SSM - Population Health 26 (2024) 101672

Contents lists available at ScienceDirect

SSM - Population Health

journal homepage: www.elsevier.com/locate/ssmph

Dynamic influence of maternal education on height among Chinese children aged 0–18 years

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A R T I C L E I N F O

Keywords:
Height
Maternal education level
Weight
Birth weight
Vitamin D

A B S T R A C T

Background: Maternal education is one of key factors affecting nurturing environment which significantly impacts children's height levels throughout their developmental stages. However, the influence of maternal education on children's height is less studied. This study aims to investigate the dynamic influence of maternal education on children's height among Chinese children aged 0-18 years.

Methods: Children undergoing health examinations from January 2021 to September 2023 were included in this study. Clinical information including height, weight, maternal pregnancy history, blood specimens for bone metabolism-related indicators and maternal education level was collected. Children's height was categorized into 14 groups based on age and gender percentiles, following WHO 2006 growth standards. One-way analysis of variance (ANOVA), linear regression, chi-square test and Fisher's exact test were applied for data analysis.

Results: A total of 6269 samples were collected, including 3654 males and 2615 females, with an average age of 8.38 (3.97) for males and 7.89 (3.55) for females. Significant correlations between maternal education level, birth weight, birth order, weight percentile, vitamin D, serum phosphorus, alkaline phosphatase levels, and children's height were identified. Birth weight's influence on height varied across age groups. Compared with normal birth weight children, low birth weight children exhibited catch-up growth within the first 6 years and a subsequent gradual widening of the height gap from 6 to 18 years old. Remarkably, the impact of maternal education on height became more pronounced among children above 3–6 years old, which can mitigate the effect of low birth weight on height.

Conclusion: We found that weight percentile, birth weight, birth order, bone marker levels, and maternal education level have significant effect on height. Maternal education attenuates the impact of low birth weight on height. The findings indicated that maternal education plays a consistent and critical role in promoting robust and healthy growth.

1. Introduction

Higher height is intricately linked to various health outcomes, as evidenced by consistent research findings associating stature with conditions such as lower risk of cardiovascular disease (Howe et al., 2022), lower risk of diabetes (X. Li et al., 2023), and lower level of overall

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https://doi.org/10.1016/j.ssmph.2024.101672
Received 29 December 2023; Received in revised form 25 March 2024; Accepted 20 April 2024
Available online 23 April 2024

mortality (Magnusson et al., 2005). Additionally, height significantly influences interactions, salary, and social status in both the workplace and society, with taller individuals often exhibiting higher income levels (Candela-Martínez et al., 2022; Patel & Devaraj, 2018). One possible explanation for this phenomenon is people's bias toward height: taller individuals are often perceived as more self-confident than shorter ones (Judge & Cable, 2004). Moreover, taller people are often regarded as more authoritative and leader-like by others (Judge & Cable, 2004). Understanding the determinants of height is crucial for unraveling growth and development patterns across diverse demographics.

Height is governed by a combination of genetic, environmental, and epigenetic factors. The genetic contribution to height has been well-established, with numerous studies identifying specific genetic variants associated with variations in height (Wood et al., 2014; Yang et al., 2010, 2015). Currently, it is estimated that genetics accounts for at least 65–80% of height determination, although many loci are yet to be discovered (Marouli et al., 2017; Perkins et al., 2016).

The most important nongenetic factors affecting growth and adult body height are nutrition and diseases (Perkins et al., 2016). The socioeconomic position of the family also has been identified as positively associated with the stature of children (Candela-Martínez et al., 2022; Subramanian et al., 2011). The most frequently used indicator is the father's social position, but the association is also found for the father's and mother's education and family income in studies in developing countries (Gigante et al., 2006). Several studies have shown an increase in height in countries throughout the twentieth century (Hatton & Bray, 2010; Holmgren et al., 2018, 2019). The increase in height aligns with improvements in several aspects of living conditions, including diets, educational level, income, working conditions, improvements in health services, and enhanced focus on public health (Arntsen et al., 2023; Cole, 2003; German et al., 2020; Little, 2020; Negasheva et al., 2024; Silventoinen, 2003).

