Original article

Effects of birth weight on body composition and overweight/obesity at early school age

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Summary

Objectives

The prevalence of childhood obesity has increased substantially. We aimed to characterize the effect of birth weight on body composition and overweight/obesity at early school age.

Study design

A total of 1669 children with available birth records from a double-blind cluster-randomized controlled trial exploring micronutrient supplementation during pregnancy were included. Data regarding school-aged body composition, social-demographic factors and health behaviours were prospectively collected.

Result

s: The study population consisted of 1004 boys and 665 girls aged between 7 and 10 years. The prevalence of overweight/obesity (>85th age-sex-specific percentiles) was 7.4% for boys and 5.0% for girls. Generalized estimating equation models were used to account for the cluster nature of the data. A significant upward trend across quintiles of birth weight was observed for fat mass index (boys: P for trend 0.002; girls: P for trend <0.001), fat-free mass index (boys: P for trend <0.001; girls: P for trend <0.001), and percentage of body fat (boys: P for trend 0.003; girls: P for trend <0.001). A birth weight in the higher three quintiles could increase the risk ratios [RRs (95% CI) third quintile: 2.88, (1.13, 7.32); fourth quintile: 2.40, (0.87, 6.66); top quintile: 2.31, (0.92, 5.80)] of overweight/obesity at early school age compared with the RRs of the reference group (the second quintile of birth weight) among boys.

Conclusions

Higher birth weight could increase the risk of being overweight/obese among 7- to 10-year-old boys in rural western China. Sex differences in this association need to be considered when planning interventions.

Research registration

This trial was registered at www.isrctn.com with the identifier ISRCTN08850194.

Keywords: Birth weight; Obesity; Body composition; Early school-aged; Follow-up study

Abbreviations: BMI, body mass index; CIs, confident intervals; FFM, fat-free mass; FFMI, fat-free mass index; FM, fat mass; FMI, fat mass index; RR, risk ratio; PBF, percentage of body fat; SD, standard deviation; SDS, standard deviation score

1 Introduction

In the past three decades, the prevalence of childhood overweight/obesity has risen substantially in most high-income countries [1]. Although the onset is later, the prevalence of overweight has rapidly increased in the past two decades in several low- and middle-income countries [1]. Obesity in childhood can contribute to physical and psychological health consequences during childhood [2,3]. More importantly, childhood obesity can continue into adolescence and adulthood, resulting in health and economic consequences [4,5].

The prenatal period has been suggested to be a "critical period" for the development of obesity [6]. Birth weight is the most commonly used indicator of the conditions experienced in utero [7]. A number of studies have indicated that high birth weight is associated with an increased risk of obesity in childhood [8,9]. However, most studies investigating the association between birth weight and obesity have used BMI as a proxy measure for body "fatness" [8,10]. As a result, it is unclear whether these associations with BMI are due to greater fat mass (FM) or fat-free mass (FFM). Much more accurate measurement of body composition, adjusted for height squared, can provide independent and more precise indicators of fatness, leanness, and adiposity among children [11].

Various techniques are available for measuring body composition [12]. Traditionally, skinfold thickness measurements are useful to rank individuals in terms of relative fatness, but in obese children, accuracy and precision are poor. Other techniques for body composition assessment, such as dual-energy X-ray absorptiometry, magnetic resonance imaging, and densitometry, provide more accurate information regarding fat mass and fat-free mass. However, these techniques are expensive and impractical for use in routine clinics and epidemiological studies. Bioelectrical impedance analysis (BIA), which measures the impedance of the body to a small electric current, is relatively cheap and easy to use. Therefore, at present BIA is primarily an epidemiological technique.

Environmental and behavioural factors may interact with birth outcomes to modify body composition [13]. Parental BMI, socioeconomic status, dietary intake and physical activity are all associated with fat mass, fat-free mass, and paediatric obesity [14–16]. However, previous studies that have found associations between birth weight and paediatric body composition often lack environmental or behavioural assessments that also affect current body mass. Although the relationship between birth weight and body composition has been addressed in multiple studies worldwide, there is a lack of data in rural developing Asian countries. Therefore, we investigated the association between birthweight and fat mass, fat-free mass, percentage of body fat and obesity, controlling for environmental and behavioural risk factors in a 10-year follow-up randomized clinical trial conducted in rural western China.

