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ORIGINAL ARTICLE

Effect of birth size and proportionality on BMI and skinfold thickness in early adolescence: prospective birth cohort study

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Objectives: To assess the effect of birth weight, length and ponderal index at birth on body mass index (BMI) and skinfold thickness in early adolescence.
Subjects/Methods: Population-based, prospective birth cohort study in Pelotas, Brazil. Out of 5249 cohort members, 87.5% were traced at 11 years of age. Birth weight, length and ponderal index (birth weight/birth length$^3 \times 100$)—treated as continuous variable and divided into fourths—were the exposure variables. BMI at 11 years, triceps and subscapular skinfolds were the outcomes. Confounders included sex, gestational age, parity, maternal schooling, family income, maternal smoking during pregnancy and maternal BMI.
Results: All three exposure variables were significantly associated with BMI in early adolescence, but the strongest effect was observed for birth weight. Each unit (*Z*-score) increase in birth weight was associated with 0.46 kg m^{-2} increase in BMI at 11 years. The equivalent coefficients for ponderal index and birth length were 0.22 and 0.21 kg m^{-2}, respectively. High birth weight, length and ponderal index were also associated with increased values for triceps and subscapular skinfolds at 11 years, and with increased prevalence of obesity.
Conclusions: Of the three birth exposures studied, birth weight presented the strongest effect on anthropometry in early adolescence. Ponderal index, a proportionality indicator associated with infant mortality, hospitalizations and anthropometry in infancy, was also associated with anthropometry in early adolescence, but its predictive value for the latter is lower than that of birthweight alone. All three birth size indicators studied presented poor predictability of the later risk of obesity.
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Keywords: body mass index; body size; skinfold thickness; cohort studies; adolescence; prospective studies

Introduction

Weight and length at birth and during the first years of life are associated with the risk of morbidity and mortality both in the short and in the long term (Morris *et al*., 1998; Barker *et al*., 2001; Kajantie *et al*., 2005; Mzayek *et al*., 2007). There is also evidence that these variables predict growth during infancy, childhood and adolescence, as well as nutritional status in adulthood (Thorburn and Proietto, 2001; Ong and Dunger, 2002; Samaras *et al*., 2003; Rogers, 2003). More recently, studies have also addressed the issue of proportionality at birth and its effects on health and nutritional status (Lande *et al*., 2005; Wells *et al*., 2005). It was previously shown that birth proportionality was positively associated with breastfeeding duration (Lande *et al*., 2005) and height at 9 years of age (Wells *et al*., 2005).

In the present study, we evaluate the effects of birth weight, length and ponderal index on body mass index (BMI) and skinfold thickness in early adolescence in a prospective birth cohort study in Southern Brazil. Our particular interest was investigating whether the ponderal index at birth is a better predictor than birth weight or length for determining BMI and skinfold thickness in adolescence.

Subjects and methods

Pelotas is a middle-sized city (current population, ~320 000 inhabitants) located in the South of Brazil, near the borders

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of Argentina and Uruguay. During the calendar year of 1993, hospital deliveries were monitored. At that time, less than 1% of all deliveries in the city took place at home. Soon after giving birth, mothers answered a short questionnaire on demographic, socioeconomic and behavioral variables. Birth weight and length were measured to the nearest 10 g and 0.1 cm, respectively.

At the age of 11 years, all cohort members were sought for a home visit. Subjects answered a questionnaire and weight, height, triceps and subscapular skinfolds were measured. Weight and height were collected twice and the mean value was used in the analyses. Weight was measured to the nearest 100 g using an electronic SECA scale. Height was measured to the nearest 0.1 cm using a locally made portable stadiometer. Skinfold measurements—collected using CESCORF calipers—were each taken three times and the mean value was used in analyses. Interviewers were trained and standardized on weight, height and skinfold measurements according to the margins of error of the National Center for Health Statistics (Cameron, 1984). Standardization sessions were repeated every 2 months during fieldwork.

Obesity at 11 years was defined as BMI $\geqslant$85th percentile, and triceps and subscapular skinfolds $\geqslant$90th percentile, according to World Health Organization recommendation (WHO Expert committee, 1995), using the National Center for Health Statistics (NCHS, 1978) reference. Ten percent of interviews and examinations were repeated by field supervisors for quality control purposes during both cohort visits.