With the economic development of nations and improved living standards in China, there has been a notable decline in malnutrition and factors contributing to stunted growth (Morgan, 2000; Yan et al., 2023). Concurrently, there has been an upward trend in adult height in China (Chae et al., 2023; Schwekendiek & Baten, 2019). China has shown the largest gains in height, particularly for boys, ranking first globally from 1985 to 2019 among 200 countries and territories, while girls ranked third (NCD-RisC, 2020). Alongside these improvements, China has achieved significant progress in education, with 9 years of compulsory education and a remarkable increase in university enrollment rates. The rates surged from 1.95% in 1965 to 3.4% in 1990, further escalating to 12.5% in 2000, 26.5% in 2010, and an impressive 57.8% in 2020 (Chen et al., 2023). This upward trajectory prompts the question: What role does maternal educational level play in the development of height? Furthermore, while previous research has focused on the relationship between adult height and educational level, the specific impact of educational level on children's height at different age stages remains unknown.

In this study, our objective is to explore height trends across different age stages (encompassing infancy to adolescence (0–18 years)) in Chinese children under current economic conditions, examining influencing factors and specifically addressing whether maternal education levels impact children's height throughout all developmental stages. Diverging from previous research, we categorize children's height levels into 14 groups based on percentiles relative to age and gender-specific height levels according to WHO 2006 growth standards, offering more detailed and comprehensive data ("WHO Child Growth Standards based on length/height, weight and age," 2006). Our study delves into the nuanced aspects of height regulation, aiming to unravel the distinctive patterns of height changes throughout different developmental stages. By scrutinizing the influence of factors such as maternal education levels, our overarching goal is to contribute a more intricate and profound understanding to the broader discourse on human development and health. This comprehensive understanding will serve as a valuable foundation, offering essential insights for targeted interventions aimed at positively influencing growth trajectories and promoting optimal health outcomes.

2. Material and methods

2.1. Study population

Data from 7817 healthy children undergoing routine health examinations were collected at the Outpatient Department between January 2021 and September 2023. Children aged 0–18 years, who upon inquiry of medical history, have not exhibited clinical manifestations of acute febrile illness in the past two weeks, have no history of long-term medication intake, and are willing to participate in clinical data collection and blood sampling, are eligible for inclusion. The collected data included crucial clinical information, such as gender, age, height, weight, gestational age, born order, birth weight (BW), maternal childbearing age, maternal education level, and bone density status.

Strict exclusion criteria were applied to ensure data reliability. Children found to have congenital diseases during this physical examination or medical history review, including heart disease, congenital hypothyroidism, certain syndromes, or those with chronic diseases such as respiratory diseases, abnormal liver function, renal dysfunction, etc., are excluded. Additionally, children with incomplete clinical data collection or refusal to undergo blood tests are also excluded. A total of 6269 qualified samples were included in the analysis. Informed consent was obtained from family members, who willingly participated in blood tests.

2.2. Blood sample collection and grouping

Blood specimens were sent to Hehe Corporation, a third-party organization with which our hospital has signed agreement. High Performance Liquid Chromatography-Mass Spectrometry (HPLC-MS) detection method was used to analysis of bone metabolism markers including levels of Vitamin D (Vit D), vitamin K1 (Vit K1), vitamin K2 (Vit K2), serum calcium, serum phosphorus, and serum alkaline phosphatase (ALP). Serum was obtained by centrifugation using AB4500 (USA) and Shimadzu 8050 (Japan) instruments.

Samples were categorized based on WHO 2006 growth standards ("WHO Child Growth Standards based on length/height, weight and age, " 2006), assigning numerical labels from 0 to 13 to represent the 14 height percentiles: <p3, p3-5, p5-10, p10-20, p20-30, p30-40, p40-50, p50-60, p60-70, p70-80, p80-90, p90-95, p95-97, and >p97. Further analysis was conducted on factors influencing height. Additionally, weight levels were categorized into 14 group, utilizing the same percentile criteria according to WHO standards for children of the same age and gender ("WHO Child Growth Standards based on length/height, weight and age," 2006). Numerical values from 0 to 13 were assigned to represent low to high weight percentiles.