2 Methods

2.1 Study design and participants

This study is a prospective study of growth and development in the offspring of mothers who had participated in a cluster-randomized, double-blind trial regarding micronutrient supplementation during pregnancy (http://www.isrctn.com/Identifier: ISRCTN08850194) [17]. From August 1, 2002, to February 28, 2006, all pregnant women in two low-income rural counties in northwest China were randomly assigned to take a daily capsule of either folic acid (400 μg), iron - folic acid (400 μg of folic acid and 60 mg of iron), or multiple micronutrients (consistent with the suggested composition of multiple micronutrients for antenatal use as recommended by the World Health Organization [WHO]) [18].

Follow-up was conducted from October 10, 2012 to August 12, 2013, when the offspring were at early school age (7–10 years). To confirm the offspring's survival and school attended, information on the children, including name (and parent name), sex, birth date, home address, and telephone number, were sent to the village physicians, and consent from parents or guardians to enrol in the present study was obtained. The local education bureau and health bureau in two counties gave us permission to conduct the study in schools. Offspring from multiple births, who moved out of the study area, who had a major congenital abnormality, who died, or who had missing birth weight data were excluded. We excluded migrated children because it was difficult to track them. More importantly, some potential confounders that may be associated with the nutritional status of children could not be well estimated in migrated children.

The early school-aged growth and development evaluation performed for the study was approved by the Science and Research Ethics Committee of Xi'an Jiaotong University Health Science Center in Xi'an, Shaanxi, China.

Written informed consent was obtained from each parent or caregiver, and oral consent was obtained from the early school-aged participants after the purpose of the study was explained.

2.2 Birth weight, body composition and overweight/obesity

Birth weight was measured by hospital nursing staff within 1 h of delivery with an electronic scale (BD-585, Tanita Corporation, Dongguan, Guangdong Province, China) to the nearest 10 g and was recorded in the infant's personal health record. Because the relationship between birth weight and the risk of overweight/obesity was nonlinearity and the model with four knots had smaller AIC (data not shown), birth weight was expressed as quintiles. The cut-off points for each group were 2900 g, 3100 g, 3300 g and 3500 g. The median of the second quintile (3000 g) was equal to the birth weight of normal-term infants [19], so we used this quintile as the reference group.

Early school-aged anthropometric parameters were measured with standardized techniques and are expressed as standard deviations (SDs) from sex- and age-specific references from the WHO growth standards, including weight-for-age Z score, height-for-age Z score, and body mass index (calculated as weight in kilograms divided by height in metres squared) for age Z score [20]. Body composition was measured with bioelectrical impedance examinations (BC-420, TANITA Corporation, Tokyo, Japan), which were conducted by skilled technicians. Fat mass index (FMI) and fat-free mass index (FFMI) were calculated by dividing the total fat mass or fat-free mass in kilograms by the height in metres squared separately to adjust the body composition for height [11]. The percentage of body fat (PBF) was calculated by dividing the total fat mass by the total body mass times 100. Overweight was defined as a PBF between the 85th and 95th percentiles of each age and sex group, and obesity was defined as PBF above the 95th percentile of each age and sex group [21].

2.3 Confounding variables

Factors that might act as confounding variables of the relationship between birth weight and body composition were assessed using a structured questionnaire. Gestational age was computed as the number of completed weeks of gestation from the date of the mother's last menstrual period to delivery. Household wealth was estimated from an inventory of 15 household assets or facilities using a principal components analysis [16]. The household wealth index was categorized into tertiles, indicating the low-income, middle-income, and highest-income households. Measured parental height and weight were used to calculate parental BMI.

2.4 Statistical analysis

We performed range and logical assessments of the data for accuracy. Quantitative variables are expressed as the mean (standard deviation) for normally distributed data or the median (interquartile range) for variables with skewed distributions. Qualitative variables are expressed as frequencies (percentages). Characteristics of lost and followed-up participants as well as those of participants across birth weight quintile groups were compared using analyses of variance (normally distributed data) or Mann–Whitney *U* tests (abnormally distributed data) and χ^2 tests.