Birth weight, length and ponderal index (birth weight/birth length$^3 \times 100$)—the exposures under investigation—were divided into fourths for categorical analyses and treated as continuous variables in the regression analyses; variables were converted in *Z*-scores to make effect sizes comparable. The outcome variables used were BMI and skinfolds at 11 years, treated as continuous variables and obesity at 11 years, treated as a dichotomous variable. The variables sex, family income (fifths), maternal schooling (years of formal education), smoking during pregnancy, maternal age, BMI and parity were used as confounders in the present analysis.

The linear regression analyses, using BMI at 11 years as the outcome variable, were carried out in several steps. First, the unadjusted effects of the exposures were estimated. Next, the effects of the exposures were adjusted for each independent variable individually. Finally, the effects of the exposures on BMI at 11 years were adjusted for all confounding variables (sex, gestational age, family income, maternal schooling, smoking during pregnancy, pre-pregnancy BMI, maternal age and parity) simultaneously.

The Ethics Committee of the Federal University of Pelotas Medical School approved all phases of the 1993 Pelotas (Brazil) Birth Cohort Study. Parents signed informed consent forms in each visit. Further details of the methodology of the 1993 Pelotas cohort are available elsewhere (Victora *et al.*, 2006, 2007).

Results

Of the 5265 children born in 1993 in Pelotas, 5249 were enrolled in the study, of whom 5160 (98.3%) had valid values of birth weight and length. At 11 years of age, 87.5% of all cohort members were located. Subjects who were lost to follow-up presented virtually identical mean values of ponderal index at birth in comparison to those located ($2.72\,g\,cm^{-3} \times 100$ in both groups). Mean birth weight and length were slightly higher among adolescents lost to follow-up (3176 g and 48.8 cm) in comparison to those located (3051 g and 48.5 cm) (Table 1).

Mean ponderal index was $2.72\,g\,cm^{-3} \times 100$ (s.d. 0.35) in the whole sample, $2.72\,g\,cm^{-3} \times 100$ (s.d. 0.33) among boys and $2.73\,g\,cm^{-3} \times 100$ (s.d. 0.37) among girls ($P = 0.33$). Ponderal index, weight and length values at birth tended to increase with increasing family income (data not shown). Ponderal index was also higher among children born to obese mothers; the mean value was $2.75\,g\,cm^{-3} \times 100$ among those born to mothers with a BMI of $30\,kg\,m^{-2}$ or above and $2.72\,g\,cm^{-3} \times 100$ among mothers with lower BMI.

At 11 years of age, mean BMI was $18.6\,kg\,m^{-2}$ (s.d. 3.6), with no difference between the sexes ($P = 0.95$). Mean triceps and subscapular skinfold values were 13.4 mm (s.d. 6.8) and 9.1 (s.d. 5.8), respectively. Mean values of both skinfold measurements were higher among girls in comparison to boys. BMI at 11 years tended to increase with increasing family income ($P < 0.001$).

In Table 2, the prevalence of obesity at 11 years is compared across fourths of birth weight, length and ponderal index at birth. Individuals belonging to the highest fourths presented higher mean BMI than those belonging to

Table 1 Descriptive statistics for ponderal index, birth weight and length

Fourths	*Ponderal index ($g\,cm^{-3} \times 100$)* Mean (s.d.)	*Birth weight (grams)* Mean (s.d.)	*Birth length (cm)* Mean (s.d.)
1st	2.37 (0.15)	2473 (386)	45.8 (2.0)
2nd	2.62 (0.05)	3025 (93)	48.5 (0.5)
3rd	2.79 (0.05)	3341 (94)	49.9 (0.2)
4th	3.12 (0.42)	3817 (278)	51.6 (1.0)
Whole sample	2.72 (0.35)	3156 (549)	48.8 (2.4)

Abbreviation: s.d., standard deviation.

Table 2 Prevalence (95% CI) of obesity at 11 years according to ponderal index at birth, birth weight and length

