mastroeni *et al.*, 2017). Birth weight was classified into three categories according to the INTERGROWTH-21st Project (Villar *et al.*, 2014): small for gestational age (<10th percentile), adequate for gestational age (10-90th percentile), and large for gestational age (>90th percentile).

Follow-ups

In all follow-ups, data were collected at the participants' homes, individually and in one of the rooms of the house. Breastfeeding duration (in months) was self-reported by the mothers in the 1st follow-up. In the 4th and 5th follow-ups, the child's weight was measured to the nearest 0.1 kg on a digital scale (G-Tech®, Glass 7 Model, Zhongshan, China) with a capacity of 180 kg, with the child wearing light clothing and no shoes or accessories (Corrêa *et al.*, 2024). Height was measured to the nearest 0.1 cm using a portable ultrasonic digital stadiometer (AvaNutri®, CAVA-040, Rio de Janeiro, Brazil) (Corrêa *et al.*, 2024). The measurements were taken according to the Brazilian Guidelines for Collection and Analysis of Anthropometric Data in Health Services. The children's nutritional status was divided into two categories of BMI-for-age and sex: ≤85th percentile and >85th percentile (Onis, 2007).

Figure 1 - Flow diagram of the PREDI cohort study, Joinville, Brazil, 2012-2024.



Adapted from (Corrêa *et al.*, 2024).

All anthropometric measurements were performed in duplicate and the mean of the two measurements was used for analysis (Corrêa *et al.*, 2024).

Sexual maturation

The child's sexual maturation data were collected according to the Brazilian Society of Pediatrics (Sbp, 2022) and were classified following the criteria proposed by Tanner (Marshall; Tanner, 1969; 1970). The mothers received information about the Tanner criteria and the importance of the evaluation (Corrêa *et al.*, 2024). A researcher then asked the mother to point out the stage of development of her child based on the printed Tanner scale criteria (Sbp, 2022). The scales consisted of line drawings of each Tanner stage: genital development for boys (Tanner G1–G5), breast development for girls (Tanner B1–B5), and pubic hair development for boys and girls (Tanner P1–P5) (Marshall; Tanner, 1969; 1970). In this study the Tanner stage (outcome) was divided into two categories (stage 1-2 vs. stages 3-5) due to the limited number of individuals by category.

The Tanner criteria are a noninvasive, low-cost, and easy-to-use method with good reproducibility, which are the international standard for estimating sexual maturation (Cheuiche *et al.*, 2021). These criteria are essential in clinical and epidemiological studies since biological maturation influences anthropometric parameters, body composition, and metabolic variables and is a potential confounding factor in analyses involving children and adolescents of similar chronological ages but different maturational stages (Cheuiche *et al.*, 2021). To minimize bias in the identification of sexual maturation, the same properly trained evaluator was responsible for obtaining the sexual maturation measurements throughout the study, always using the same standardized protocol for all participants.

Statistical analysis

To examine differences between the mother-child pairs enrolled at baseline and those not enrolled in the 5th follow-up, maternal education, birth weight, marital status, and child sex were compared using the Student t-test and the chi-square test for continuous and categorical variables, respectively.

The chi-square test was applied to compare the prevalence of categorical variables according to the child's weight status and follow-up (Table 1). Relative risk and 95% CI were calculated using Poisson regression analysis to investigate the effect of Tanner stages and other predictors with BMI (Table 2). For this analysis, sexual maturation was defined as the number of times the Tanner stage was assessed in each child throughout the cohort (Table 2). Each exposure was examined separately in Model 1 and two exposures were not entered at once. Covariates from Table 1 with $p<0.10$ (weight status at birth and pre-pregnancy BMI) were selected for inclusion in the adjusted models in order to identify independent determinants of Tanner stage (Table 2).

The goodness-of-fit of the models was assessed using the -2 log-likelihood value, with lower values indicating better fits. A p value <0.05 was considered statistically significant in all analyses. The IBM SPSS Statistics for Macintosh, version 29.0 (Released 2022, IBM Corp., Armonk, New York, USA), was used for statistical analysis.