Adjusted mean values and 95% confidence intervals (CIs) of fat mass index, fat-free mass index, and percentage of body fat for different birth weight quintiles among boys and girls were assessed by using generalized estimating equation linear models, which took into account the cluster randomization. The possible confounders we considered were the children's age, gestational weeks at birth, antenatal micronutrient supplementation, household wealth level, maternal BMI, and paternal BMI. Furthermore, using the second quintile of birth weight group as a reference, we applied generalized estimating equation binomial regression models with log link and exchangeable structure to estimate the adjusted risk ratios (RRs) and 95% CIs for overweight/obesity. Although the interaction between gender (boy vs girl) and birth weight categories in relation to early school aged overweight/obesity are not statistically significant, we chose to stratify by sex based on biological plausibility. Two models were constructed and tested as follows: adjustments for age only (model 1) and adjustments for age plus gestational weeks at birth, antenatal micronutrient supplementation, household wealth index at early school age, maternal BMI and paternal BMI (model 2). All reported P-values are 2-tailed, and the level of significance was set to 0.05. All statistical analyses were conducted using SPSS version 20.0 for PC (International Business Machines Corporation, Armonk, New York, United States).

3 Results

3.1 Followed participants

Figure 1 shows the flowchart of participant selection. Most baseline characteristics were balanced between lost and followed-up participants except for maternal educational level (Table 1). In total, 1669 early school-aged children (1004 [60.2%] were boys and 665 [39.8%] were girls, with a mean [SD] age of 8.8 [0.8] years) were followed, representing 62.2% of the 2682 single live births that were eligible to participate in this follow-up study.

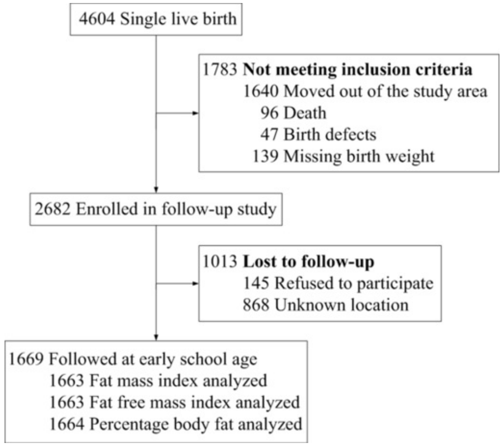

Fig. 1 Flow diagram of recruitment and follow-up in the study cohort.

alt-text: Fig. 1

Table 1 Baseline characteristics of follow-up and lost to follow-up participants.[a]

alt-text: Table 1

Characteristics	Follow-up (n = 1669)		Lost to follow-up (n = 1013)	
	n	n (%)/Mean (SD)	n	n (%)/Mean (SD)
Maternal age, y	1665	24.8 (4.4)	1011	24.8 (4.3)
Paternal age, y	1663	28.0 (4.2)	1011	28.0 (4.1)
Maternal education (primary and below)	1665	590 (35.4)	1010	315 (31.2)[b]
Paternal education (primary and below)	1664	260 (15.6)	1012	130 (12.8)
Maternal occupation (farmer)	1661	1443 (86.9)	1006	870 (86.5)
Paternal occupation (farmer)	1665	1333 (80.1)	1012	786 (77.7)
Household wealth index, median (IQR)	1669	−0.17 (1.87)	1013	−0.23 (1.85)
Poorest third		581 (34.8)		360 (35.5)
Middle third		594 (35.6)		341 (33.7)
Richest third		494 (29.6)		312 (30.8)
Primipara	1669	1068 (64.0)	1013	645 (63.7)
No of male child	1669	1004 (60.2)	1013	583 (57.6)
Gestation at birth, wk	1669	39.8 (1.7)	1013	39.8 (1.7)
Preterm (gestational age at birth<37wks)	1669	78 (4.7)	1013	48 (4.7)
Birth weight, g	1669	3198 (424)	1013	3201 (420)
Low birth weight (≤2500 g)[c]	1669	117 (7.1)	1013	63 (6.2)
Small for gestational age[d]	1669	277 (16.6)	1013	161 (15.9)

Birth length, cm	1487	49.1 (2.8)	907	49.1 (2.7)

[a] IQR, interquartile range; SD, standard deviation.