	Prevalence (95% CI) of obesity at 11 years		
	Overall	*Boys*	*Girls*
Ponderal index at birth (fourths)			
1st (<2.53)	9.2 (7.5; 10.9)	11.8 (9.0; 14.5)	6.9 (4.8; 8.9)
2nd (2.53–2.70)	12.3 (10.3; 14.2)	15.9 (12.8; 19.0)	8.6 (6.2; 11.0)
3rd (2.71–2.89)	11.9 (10.0; 13.8)	16.6 (13.5; 19.7)	7.0 (4.9; 9.2)
4th (>2.89)	12.9 (10.9; 14.9)	15.7 (12.6; 18.8)	10.4 (7.9; 12.9)
P-value (linear trend)	0.01	0.07	0.08
P-value (heterogeneity)	0.04	0.11	0.11
Birth weight (fourths)			
1st (<2.850)	8.7 (7.0; 10.4)	11.3 (8.4; 14.2)	6.8 (4.9; 8.9)
2nd (2.850–3.180)	10.3 (8.5; 12.0)	13.4 (10.5; 16.4)	7.5 (5.4; 9.7)
3rd (3.181–3.500)	12.2 (10.2; 14.1)	14.8 (11.9; 17.8)	9.4 (6.9; 11.8)
4th (>3.500)	15.3 (13.2; 17.4)	19.3 (16.2; 22.3)	9.8 (7.1; 12.5)
P-value (linear trend)	<0.001	<0.001	0.04
P-value (heterogeneity)	<0.001	0.002	0.21
Birth length (fourths)			
1st (<47.5)	8.9 (7.2; 10.5)	11.0 (8.1; 13.8)	7.5 (5.5; 9.4)
2nd (47.5–49.0)	11.7 (10.0; 13.4)	15.8 (13.0; 18.6)	8.2 (6.2; 10.1)
3rd (49.01–50.0)	11.8 (9.7; 14.0)	14.5 (11.1; 17.7)	9.0 (6.2; 11.8)
4th (>50.0)	14.2 (12.0; 16.3)	17.6 (14.5; 20.6)	9.1 (6.2; 11.8)
P-value (linear trend)	<0.001	0.01	0.29
P-value (heterogeneity)	0.002	0.02	0.76

Abbreviation: CI, confidence interval.
P-values were calculated using the χ^2 test.

the lowest fourths for all exposures. Differences were more pronounced for boys than for girls.

Table 3 shows mean skinfold values at 11 years according to fourths of birth weight, length and ponderal index at birth. In all analyses (whole sample, boys and girls), mean triceps skinfold tended to increase with increasing birth weight, length and ponderal index at birth. The same was true for subscapular skinfolds. Those belonging to the highest fourth of ponderal index at birth had, on average, 1.7 mm higher triceps skinfold values and 0.9 mm higher subscapular skinfold values in comparison to those belonging to the lowest fourth. However, the most extreme differences between the highest and lowest fourths were observed for birth weight (2.5 mm for the triceps and 1.2 mm for the subscapular skinfolds). Among those classified as obese at 11 years, the mean ponderal index at birth was $2.77\,g\,cm^{-3} \times 100$ (s.d. 0.39), as compared to $2.71\,g\,cm^{-3} \times 100$ (s.d. 0.34) among those classified as nonobese ($P<0.001$). Mean birth weight was 3289 and 3161 g among obese and nonobese subjects, respectively, and mean birth length was 49.2 and 48.8 cm among obese and nonobese subjects, respectively.

Of the postulated confounding variables, sex and gestational age were not associated with BMI, whereas maternal education, family income, maternal smoking during pregnancy and pre-pregnancy maternal BMI were directly associated with BMI at 11 years. Parity was inversely associated with BMI at 11 years (data not shown in tables).

Table 4 presents the results of linear regression analysis using continuous BMI values at 11 years as the outcome variable and continuous birth weight, length and ponderal index *Z*-scores as the main exposures. In the unadjusted analyses, each *Z*-score increase in ponderal index at birth was associated with $0.35\,kg\,m^{-2}$ increase in BMI at 11 years. The equivalent values for birth weight and length *Z*-scores were 0.62 and $0.36\,kg\,m^{-2}$, respectively. When all covariates were adjusted for, the coefficients associated with ponderal index, birth weight and length were 0.22, 0.46 and $0.21\,kg\,m^{-2}$.

Figure 1 presents receiver operating characteristic curves using obesity as the outcome variable and the three exposures (birth weight, length and ponderal index) as the predicting variables. The areas under the curve were 0.57 for birth weight, 0.55 for birth length and 0.54 for ponderal index.