RESULTS AND DISCUSSION

The Student t-test and chi-square test showed no significant differences in maternal education, birth weight, marital status, or child sex between the mother-child pairs enrolled in the 5th follow up (n=100) and those not enrolled in the 5th follow-up (n=335) (Supplementary material 1).

Table 1 shows the characteristics of the study participants according to follow-up and weight status (4th and 5th follow-ups). Weight status at birth and pre-pregnancy BMI were significantly ($p<0.05$) associated with BMI at 9 years of age (Table 1). Large-for-gestational age children (42.4%) whose mothers had an excessive pre-pregnancy BMI (42.3%) had excess body weight (>85th percentile) at 4th follow-up. No association was found between the predictors investigated and weight status at 5th follow-up (12 years of age).

Figure 2 shows the distribution of Tanner stages according to weight status and age. Compared to children with excess body weight in stage B1-B2 (7.7%),

Table 1 - Characteristics of the study participants according to the child's weight status at 9-12 years of age. The PREDI Study, Joinville, Brazil, 2012-2024.

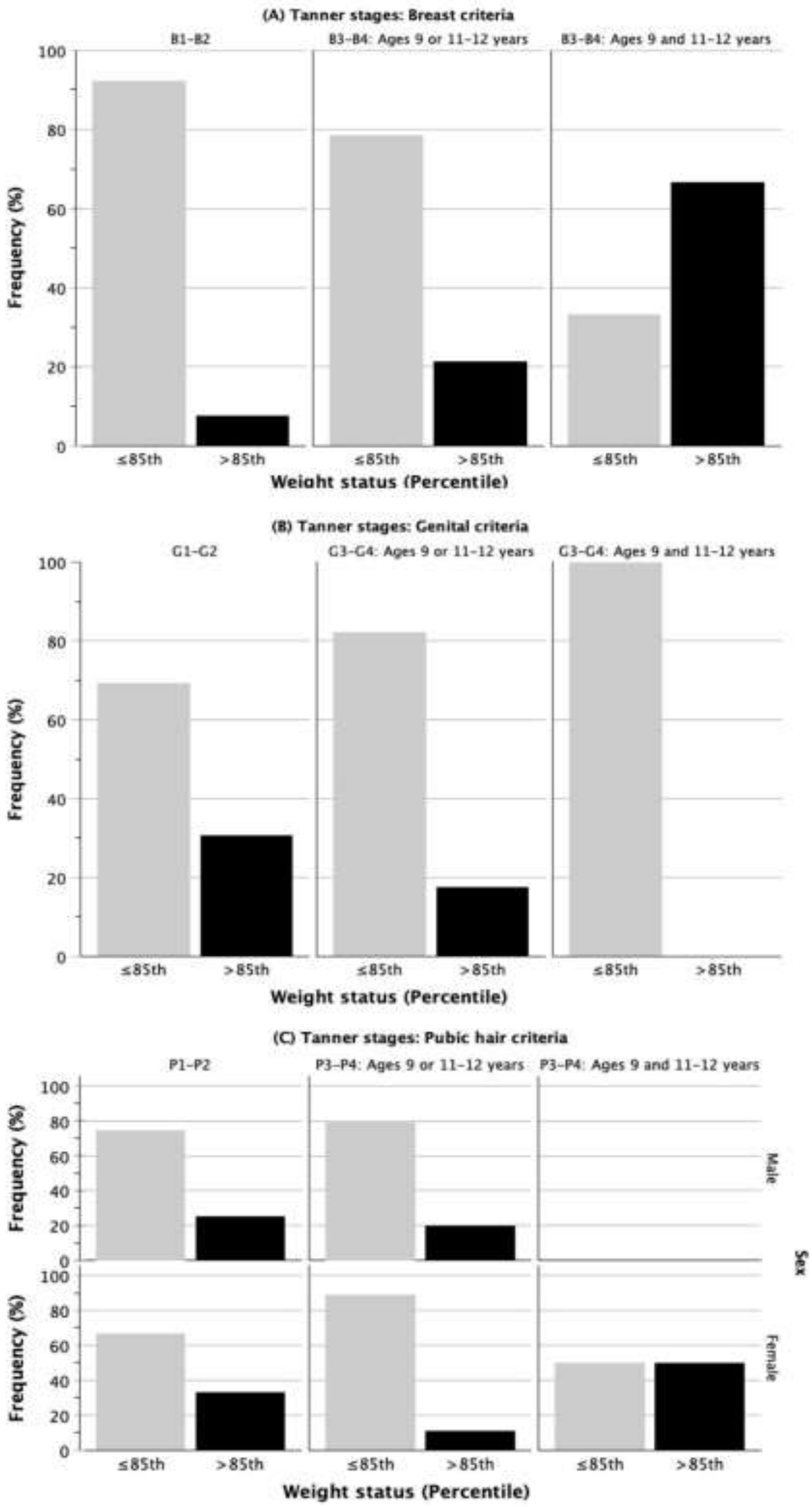
Characteristic	Child aged 9 years			p^*	Child aged 11-12 years			p^*
	≤85th (n=105)	>85th (n=39)	Total (n=144)		≤85th (n=77)	>85th (n=23)	Total (n=100)	
	n (%)	n (%)	n (%)		n (%)	n (%)	n (%)	