Besides, those infants born with a gestational age of less than 37 weeks were considered premature infants while those born at 37 weeks or later are considered full-term infants. BW was divided into the following categories: very low birth weight (VLBW), defined as BW less than 1.5 kg; low birth weight (LBW), defined as BW greater than or equal to 1.5 kg and less than 2.5 kg; normal birth weight (NBW), defined as BW greater than or equal to 2.5 kg and less than 4.0 kg; and high birth weight (HBW), defined as BW greater than or equal to 4.0 kg.

2.3. Statistical analysis

Statistical analyses were performed using SPSS 25.0 software. Normally distributed measurement data were presented as mean ± standard deviation (mean ± SD). Count data were presented as the number of cases and percentage (%). One-way analysis of variance (ANOVA) was initially employed to assess the correlation between various factors and height. Factors with a p-value <0.05 were further included in a linear regression analysis model for additional statistical analysis. Count data were compared between groups using the chi-square test and Fisher's exact test. Factors with a p-value still <0.05 were considered influential on height. All statistical tests used a two-sided approach with a significance level set at $\alpha = 0.05$, and the Bonferroni correction adjusted the modified significance level.

3. Results

3.1. Clinical data of the subjects

A total of 6269 samples, including 3654 males and 2615 females, with an average age of 8.38 (3.97) for males and 7.89 (3.55) for females were collected. The imbalance in the male-to-female ratio can be attributed to China's historical gender ratio at birth and the traditional preference for sons over daughters (National Bureau of Statistics, 2021). Details regarding the distribution of age and gender are presented in supplementary data (Table S1). The groups were numerically labeled from 0 to 13, corresponding to their respective percentiles. Clinical data including weight percentile score, maternal childbearing age, gestational age, age, BW, along with blood test results (concentration of Vit K1, Vit K2, Vit D, serum calcium, serum phosphorus and ALP) are presented as mean (SD) for each group (Table 1). Maternal education levels are divided into four categories: below junior high school (Edu 1), with an associate degree (Edu 2), with a bachelor's degree (Edu 3), and with postgraduate education (Edu 4). The numbers of maternal education level with Edu 1, Edu 2, Edu 3, and Edu 4 are 1477, 2976, 1671, and 145, respectively. The distribution of maternal education across different height groups is detailed in Table 2. Additionally, the average height percentile scores of the first born, second born, third born and beyond the third born is 6.15 (3.260), 5.92 (3.352), 5.58 (3.347) and 6.20 (4.021), respectively (Table S2). The average height of firstborn children is found to be higher than that of second born children ($p = 0.046$) (Fig. 1A).

3.2. Analysis of factors influencing height levels

Initial comparisons of mean values among different groups using analysis of variance revealed statistically significant differences ($p < 0.05$) for variables such as weight percentile, maternal education level, birth order, BW, gestational age, Vit K1, Vit D, serum phosphorus, and ALP (Table 1). Subsequent linear regression analysis demonstrated that, even after adjusting for other variables, these factors including weight percentile, maternal education level, birth order, BW, Vit D, serum phosphorus, and ALP maintained statistically significant correlations with height levels (Table 3, Table S3). The multiple R for this model is 0.748, R^2 is 0.560, adjusted R^2 is 0.559, standard error is 2.18. The top 5 variables with Beta-values are weight percentile score, ALP, BW, Vit D, and maternal education level. The weight percentile score, BW, ALP, and serum phosphorus showed a positive correlation, while the Vit D level showed a negative correlation (Fig. 1B–F).

3.3. Maternal education levels associate with child's height levels

Maternal education level exhibited a strong correlation with children's height. The proportions of children below the 10th percentile across educational levels are 0.21, 0.18, 0.12, and 0.08 respectively ($p < 0.001$) (Fig. 2A). The BW levels of children from mothers with different educational backgrounds showed no statistically significant differences ($p = 0.845$) (Fig. 2B). Analyzing near-adult height levels between 12 and 18 years revealed a significantly greater height in the maternal education group with Edu 3 compared to the Edu2 group and Edu 1 group, with a statistically significant difference ($p = 0.047$, and $p = 0.005$) (Fig. 2C). Further investigation disclosed consistent height trends, characterized by a trough at 3–6 years and a subsequent rise between 6

Table 1
Clinical data and One-way ANOVA analysis results for each group of children.