Discussion

Few data on the long-term effects of the ponderal index at birth are available, particularly in low- and middle-income countries. Our study aims to help fill this gap using information from a prospective birth cohort study (Victora *et al*., 2006, 2007). The cohort is representative of the population of the city, as over 99% of all deliveries in that year were covered and only 16 mothers refused to take part in the study. At the 11-year visit, almost 90% of the cohort

Table 3 Mean (s.d.) triceps and subscapular skinfolds at 11 years according to ponderal index at birth, birth weight and birth length

	Triceps (Mean, s.d.)			*Subscapular (Mean, s.d.)*		
	Overall	*Boys*	*Girls*	*Overall*	*Boys*	*Girls*
Ponderal index at birth (fourths)						
1st	12.6 (6.4)	11.8 (6.5)	13.3 (6.2)	8.6 (5.5)	7.9 (5.3)	9.3 (5.7)
2nd	13.3 (6.9)	12.8 (7.3)	13.8 (6.5)	9.0 (6.0)	8.6 (6.2)	9.5 (5.8)
3rd	13.4 (6.6)	12.9 (7.0)	13.9 (6.1)	9.0 (5.8)	8.6 (5.9)	9.5 (5.6)
4th	14.3 (6.9)	13.5 (7.3)	15.1(6.5)	9.5 (5.9)	8.7 (5.9)	10.6 (5.7)
P-value (linear trend)	<0.001	<0.001	<0.001	<0.001	0.02	0.005
P-value (heterogeneity)	<0.001	0.001	<0.001	0.002	0.06	0.02
Birth weight (fourths)						
1st	12.2 (6.2)	11.3 (6.2)	12.9 (6.2)	8.6 (5.5)	7.7 (5.1)	9.2 (5.7)
2nd	12.9 (6.4)	12.1 (6.7)	13.5 (5.0)	8.7 (5.6)	8.0 (5.8)	9.3 (5.4)
3rd	13.7 (6.9)	12.9 (7.2)	14.6 (6.4)	9.2 (5.9)	8.5 (5.9)	9.9 (5.9)
4th	14.7 (7.2)	14.2 (7.6)	15.4 (6.6)	9.8 (6.1)	9.3 (6.3)	10.4 (5.9)
P-value (linear trend)	<0.001	<0.001	<0.001	<0.001	<0.001	0.002
P-value (heterogeneity)	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
Birth length (fourths)						
1st	12.4 (6.2)	11.1 (6.1)	13.3 (6.1)	8.7 (5.5)	7.6 (5.0)	9.5 (5.6)
2nd	13.4 (6.9)	13.0 (7.3)	13.8 (6.5)	9.0 (5.9)	8.5 (6.2)	9.4 (5.5)
3rd	13.6 (6.4)	12.6 (6.7)	14.6 (6.0)	9.0 (5.6)	8.2 (5.3)	9.9 (5.7)
4th	14.3 (7.2)	13.8 (7.5)	15.0 (6.8)	9.6 (6.2)	9.2 (6.2)	10.2 (6.1)
P-value (linear trend)	<0.001	<0.001	<0.001	0.006	<0.001	0.02
P-value (heterogeneity)	<0.001	0.001	<0.001	<0.001	<0.001	0.06

Abbreviations: ANOVA, analysis of variance; s.d., standard deviation.
P-values were calculated using one-way ANOVA.

Table 4 Linear regression analyses using body mass index at 11 years as the outcome variable and birth weight, length and ponderal index as the exposure variables

Analysis	*Birth weight (Z-score)*		*Birth length (Z-score)*		*Ponderal index (Z-score)*	
	Coefficient (95% CI)	P	*Coefficient (95% CI)*	P	*Coefficient (95% CI)*	P
Unadjusted	0.62 (0.51; 0.73)	<0.001	0.36 (0.26; 0.47)	<0.001	0.35 (0.25; 0.46)	<0.001
Adjusted for sex	0.63 (0.52; 0.74)	<0.001	0.37 (0.27; 0.48)	<0.001	0.35 (0.25; 0.46)	<0.001
Adjusted for gestational age	0.68 (0.55; 0.80)	<0.001	0.35 (0.23; 0.47)	<0.001	0.33 (0.22; 0.44)	<0.001
Adjusted for family income	0.61 (0.50; 0.62)	<0.001	0.36 (0.25; 0.47)	<0.001	0.36 (0.25; 0.46)	<0.001
Adjusted for maternal schooling	0.59 (0.48; 0.70)	<0.001	0.34 (0.23; 0.44)	<0.001	0.33 (0.22; 0.44)	<0.001
Adjusted for smoking in pregnancy	0.65 (0.54; 0.76)	<0.001	0.38 (0.27; 0.49)	<0.001	0.36 (0.25; 0.46)	<0.001
Adjusted for pre-pregnancy maternal BMI	0.40 (0.29; 0.51)	<0.001	0.21 (0.10; 0.32)	<0.001	0.24 (0.14; 0.35)	<0.001
Adjusted for maternal age	0.62 (0.51; 0.73)	<0.001	0.36 (0.25; 0.47)	<0.001	0.35 (0.25; 0.46)	<0.001
Adjusted for parity	0.64 (0.53; 0.75)	<0.001	0.37 (0.26; 0.48)	<0.001	0.37 (0.26; 0.47)	<0.001
Adjusted for all confounders	0.46 (0.33; 0.59)	<0.001	0.21 (0.09; 0.33)	0.001	0.22 (0.12; 0.33)	<0.001