Child								
Weight status at birth				0.024				0.410
SGA/AGA	86 (77.5)	25 (22.5)	111 (77.1)		60 (78.9)	16 (21.1)	76 (76.0)	
LGA	19 (57.6)	14 (42.4)	33 (22.9)		17 (70.8)	7 (29.2)	24 (24.0)	
Sex				0.097				0.592
Male	51 (67.1)	25 (32.9)	76 (52.8)		42 (75.0)	14 (25.0)	56 (56.0)	
Female	54 (79.4)	14 (20.6)	68 (47.2)		35 (79.5)	9 (20.5)	44 (44.0)	
Duration of breastfeeding (months)				0.590				0.928
≥6	37 (75.5)	12 (24.5)	49 (34.3)		26 (76.5)	8 (23.5)	34 (34.0)	
<6	67 (71.3)	27 (28.7)	94 (65.7)		51 (77.3)	15 (22.7)	66 (66.0)	
Tanner stage								
Breast				0.272				0.242
B1-B2	51 (81.0)	12 (19.0)	63 (92.6)		12 (92.3)	1 (7.7)	13 (29.5)	
B3-B4	3 (60.0)	2 (40.0)	5 (7.4)		23 (74.2)	8 (25.8)	31 (70.5)	
Genitalia				0.726				0.334
G1-G2	48 (67.6)	23 (32.4)	71 (93.4)		25 (69.4)	11 (30.6)	36 (64.3)	
G3-G4	3 (60.0)	2 (40.0)	5 (6.6)		17 (85.0)	3 (15.0)	20 (35.7)	
Pubic hair				0.296				0.157
P1-P2	103 (73.6)	37 (26.4)	140 (97.2)		48 (72.7)	18 (27.3)	66 (66.0)	
P3-P4	2 (50.0)	2 (50.0)	4 (2.8)		29 (85.3)	5 (14.7)	34 (34.0)	
Mother								
Age (years)				0.749				0.928
<40	65 (73.9)	23 (26.1)	88 (61.1)		36 (76.6)	11 (23.4)	47 (47.0)	
≥40	40 (71.4)	16 (28.6)	56 (38.9)		41 (77.4)	12 (22.6)	53 (53.0)	

Table 1 - Characteristics of the study participants according to the child's weight status at 9-12 years of age. The PREDI Study, Joinville, Brazil, 2012-2024. (continuação)