[b] Significantly different from follow-up subjects: $P < 0.05$; continuous data were ~~analyzed~~ analysed with t tests (normally distributed data) or Mann–Whitney U test (abnormally distributed data), and categorical data were ~~analyzed~~ analysed with χ^2 tests.

[c] Assessed because of heaping of birth weight exactly on 2500 g.

[d] Defined as birth weight below the 10th percentile by gestational age and sex based on international standards.

3.2 Baseline treatment, birth, and early school aged characteristics

Table 2 presents the baseline characteristics, which were balanced across birth weight quintile groups, with the exception of birth length, BMI, gestational age, and household wealth. The medians and interquartile ranges of birth weight in each quintile were 2600 (300) g, 3000 (190) g, 3200 (190) g, 3400 (190) g, and 3600 (300) g.

Table 2 Characteristics of the study subjects by birth weight quintiles[1].

alt-text: Table 2

	Q1 (<2900 g)		Q2 (2900–3100 g)		Q3 (3100–3300 g)		Q4 (3300–3500 g)		Q5 (>3500 g)	
	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
Pregnancy										
Treatment, n (%)	300		350		315		221		483	
Folic acid		115 (38.3)		127 (36.3)		105 (33.3)		73 (33.0)		156 (32.3)
Iron + Folic acid		84 (28.0)		113 (32.3)		101 (32.1)		82 (37.1)		154 (31.9)
Multiple Micronutrients		101 (33.7)		110 (31.4)		109 (34.6)		66 (29.9)		173 (35.8)
Birth										
Gender, boys, n (%)	300	144 (48.0)	350	181 (51.7)	315	197 (62.5)	221	144 (65.2)	483	338 (70.0)
Birth weight, g, median (IQR)	300	2600 (300)	350	3000 (190)	315	3200 (190)	221	3400 (190)	483	3600 (300)[4]
Birth length, cm	260	46.8 (2.6)	314	48.7 (2.4)	291	49.0 (2.0)	205	49.5 (2.6)	417	50.6 (2.7)[4]
BMI, kg/m^2	260	11.8 (1.3)	314	12.6 (1.3)	291	13.3 (1.1)	205	13.8 (1.5)	417	14.5 (1.6)[4]
Gestation at birth, wk	300	39.3 (2.1)	350	39.7 (1.8)	315	39.9 (1.4)	221	40.0 (1.3)	483	40.2 (1. 6)[4]
Early school age										
Age, y	300	8.6 (0.8)	350	8.8 (0.8)	315	8.7 (0.8)	221	8.8 (0.8)	483	8.9 (0.8)[3]
Household wealth index	300	−0.02 (1.01)	350	−0.09 (0.93)	315	0.07 (0.98)	221	0.21 (1.08)	483	−0.01 (0.99)[2]
Maternal BMI, kg/m^2	284	21.6 (3.2)	333	21.5 (2.9)	298	21.8 (2.9)	208	22.0 (2.6)	465	22.0 (2.7)
Paternal BMI, kg/m^2	283	22.5 (3.0)	332	22.4 (3.0)	297	22.2 (2.8)	206	22.7 (2.8)	465	22.2 (3.0)
Dietary pattern, n (%)	300		350		315		221		483	
Poor		192 (64.0)		228 (65.1)		209 (66.3)		135 (61.1)		301 (62.3)
Balanced		31 (10.3)		33 (9.4)		27 (8.6)		24 (10.9)		45 (9.3)

Rich		77 (25.7)		89 (25.4)		79 (25.1)		62 (28.1)		137 (28.4)
Physical activities, n (%)	289		345		306		217		472	
Often		177 (61.2)		200 (58.0)		168 (54.9)		127 (58.5)		270 (57.2)
Occasionally		112 (38.8)		145 (42.0)		138 (45.1)		90 (41.5)		202 (42.8)

[1]IQR, interquartile range; BMI, body mass index = body mass (kg)/length or height $(m)^2$.