Abbreviations: BMI, body mass index; CI, confidence interval.

members were examined; these subjects were similar to those not located in terms of birth weight, length and ponderal index at birth. Unlike most large studies in low- and middle-income countries, we did not rely solely on BMI, but also used triceps and subscapular skinfold measurements to classify subjects for obesity (WHO Expert committee, 1995), but unfortunately no data were available on arm or waist circumference, nor on other indicators of body composition. Another limitation is lack of data on pubertal status.

Regardless of the outcome—BMI, skinfolds or obesity—positive associations with ponderal index, birth weight and length were found. The effects were greater for skinfolds than for BMI, and did not differ according to sex. It was previously shown that triceps skinfold is a good indicator of fatness in children and adult women, but not in adult men (WHO Expert committee, 1995). Subscapular skinfold has also been shown to indicate total fatness. In a previous analysis in our cohort, using isotopic methods in 172 boys aged 9 years, Wells *et al*. (2005) found a positive association between ponderal index at birth and later height, but not fatness *per se*.

A cohort study in India (Sachdev *et al*., 2005) showed that birth weight predicts later lean, but not fat mass. This

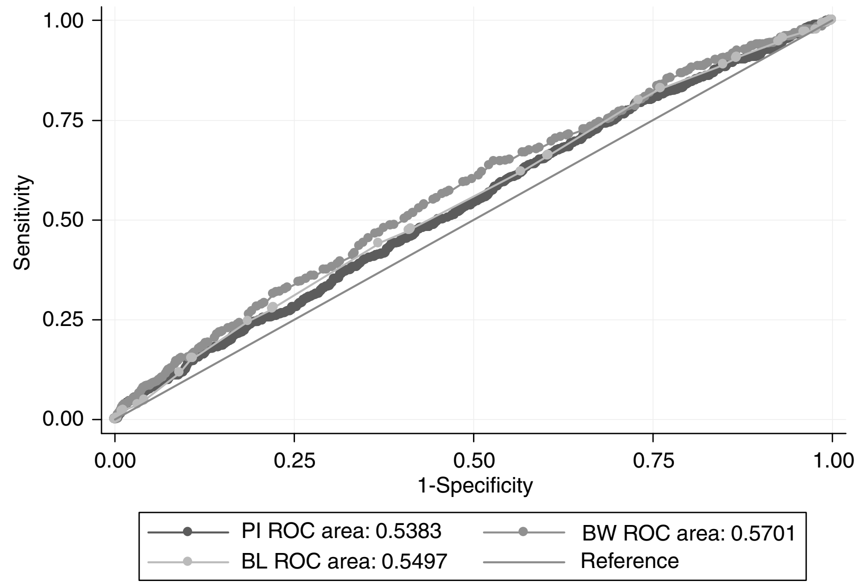

Figure 1 Receiver operating characteristic curves using obesity at 11 years as the outcome variable and ponderal index (wide line), birth weight (dashed line) and birth length (thin line) *Z*-scores as the predicting variables. The areas under the curve were 0.57 for birth weight, 0.55 for birth length and 0.54 for ponderal index. BL, birth length *Z*-score; BW, birth weight *Z*-score; PI, ponderal index *Z*-score at birth.

finding was confirmed in a subsample analysis of our cohort at the age of 9 years (Wells *et al*., 2005). We show that birth weight is positively associated with skinfolds in early adolescence, but because body composition was not evaluated at this age we cannot make further inferences on its association with birthweight.

Previous studies have shown that a high ponderal index at birth was associated with lower mortality and hospitalizations in infancy and childhood (Morris *et al*., 1998). However, a high ponderal index at birth has also been associated with higher BMI in infancy in a study carried out in Norway (Lande *et al*., 2005) and in the present analyses.

Our main objective was to test whether ponderal index would predict later BMI and skinfolds better than single indicators, such as birth weight and length. The receiver operating characteristic analyses, however, showed that birth weight alone is a better predictor of later anthropometry than ponderal index or birth length and more importantly, that all three birth size indicators studied presented poor predictability of the later risk of obesity. Further studies are necessary to evaluate the separate effects of birth weight, length and ponderal index on other outcomes, such as blood pressure and glucose.

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