Characteristic	Child aged 9 years			p*	Child aged 11-12 years			p*
	≤85th (n=105)	>85th (n=39)	Total (n=144)		≤85th (n=77)	>85th (n=23)	Total (n=100)	
	n (%)	n (%)	n (%)		n (%)	n (%)	n (%)	
Marital status				0.424				0.454
Married/consensual union	66 (70.2)	28 (29.8)	94 (66.7)		56 (73.7)	20 (26.3)	76 (81.7)	
Other	36 (76.6)	11 (23.4)	47 (33.3)		14 (82.4)	3 (17.6)	17 (18.3)	
Monthly household income (MW)				0.667				0.890
≥5	28 (75.7)	9 (24.3)	37 (27.0)		18 (75.0)	6 (25.0)	24 (25.0)	
<5	72 (72.0)	28 (28.0)	100 (73.0)		55 (76.4)	17 (23.6)	72 (75.0)	
Education (years)				0.402				0.926
≥12	52 (75.4)	17 (24.6)	69 (49.2)		48 (75.0)	16 (25.0)	64 (70.3)	
<12	49 (69.0)	22 (31.0)	71 (50.8)		20 (74.1)	7 (25.9)	27 (29.7)	
Pre-pregnancy BMI (kg/m^2)				0.002				0.394
<25	75 (81.5)	17 (18.5)	92 (63.9)		51 (79.7)	13 (20.3)	64 (64.0)	
≥25	30 (57.7)	22 (42.3)	52 (36.1)		26 (72.2)	10 (27.8)	36 (36.0)	
Gestational weight gain				0.450				0.088
Appropriate	60 (70.6)	25 (29.4)	85 (59.0)		38 (70.4)	16 (29.6)	54 (54.0)	
Excessive	45 (76.3)	14 (23.7)	59 (41.0)		39 (84.8)	7 (15.2)	46 (46.0)	
Age at menarche (years)				0.387				0.481
≥12	85 (74.6)	29 (25.4)	114 (79.1)		62 (75.6)	20 (24.4)	82 (82.0)	
<12	20 (66.7)	10 (33.3)	30 (20.9)		15 (83.3)	3 (16.7)	18 (18.0)	

*Chi-square test or Fisher's exact test. SGA: Small for Gestational Age; AGA: Adequate for Gestational Age; LGA: Large for Gestational Age; B: Breast; G: Genital; P: Pubic Hair; BMI: Body Mass Index; MW: Minimum Wage (1 MW = US$ 207.00 in 2021).

Figure 2 - Tanner stages in children aged 9-12 years according to weight status, Joinville, Brazil, 2012-2024.



A) B1-B2: Breast Tanner stages 1 or 2; B3-B4: Breast Tanner stages 3 or 4. B) G1-G2: Genital Tanner stages 1 or 2; G3-G4: Genital Tanner stages 3 or 4. C) P1-P2: Pubic hair Tanner stages 1 or 2; P3-P4: Pubic hair Tanner stages 3 or 4.

the prevalence of children with excess body weight increased from 21.4%, when the child was classified as stage B3-B4 at ages 9 or 11 years, to 66.7%, when the child was classified as stage B3-B4 at both ages (9 and 11 years) (Figure 2a). Regarding genital criteria, 30.6% of boys had excess body weight at the beginning of sexual maturation (Figure 2b, G1-G2) and 17.6% in stages G3-G4 at ages 9 or 11-12 years (Figure 2b, G3-G4). For pubic hair criteria, girls entered puberty with a higher (33.3%) prevalence of excess body weight when compared to boys (25.5%) (Figure 2c, P1-P2). However, the highest prevalence of excess body weight in stages P3-P4 was observed among boys (20.0%), which was almost double that of girls (11.1%) (Figure 2c, P3-P4). Additionally, only girls maintained stages P3-P4 from 9 to 12 years and about 50% had excess body weight (Figure 2c, P3-P4).

The effects of weight status at birth, pre-pregnancy BMI, and stages of sexual maturation on the child's weight status at 9-12 years of age are described in Table 2. Poisson regression analyses showed no association ($p<0.05$) between sexual maturation and the child's weight status from 9 to 12 years of age, even after adjusting for weight status at birth and pre-pregnancy BMI (Table 2).