[2,3,4]Significantly different among birth weight quintiles:[2]P < 0.05,[3]P < 0.005,[4]P < 0.0005; continuous data were ~~analyzed~~ analysed with one-way ANOVA and categorical data were ~~analyzed~~ analysed with χ^2 tests.

3.3 Birth weight and early school aged body size and composition

Body size and composition at early school age by birth weight quintiles are reported in Table 3. Mean weight, height, BMI, and fat-free mass were significantly higher in children with birth weights in the top three quintiles than in those in the second quintile, whereas fat mass and percentage of body fat were significantly higher only in children with birth weights in the third and fourth quintiles than in those in the second quintile of birth weight. The incidence of overweight/obesity was significantly higher in children in the upper three quintiles of birth weight when than in children in the second quintile of birth weight.

Table 3 Body size and composition of the study subjects by birth weight quintiles[1].

alt-text: Table 3

	Q1 (<2900 g)		Q2 (2900–3100 g)		Q3 (3100–3300 g)		Q4 (3300–3500 g)		Q5 (>3500 g)	
	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)	n	Mean (SD)
Weight, kg	299	23.5 (3.5)	347	24.9 (3.9)	315	26.0 (4.8)	221	26.5 (4.3)	483	26.8 (4.6)[4]
WAZ[5]	283	−0.96 (0.95)	324	−0.74 (0.86)	302	−0.43 (0.97)	210	−0.31 (0.92)	438	−0.32 (0.91)[4]
Height, cm	299	125.8 (6.1)	348	128.1 (6.4)	315	129.0 (6.3)	221	129.7 (6.6)	483	130.7 (6.6)[4]
HAZ	299	−0.76 (0.93)	348	−0.53 (0.84)	315	−0.32 (0.80)	221	−0.26 (0.89)	483	−0.16 (0.86)[4]
BMI, kg/m^2	298	14.8 (1.4)	347	15.1 (1.5)	315	15.6 (1.9)	221	15.7 (1.6)	483	15.6 (1.6)[4]
BAZ	298	−0.85 (0.98)	347	−0.67 (0.92)	315	−0.40 (1.05)	221	−0.31 (0.98)	483	−0.40 (0.98)[4]
FM, kg, median (IQR)	298	2.2 (1.6)	347	2.7 (1.6)	315	2.9 (1.9)	221	3.0 (2.2)	482	2.8 (2.1)[4]
FFM, kg, median (IQR)	298	20.6 (3.9)	347	21.8 (3.8)	315	22.6 (4.2)	221	23.0 (3.7)	482	23.3 (4.4)[4]
FMI, kg/m^2, median (IQR)	298	1.4 (0.9)	347	1.7 (1.0)	315	1.7 (1.1)	221	1.8 (1.4)	482	1.7 (1.2)[4]
FFMI, kg/m^2, median (IQR)	298	13.2 (1.1)	347	13.4 (1.1)	315	13.6 (1.1)	221	13.7 (1.0)	482	13.8 (0.9)[4]
PBF, %, median (IQR)	298	9.8 (5.5)	347	11.1 (5.9)	315	11.3 (6.4)	221	11.7 (7.0)	482	11.0 (7.0)[3]
Overweight/obesity, n (%)[6]	298	11 (3.7)	347	12 (3.5)	315	32 (10.2)	221	17 (7.7)	482	35 (7.3)[2]

[1] WAZ, weight-for-age Z score; HAZ, height-for-age Z score; BMI, body mass index = body mass(kg)/length or height$(m)^2$; BAZ, BMI-for-age Z score; FM, fat mass; FFM, fat free mass; FMI, fat mass index = fat mass(kg)/height$(m)^2$; FFMI, fat free mass index = fat free mass(kg)/height$(m)^2$; PBF: percentage of body fat = fat mass(kg)/total body mass(kg) × 100; SD, standard deviation.

[2,3,4]Significantly different among birth weight quintiles:[2]P < 0.05,[3]P < 0.005,[4]P < 0.0005; continuous data were ~~analyzed~~ analysed with one-way ANOVA (normally distributed data) or Mann–Whitney U test (abnormally distributed data), and categorical data were ~~analyzed~~ analysed with χ^2 tests.