Group	0 (n = 207)	1 (n = 203)	2 (n = 430)	3 (n = 782)	4 (n = 729)	5 (n = 649)	6 (n = 593)	7 (n = 538)	8 (n = 511)	9 (n = 476)	10 (n = 521)	11 (n = 276)	12 (n = 106)	13 (n = 248)	p-value
p%	<p3	P3-5	P5-10	P10-20	P20-30	P30-40	P40-50	P50-60	P60-70	P70-80	P80-90	P90-95	P95-97	>P97	
W score	1.29 (1.76)	1.99 (1.624)	2.74 (2.090)	3.65 (2.171)	4.15 (2.145)	5.24 (2.590)	5.92 (2.537)	6.54 (2.735)	7.34 (2.605)	8.18 (2.571)	9.14 (2.637)	10.01 (2.423)	10.87 (2.251)	11.73 (1.806)	0.000*
MCA	28.45 (4.91)	27.82 (4.31)	27.87 (4.41)	28.22 (4.32)	28.17 (4.36)	28.69 (4.58)	28.27 (4.36)	28.25 (4.44)	28.39 (4.62)	28.47 (4.52)	28.36 (4.47)	28.31 (4.49)	28.99 (5.21)	28.53 (4.85)	0.108
GA	38.36 (2.29)	38.76 (1.89)	38.83 (1.73)	38.98 (1.63)	38.94 (1.58)	38.97 (1.79)	39.07 (1.46)	39.09 (1.44)	39.08 (1.53)	39.05 (1.58)	38.93 (1.60)	39.02 (1.72)	39.25 (1.52)	39.17 (1.55)	0.011**
Age	6.33 (3.91)	7.26 (3.97)	7.07 (3.98)	7.82 (3.82)	7.54 (3.90)	8.07 (4.00)	8.67 (3.81)	8.98 (3.75)	8.56 (3.58)	8.72 (3.63)	8.84 (3.44)	8.64 (3.46)	8.89 (3.29)	8.63 (3.05)	0.476
BW	2.98 (0.55)	3.03 (0.54)	3.09 (0.49)	3.15 (0.45)	3.17 (0.44)	3.22 (0.45)	3.27 (0.48)	3.26 (0.44)	3.30 (0.43)	3.26 (0.45)	3.34 (0.46)	3.36 (0.49)	3.39 (0.52)	3.40 (0.48)	0.000*
Vit K1	0.75 (0.89)	0.62 (1.20)	0.73 (1.03)	0.64 (0.82)	0.73 (1.38)	0.78 (2.05)	0.64 (0.82)	0.57 (1.34)	0.67 (1.67)	0.55 (0.69)	0.55 (0.75)	0.56 (0.97)	0.45 (0.42)	0.54 (0.80)	0.037*
Vit K2	0.16 (0.20)	0.19 (0.28)	0.17 (0.21)	0.23 (0.97)	0.21 (0.46)	0.30 (2.31)	0.19 (0.25)	0.24 (1.07)	0.21 (0.89)	0.27 (1.33)	0.18 (0.31)	0.28 (2.16)	0.17 (0.20)	0.16 (0.17)	0.486
Vit D	27.33 (11.64)	26.60 (9.50)	26.82 (9.72)	25.60 (8.70)	26.06 (8.95)	25.56 (9.39)	24.47 (8.83)	23.30 (8.51)	23.90 (8.69)	23.12 (7.66)	22.63 (7.93)	22.15 (9.61)	21.85 (8.43)	21.81 (6.85)	0.000*
Ca^{2+}	2.42 (0.15)	2.42 (0.13)	2.43 (0.14)	2.41 (0.15)	2.42 (0.15)	2.42 (0.16)	2.40 (0.18)	2.42 (0.14)	2.40 (0.17)	2.40 (0.18)	2.40 (0.16)	2.41 (0.17)	2.43 (0.13)	2.43 (0.13)	0.920
P	1.66 (0.19)	1.67 (0.18)	1.68 (0.19)	1.65 (0.17)	1.66 (0.20)	1.67 (0.21)	1.69 (0.18)	1.66 (0.18)	1.68 (0.18)	1.67 (0.21)	1.69 (0.18)	1.71 (0.20)	1.73 (0.19)	1.74 (0.20)	0.000*
ALP	263.44 (310.14)	240.03 (68.74)	246.61 (148.46)	256.26 (119.53)	259.98 (93.87)	260.98 (79.60)	270.32 (90.00)	275.97 (153.21)	293.09 (175.92)	289.30 (88.14)	291.10 (89.30)	290.58 (98.87)	286.58 (69.45)	306.67 (84.55)	0.000*

W score: the score of weight percentile, MCA: maternal childbearing age, GA: gestational age, BW: Birth weight, ALP: alkaline phosphatase, P: Serum phosphorus.