In this study, the child's excess body weight status at birth and excessive pre-pregnancy BMI were associated with excess body weight in children at 9 years of age. However, we found no association between sexual maturation and weight status from 9 to 12 years of age, even after adjusting for important covariates. Our results agree with some longitudinal studies that reported a lack of association between sexual maturation and excess body weight in children (Gaml-Sørensen *et al.*, 2021; Gaml-Sørensen *et al.*, 2024), while other longitudinal studies found a relationship between sexual maturation and excess body weight (Abou El Ella *et al.*, 2020; Adami *et al.*, 2020; Durda-Masny *et al.*, 2019; Matsuo *et al.*, 2022).

A study conducted with Danish children revealed that the early stages of sexual maturation were associated with environmental factors such as prenatal exposure to maternal stress and emotional distress (Gaml-Sørensen *et al.*, 2024). A meta-analysis study demonstrated that food insecurity and high consumption of yogurt and proteins were associated with early or delayed sexual maturation, especially in girls (Tang *et al.*, 2022). Insulin resistance and hyperinsulinemia have also been associated with precocious puberty in girls (Durá-Travé; Gallinas-Victoriano, 2022).

Table 2 - Poisson regression models for excess body weight in Brazilian children (n=144). The PREDI Study, Joinville, Brazil, 2012-2024.

	Model 1		Model 2	
	RR (95% CI)	*p*	RR (95% CI)	*p*
Tanner stage				
B3-B4 (times)				
0	Reference		Reference	
1-2	3.35 (0.46; 24.18)	0.230	3.39 (0.46; 24.77)	0.229
G3-G4 (times)				
0	Reference		Reference	
1-2	0.49 (0.15; 1.55)	0.227	0.44 (0.16; 1.24)	0.122
P3-P4 (times)				
0	Reference		Reference	
1-2	0.54 (0.22; 1.33)	0.179	0.54 (0.22; 1.35)	0.189
Weight status at birth				
SGA/AGA	Reference		-	
LGA	1.38 (0.65; 2.96)	0.401	-	-
Pre-pregnancy BMI (kg/m²)				
<25	Reference		-	
≥25	1.37 (0.67; 2.80)	0.392	-	-

Model 1: Unadjusted relative risk. Model 2: Relative risk adjusted for weight status at birth and pre-pregnancy BMI. Number of times Tanner stage was assessed in children. RR: Relative Risk; CI: Confidence Interval; SGA: Small for Gestational Age; AGA: Adequate for Gestational Age; LGA: Large for Gestational Age; BMI: Body Mass Index.

Another important factor associated with sexual maturation is screen time and electronic device use (Wu *et al.*, 2024). The onset of sexual maturation is mediated by the hypothalamic-pituitary-gonadal axis, which is influenced by melatonin, a hormone secreted by the pineal gland that exerts an important effect on sexual maturation (Patel *et al.*, 2020). Screen exposure, especially between 7:00 and 9:00 pm, inhibits melatonin secretion in children aged 6 to 12 years, triggering a response of the hypothalamic-pituitary-gonadal axis that induces the onset of sexual maturation (Van Geijlswijk; Korzilius; Smits, 2010). Thus, short sleep duration can increase the risk of obesity by influencing the anticipation of sexual maturation (Deng *et al.*, 2021).

The divergence between the results of studies may be due to different factors such as environmental factors, study design, behavior, physical activity, use of electronic devices, hormones, diet, and even the method used to assess the Tanner criteria (Aydin *et al.*, 2022; Bigambo *et al.*, 2023; Cheng *et al.*, 2022; Du *et al.*, 2024; Tang *et al.*, 2022; Wu *et al.*, 2024). Although the Tanner criteria are considered the gold standard for assessing sexual maturation (Yayah Jones *et al.*, 2021), the assessment method may differ between studies. Some parents and/or children do not allow the evaluator to view their children's breasts and genitals. In these cases, the criteria are reported by the parents/guardians or the children themselves based on standardized images of each stage, a fact that makes comparisons between studies difficult. In our study, the criteria were reported by the parents. Another factor that may have influenced the results was the small number of participants, which impaired individual analysis of the Tanner criteria.