[5]n = 1557 because the database for weight SDS was not available for the age of 10 y.

[6]Overweight was defined as PBF between 85th and 95th percentiles of each age and sex group and obesity was defined as PBF above 95th percentile of each age and sex group.

The results of multiple linear regression analyses between birth weight quintiles and early school aged fat mass index, fat-free mass index, and percentage of body fat as continuous variables by sex are shown in Fig. 2. When we adjusted for covariates, the mean values of fat mass index, fat-free mass index, and percentage of body fat increased significantly with increasing birth weight (boys P for trend 0.002, <0.001, and 0.003, respectively; girls P for trend: <0.001, <0.001, and <0.001, respectively). Among boys, the greatest differences in fat mass index and percentage of body fat were found between the third quintile and the reference category. However, the greatest differences in fat mass index and percentage of body fat were found between the fourth quintile and the reference category among girls. Concerning the fat-free mass index, boys and girls with birth weights in the two highest quintiles were 0.23 kg/m^2 and 0.25 kg/m^2 heavier than those with birth weights in the second quintile, respectively.

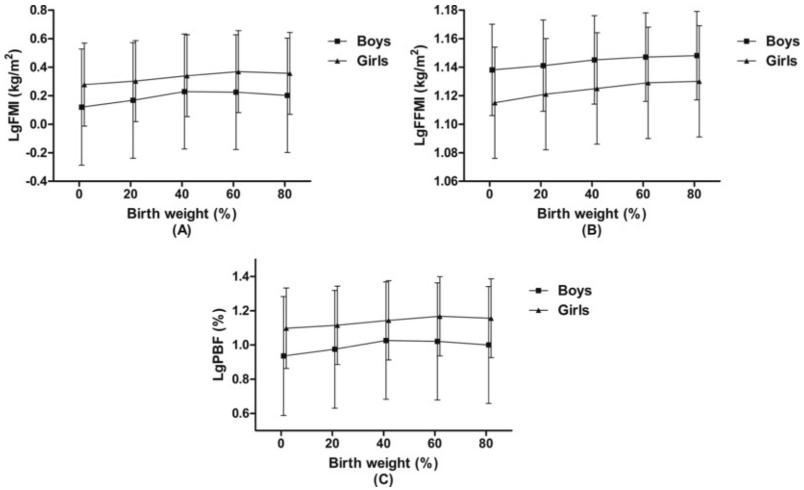

Fig. 2 Adjusted means of fat mass index (A), fat-free mass index (B), and percentage of body fat (C) in boys and girls by birth weight quintile, adjusted for age, gestational weeks at birth, antenatal micronutrient supplementation, household wealth index at early school age, maternal BMI and paternal BMI. Error bars are 95% CIs.

alt-text: Fig. 2

3.4 Birth weight and early school aged overweight/obesity

The prevalence of overweight/obesity was 7.4% for boys and 5.0% for girls. The results of multiple logistic regression analysis of the association between birth weight and the risk of being overweight/obese at early school age using the second birth weight quintile as the reference group are shown by sex in Table 4. The top three quintiles of birth weight could increase the risk of being overweight/obese at early school age by 1.31- to 1.88-times for boys after adjustment for age, gestational age, antenatal micronutrient supplementation, household wealth, maternal BMI, and paternal BMI. However, there was no statistically significant association between higher birth weight and overweight/obesity at early school age among girls [adjusted RR (95% CI) third quintile: 2.97, (0.93, 9.46); fourth quintile: 1.66, (0.42, 6.50); top quintile: 1.21, (0.34, 4.35)]. The results of the sensitivity analysis excluding preterm-born children (data not shown) showed similar associations.