Table 2
The distribution of maternal education levels among children in different height groups.

Group	Edu 1 (n = 1477)	Edu 2 (n = 2976)	Edu 3 (n = 1671)	Edu4 (n = 145)
0	70 (4.7%)	99 (3.3%)	37 (2.2%)	1 (0.7%)
1	51 (3.5%)	115 (3.9%)	29 (1.7%)	8 (5.5%)
2	121 (8.2%)	210 (7.1%)	95 (5.7%)	4 (2.8%)
3	178 (12.1%)	363 (12.2%)	219 (13.1%)	22 (15.2%)
4	161 (10.9%)	354 (11.9%)	196 (11.7%)	18 (12.4%)
5	146 (9.9%)	316 (10.6%)	165 (9.9%)	22 (15.2%)
6	133 (9.0%)	277 (9.3%)	172 (10.3%)	11 (7.6%)
7	118 (8.0%)	259 (8.7%)	148 (8.9%)	13 (9.0%)
8	109 (7.4%)	251 (8.4%)	139 (8.3%)	12 (8.3%)
9	110 (7.4%)	212 (7.1%)	142 (8.5%)	12 (8.3%)
10	133 (9.0%)	232 (7.8%)	143 (8.6%)	13 (9.0%)
11	58 (3.9%)	132 (4.4%)	83 (5.0%)	3 (2.1%)
12	30 (2.0%)	42 (1.4%)	31 (1.9%)	3 (2.1%)
13	59 (4.0%)	114 (3.8%)	72 (4.3%)	3 (2.1%)

and 12 years. Particularly noteworthy was the continuous upward trend observed in the Edu 4 group between 6-12 years and 12–18 years (Fig. 2D).

3.4. Relationship between BW and height

The relationship between BW and height exhibited specificity across different age stages (Fig. 3A). BW was categorized into very low (<1.5 kg), low (1.5 kg ≤ BW < 2.5 kg), normal (2.5 kg ≤ BW < 4.0 kg), and high (BW ≥ 4.0 kg). Children with VLBW and LBW experienced catch-up growth, while those with NBW regressed towards the mean line around 3–6 years. In the subsequent 6–12 and 12–18 age stages, the NBW group surpassed the LBW group in height percentiles, while the HBW group exhibited consistently higher percentiles at all ages ($p < 0.001$) (Fig. 3A).

3.5. High maternal education level mitigates the influence of LBW on height level

Considering the association between LBW and shorter stature and the protective effect of higher maternal education, we explored whether maternal education level could mitigate the impact of LBW on children's height. The results showed significant differences in height levels among children in Edu 1, Edu 2, and Edu 3 groups, but a noticeable catch-up trend in the Edu 3 group ($p < 0.001$). In the Edu 4 group, differences among BW groups were not statistically significant ($p = 0.978$) (Fig. 3B).

3.6. Weight percentile remains a primary environmental factor influencing height

Weight percentile remains a crucial factor influencing height across various age groups. Children were categorized into age brackets: less than 1 year, 1–3 years, 3–6 years, 6–12 years, and 12–18 years. A positive correlation between height and weight was consistently observed, with weight percentiles ascending as height percentiles increased (Fig. 3C). Children exhibited a postnatal descent in weight between 3 and 6 years, followed by a rebound and an upward trend in weight levels (Fig. 3D).

3.7. Maternal education levels associate with weight percentile and Vit D level

Although weight percentile variations across age groups were not

Table 3
Linear regression analysis results.