Although we did not find a significant relationship between weight status and sexual maturation in our study, the child's weight status at birth and pre-pregnancy BMI were significant predictors of excess body weight in children at 9 years of age, as reported by other studies (Czarnobay *et al.*, 2023; Mastroeni *et al.*, 2017; Pavlidou *et al.*, 2023; Pineros-Leano; Grafft; Aguayo, 2022). The relationship between pre-pregnancy BMI, child weight status at birth, and excess body weight is complex and involves both prenatal and postnatal factors. Additionally, birth weight in combination with subsequent weight gain over the years plays a critical role in the determination of metabolic health. Some authors showed that rapid weight gain from birth to two years is associated with lower insulin sensitivity in early adolescence, especially in conjunction with excess adiposity (Van Hulst *et al.*, 2018). In contrast, lower birth weight is associated with increased susceptibility to cardiometabolic diseases in adulthood (Würtz *et al.*, 2016). However, the magnitudes of the metabolic associations with birth weight are modest compared to the effects of adiposity, indicating that birth weight is a weak indicator of the metabolic risk profile in adulthood (Würtz *et al.*, 2016). Excessive pre-pregnancy BMI creates a vicious cycle of excess body weight not only for the mother but also for the child, especially at birth. Children who are large for gestational age tend to maintain excess body weight throughout adolescence and adulthood, with serious public health implications, including social problems, diabetes, cardiovascular disease, and associated comorbidities (Lyons-Reid *et al.*, 2021).

In summary, the relationship between maternal metabolic health, infant growth patterns, and metabolic programming highlights the importance of addressing maternal health before and during pregnancy to mitigate the risk of childhood obesity. Interventions aimed at reducing maternal excess body weight and metabolic risk factors, as well as monitoring the child's sexual maturation trajectories, are important strategies for preventing obesity in children. Regarding sexual maturation, although no significant relationship with excess body weight was found in this study, important prevalences of excess body weight were observed at the beginning of pubertal development, especially in girls. This scenario may contribute to the development of chronic non-communicable diseases over the years, in addition to obesity.

We highlight some strengths of the study. Data came from a birth cohort study and are primary data. All anthropometric measurements were collected with the same equipment and by most members of the same research group, which reduces possible biases. Nevertheless, some limitations must be mentioned. First, parents/guardians reported the information on Tanner stages, a fact that may have influenced the real stage of children's sexual maturation. Second, the small number of individuals in some stages of the Tanner classification impaired individual assessment of each stage, and it was therefore not possible to evaluate sexual maturation patterns according to the predictors investigated. Third, the pandemic situation of COVID-19 may have contributed to the refusal of some families to continue participation in the study. Furthermore, although within the expected range for cohort studies, loss to follow-up may have hampered the analysis of individuals according to risk group.

CONCLUSION

Our study found no longitudinal association between sexual maturation and weight status from 9 to 12 years of age. However, excess body weight at birth and excessive pre-pregnancy BMI were significant predictors of excess body weight in children at 9 years of age. These results reinforce the need for better monitoring of women's health during the prenatal period, especially their nutritional status. Preventing maternal excess body weight during pregnancy will potentially break the cycle of excess body weight in the child at birth and throughout life. Additional longitudinal studies including a larger number of children throughout the follow-ups are necessary to elucidate the relationship between weight status and sexual maturation.

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Supplementary material - Losses to follow-up from baseline to fifth follow-up. The PREDI Study, Joinville, Brazil, 2012-2023.

Characteristics	Study participants: Participants in 5th follow-up (n=100)	Study participants: Losses to follow-up from baseline to 5th follow-up (n=335)	
	Mean (SD)	Mean (SD)	*p*
Maternal education (years)	9.6 (2.9)	9.3 (3.1)	0.348*
Birth weight (g)	3.4 (0.4)	3.4 (0.5)	0.207*
	n (%)	n (%)	
Marital status			0.223**
Married	124 (34.3)	237 (65.7)	
Other	20 (27.0)	54 (73.0)	
Child sex			0.924**
Male	76 (32.9)	155 (67.1)	
Female	68 (33.3)	136 (66.7)	

*Student t-test. **X^2 test. SD, Standard Deviation; MW, Minimum Wage.

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