Table 4 Risk ratios of overweight/obesity at early school age by birth weight quintiles.[a]

alt-text: Table 4

Birth weight		Number of participants	Number of case	Model 1		Model 2	
				RR	95%CI	RR	95%CI
Boys	Q1	143	5	0.99	(0.29, 3.36)	0.65	(0.17, 2.47)
	Q2	179	6	1	[Reference]	1	[Reference]
	Q3	197	21	**3.40**	**(1.34, 8.64)**	**2.88**	**(1.13, 7.32)**

	Q4	144	13	**2.81**	**(1.04, 7.58)**	2.40	(0.87, 6.66)
	Q5	337	29	**2.75**	**(1.12, 6.77)**	2.31	(0.92, 5.80)
Girls	Q1	156	6	1.10	(0.34, 3.52)	1.55	(0.43, 5.57)
	Q2	168	6	1	[Reference]	1	[Reference]
	Q3	118	11	2.81	(0.99, 7.93)	2.80	(0.86, 9.06)
	Q4	77	4	1.46	(0.40, 5.34)	1.66	(0.43, 6.41)
	Q5	145	6	1.15	(0.37, 3.59)	1.18	(0.34, 4.08)

Model 1: Adjusted for age only.

Model 2: Adjusted for age, gestational weeks at birth, antenatal micronutrient supplementation (folic acid, iron + folic acid, or multiple micronutrients), household wealth index at early school age, maternal BMI and paternal BMI.

[a] RR, relative risk; CI, confidence interval. General estimating equation logistic models were used to test the effect of birth weight on the risk of overweight/obesity at early school age, boldface indicate significant at $P < 0.05$. Overweight was defined as percentage of body fat between 85th and 95th percentiles of each age and sex group and obesity was defined as percentage of body fat above 95th percentile of each age and sex group.

4 Discussion

This longitudinal study showed that birth weight was significantly positively associated with fat mass, fat-free mass, and percentage of body fat among 7- to 10-year-old children in rural western China. These associations were independent of sex, age, gestational weeks at birth, antenatal micronutrient supplementation, household wealth index, and paternal BMI. Moreover, higher birth weight could increase the risk of being overweight/obese at an early school age among boys.

4.1 Interpretation of the findings and comparison with other studies

The finding that weight at birth was positively associated with later FFM has been supported by several published studies [22,23]. However, the relationship between birth weight and FM in previous studies has been less consistent. The results from a birth cohort from Portugal revealed that there was an increase of 0.037 (0.020,0.055) g/m^2 in FMI for each 100 g increase in BW [24]. Moreover, a significant positive association was observed between birth weight and fat mass ($P = 0.007$) among children 5–8 years old in a Brazilian cohort study [23]. However, in a UK birth cohort, birth weight was not significantly associated with fat mass at 17 years old after adjustment for pregnancy confounders [25]. Additionally, another study in the UK found that birthweight was inversely associated with adult total body fat after adjusting for age, sex, height and weight [26]. Due to hormones such as cortisol, insulin, growth hormone and sex steroids, changes in body fat distribution begin during puberty [27]. The fact that children are physiologically different from adolescents and adults in terms of body composition may account for the inconsistent results from studies that targeted children, adolescents or adults.

The linear relationship between birth weight and PBF contradicted the findings of some of the previous studies in developed countries that had shown U-shaped or no relationships [28,29]. One possible explanation may be that body fat percent is ethnicity-specific, which results from the differences in relative leg length, frame size and physical activity level [30–32].

This finding was consistent with the majority of previous studies showing that higher birth weight increased the risk of overweight/obesity at early school age [33,34]. A cohort study of 10 186 term or preterm children found that high birthweight term (aRR 1.83 95% CI 1.51, 2.21) and large-for-gestational-age preterm (aRR 2.34 95% CI 1.18, 4.65) children had increased adjusted odds of obesity at school age compared to their normal birth weight counterparts [35]. Moreover, a multinational, cross-sectional study concluded that high birth weights, defined as birth weights ≥3500 g, were associated with increased odds of obesity at 9–11 years old [8]. It is known that maternal overnutrition and hyperglycaemia could lead to foetal β-cell hyperplasia and hyperinsulinism, which promote excessive fat deposition [36]. Both hyperinsulinism and increased adiposity in foetal life have been shown to continue through later life and subsequently may result in a permanent obesity disposition and predisposition to insulin resistance [37]. Additionally, higher birth weight could lead to high levels of growth factors, such as insulin and insulin-like growth factors I and -II, which may increase the risk of obesity in later life [38]. In general, prenatal overnutrition and accompanying hormonal changes during critical periods of foetal development predispose individuals to an increased risk of obesity over the long term.