	B	St. error	Beta	t	P-value
Constant	−1.001	0.733		−1.365	0.172
Maternal education level	0.153	0.038	0.036	4.022	0.000*
Birth order	−0.156	0.053	−0.026	−2.924	0.003*
BW (kg)	0.381	0.064	0.055	5.997	0.000*
Gestational age (W)	0.022	0.018	0.011	1.222	0.222
Vit K1(ng/ml)	−0.023	0.023	−0.008	−0.984	0.325
Vit D (ng/ml)	−0.016	0.003	−0.043	−4.869	0.000*
Serum phosphorus (mmol/L)	0.536	0.147	0.031	3.656	0.000*
ALP (U/L)	0.002	0.000	0.059	6.956	0.000*
Weight percentile score	0.663	0.008	0.713	81.336	0.000*

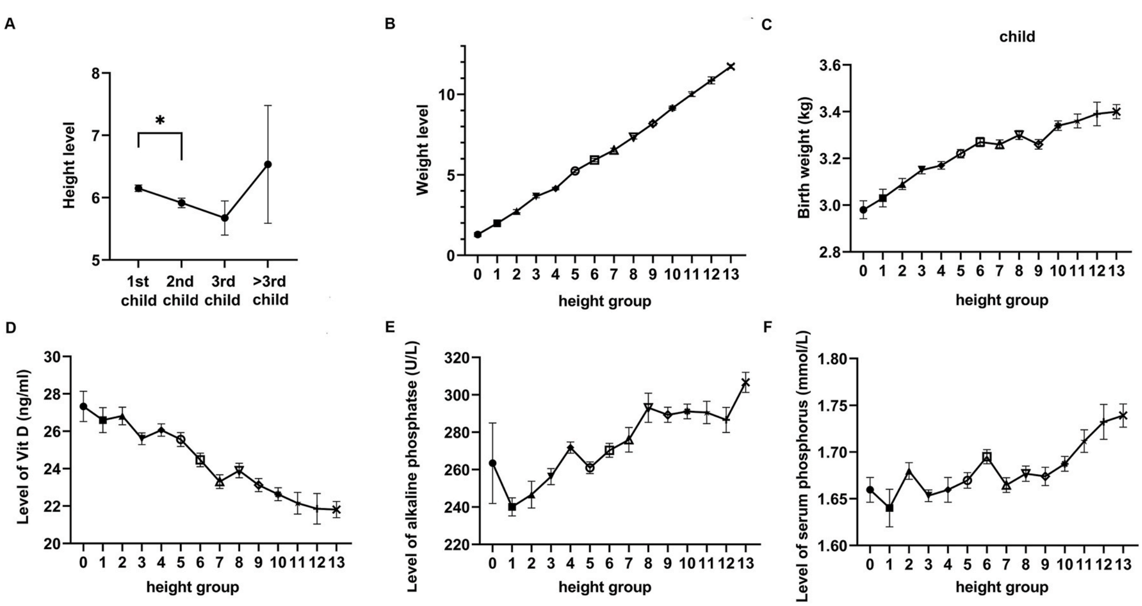

Fig. 1. The factors associate with child's height level. A. The height level of children with different birth order. B. The weight level of children with different height levels. C. The birth weight level of children with different height levels. D. The Vit D level of children with different height levels. E. The alkaline phosphatase level of children with different height levels. F. The serum phosphorus levels of children with different height levels (Data in Figures were presented as means ± SEM, Statistical significance was denoted as *$p < 0.05$).

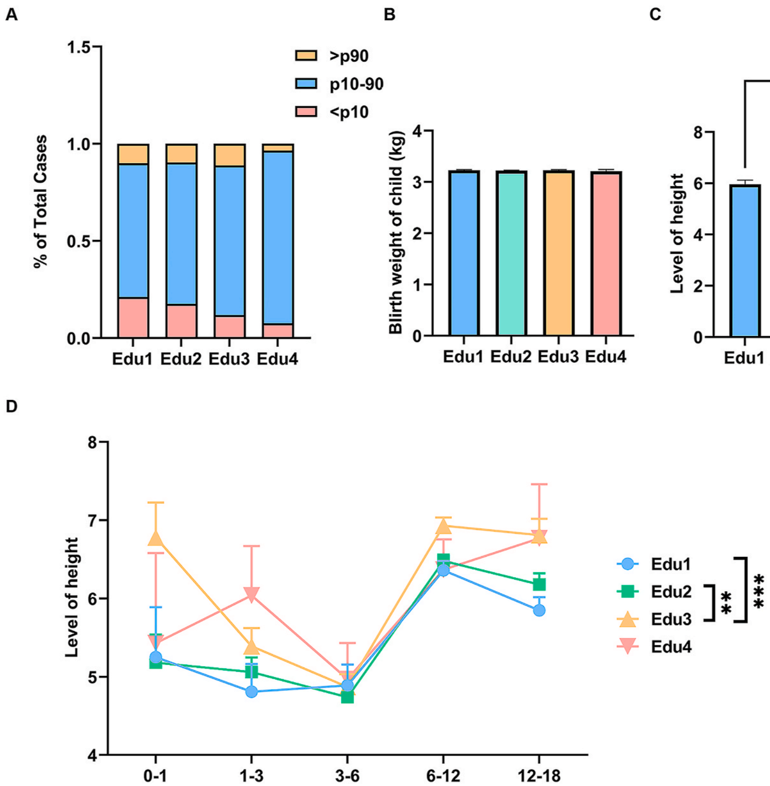

Fig. 2. Maternal education levels associate with children's height levels but not birth weight. A. The height percentile composition among children with different maternal education levels ($p < 0.001$). B. The birth weight levels of children with different maternal education levels ($p = 0.845$). C. The height levels of children with different maternal education levels during the 12–18 age range (**$p < 0.01$, *$p < 0.05$). D. The variation in height levels among children with different maternal education levels across various age groups (Data in Figures were presented as means ± SEM, **$p < 0.01$, ***$p < 0.001$).

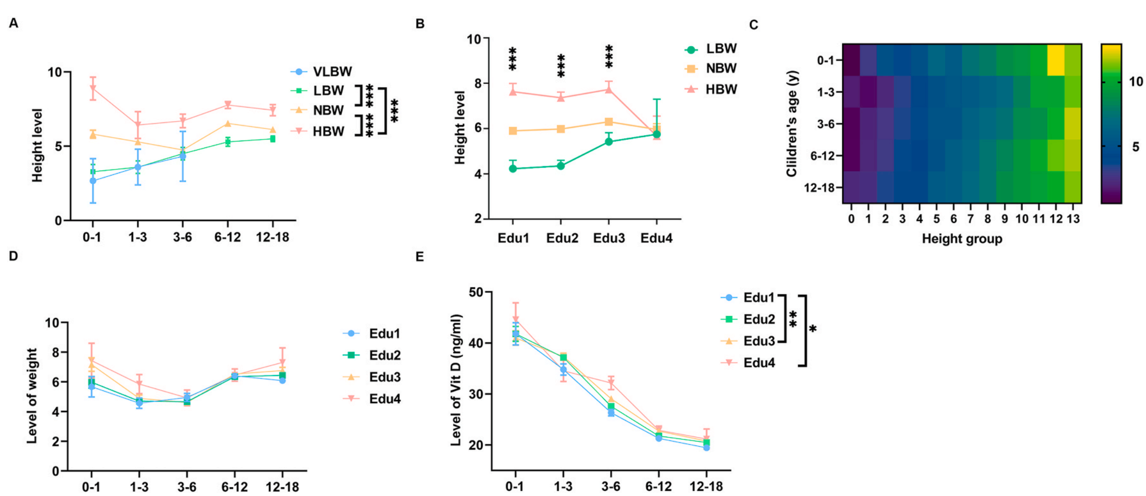

Fig. 3. Maternal education attenuates the effect of low birth weight-associated height across all developmental stages. A. The relationship between birth weight and height level in different age groups. B. Maternal educational attainment mitigates the impact of low-birth-weight children. C. The relationship between weight and height level in different age groups. D. The relationship between weight and maternal education level in different age groups. E. The relationship between Vit D levels and maternal education levels in different age groups. (Data in Figures were presented as means ± SEM, *$p < 0.5$, **$p < 0.01$, ***$p < 0.001$).

significantly influenced by maternal education level ($p = 0.446$) (Fig. 3D), trends were observed. Children with higher maternal education levels showed a higher weight percentile between 0-3 years and 12–18 years. Vit D, ranked as an influencing factor and a nutritional component, exhibited a gradual decline with increasing age and height level ($p < 0.001$) (Fig. 3E). Children of mothers with higher education levels had higher Vit D levels. Compared to the Edu 1 group, the levels of Vit D increased in the Edu 3 and Edu 4 groups, with p-values of 0.005 and 0.031 respectively (Fig. 3E), supporting the positive role of higher maternal education in children's height levels.