Sex differences have been reported in several studies from developed countries. A study found that high birth weight (>4000 g) was associated with a higher risk of child overweight/obesity (age- and sex-specific BMI cut off) in both boys and girls before and after adjustment for socio-demographic factors [39]. Another multinational, cross-sectional study of 5141 children aged 9–11 years found a U-shaped association between birth weight and the odds of childhood obesity (BMI Z score>+2 SD) among boys, whereas a positive association appeared among girls [8]. However, such findings are inconsistent with those reported in our study. This difference may be due to the different categories of birth weight and various definitions of obesity. More longitudinal studies are needed to assess whether the association between birth weight and childhood obesity differs by sex.

Our findings suggest sex-specific responses to intrauterine overnutrition that influence the development of obesity. In terms of biologic mechanisms that may underlie the associations we reported, growing evidence shows that intrauterine nutrition not only promotes excessive cell proliferation but also alters gene expression in a manner that may increase future risk of adiposity [40]. Consistent with our findings, the current literature suggests that these epigenetic marks are sex specific [41]. The prevalence of overweight/obesity among boys (7.4%) was almost 1.5 times higher than that among girls (5.0%). This finding might reflect cultural preference for boys in terms of food allocation [42] and caretaking [43].

While lower birthweight had previously been linked to cardiovascular disease [44] and increased metabolic risk [45], we did not note a clear link between lower birth weight and obesity in early school-aged children. This finding may imply that either a predominance of other metabolic changes besides postnatal weight gain contributes to later cardiovascular risk or that the influence of low birth weight on later obesity and obesity-related diseases may occur after the age of 10 years.

4.2 Strengths and limitations

There are several strengths in our study. First, birth weight was measured by hospital staff within 1 h of delivery and recorded in the infant's personal health record. Additionally, prospective data for potential confounders and body composition were available in this study, which decreased the risk of recall bias or unreliable measurements. As with any observational study, caution should be exercised when inferring causality based on the findings. However, our findings were consistent before and after adjustments for potential confounding by most known variables that were plausibly associated with birth weight and childhood body composition.

Our study also has some limitations, such as the high sample attrition rate. Among the children with available weight information at birth who were still living in the study areas, 62.2% participated in the follow-up measurements at early school age, and 99.7% of these children also participated in the body composition assessments. However, baseline characteristics were similar between the participants who were lost to follow-up and those who completed the study. Therefore, the results of the present study could be generalized to the original sample. Second, although we performed an adjustment for a wide spectrum of predictors, unobserved predictive factors might still exist among the observed associations, as is possible in any observational study. We did not include maternal lifestyles, such as cigarette smoking and alcohol consumption during pregnancy, in the adjusted models. Because no mothers were in the group for cigarette smoking and alcohol consumption. It is noticeable, however, that passive smoking was more common. In the future researches, we should collect the information of passive smoking. Finally, we used bioelectric impedance analysis to measure body composition, which is not an accurate method for the assessment of fat mass and fat-free mass. Future research should consider more precise measures of body composition, such as dual-energy X-ray absorptiometry scans or air displacement methods, to allow for a better estimate of the true strength of these associations.

5 Conclusions

Obesity has been shown to be linked to a spectrum of chronic diseases, resulting in greater healthcare needs. In the present study, we found that higher birth weight was associated with a relatively higher fat level in boys at 7- to 10-year-old. Fat mass, fat-free mass, and percentage of body fat all increased with weight at birth for both sexes. These findings suggest that those born with higher birth weight may be more susceptible to being overweight/obese in later life. Regulation of pre-pregnant and pregnant nutritional status and diet may be useful to prevent childhood obesity and obesity-related health problems by minimizing the risk of foetal overgrowth.

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Author contributions

JZ drafted the initial manuscript, designed the data collection instruments, collected data, and carried out the initial analyses; LZ and HY conceptualized and designed the study, supervised the data collection, and reviewed and revised the manuscript. DW and YX critically reviewed the manuscript. CL designed the data collection instruments and collected data. YL collected data. All authors have read and approved the final version of the manuscript. All authors agreed to be accountable for all aspects of the work.

Conflict of interest

The authors declare no conflicts of interest.

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