4. Discussion

This study delves into the determinants of height, revealing significant correlations with various factors. Notably, a child's height is closely associated with the maternal education level, the birth order, BW, weight percentile, and certain bone metabolism markers. As a societal factor, maternal education level can exert influence on children's height through multiple avenues.

4.1. The impact of BW on children's height levels

BW emerges as a crucial determinant of a child's height. Previous studies have suggested an increased risk of stunted growth in children with LBW at 3.5 and 6 years old (Berglund et al., 2016; Pilling et al., 2008; Takayanagi et al., 2019). However, LBW infants often undergo catch-up growth, a process whose long-term health implications remain relatively unknown. This study observes that the LBW group experiences an up-cross of p-scores post-birth, converging with NBW levels between ages 3–6, aligning with previous report (Jain et al., 2021; Lan et al., 2022). This catch-up growth may be attributed to the disappearance of maternal factors restricting intrauterine growth, allowing infants the opportunity for growth recovery. Additionally, it may be linked to heightened attention and nutritional guidance for LBW infants in family and hospitals. However, in our study, children with LBW, after catching up in height from ages 3–6, demonstrated a growth rate plateau. Beyond this period, the NBW group continued to outpace the LBW group, resulting in a widening height gap. This suggests that these children may inherently have a slower growth trajectory. Previous research indicates that children born small for gestational age (SGA) undergoing catch-up growth may face increased cardiometabolic risk factors, particularly with robust early neonatal growth (Jee et al., 2023; Law et al., 2002), supporting the notion of exceeding their tolerance for nutritional supplementation (Fenton et al., 2020).

Furthermore, children in the HBW group experienced a slight regression in height between 1 and 3 years, followed by a subsequent increase between 3 and 6 years, maintaining elevated height levels into near adulthood (12–18 years). As HBW is related to a higher prevalence of obesity, HBW group should be particularly vigilant against obesity (Baran et al., 2019; Ke et al., 2023; Yu et al., 2011). One potential explanation for this could be elevated levels of growth factors resulting from a higher BW, which may also explain the higher height levels in HBW group (Sauder et al., 2017; Wheatcroft et al., 2007). Unfortunately, due to a limited sample size, data collection for children aged 6–12 years and 12–18 years in the VLBW group was not feasible. Consequently, in the subsequent statistical analysis, we combined the VLBW group with the LBW group and further research is needed to delve into the specific aspects related to VLBW.

4.2. Maternal educational attainment improves children's height and mitigates the impact of LBW

The positive correlation between maternal education level and a child's height has been previously discussed (Frost et al., 2005; S. Li et al., 2024). However, specific descriptions of how maternal education impacts children's height across different age groups have been lacking. In our study, we noted that children with mothers of diverse educational backgrounds demonstrated similar height levels from ages 3 to 6. Nevertheless, beyond this age range, those with mothers possessing higher education consistently outpaced their counterparts with less education in terms of height. This underscores the facilitating role of higher maternal educational attainment in fostering the height development of children.

Notably, despite the generally lower height levels observed in children with LBW, our study revealed a narrowing height disparity between LBW (including VLBW) and NBW groups with increasing maternal education level. In the subset where mothers held postgraduate education or higher, height levels across different birth weights tended to converge, showing no statistically significant differences. Although the sample size for mothers with postgraduate education is relatively small, resulting in larger statistical variability, the discernible trend indicates that higher maternal education mitigates the impact of LBW on height levels. This suggests that mothers with advanced educational attainment excel in optimizing children's height, mitigating the usual lower stature associated with LBW.

4.3. High maternal educational attainment improves height levels through enhanced nutrition

Weight percentile, a prominent indicator of a child's nutritional status, exhibits the highest regression coefficient in this study, indicating a robust correlation with the child's height. As consistent with prior research, nutrition remains a crucial factor influencing height (Perkins et al., 2016). Although there was no significant difference in weight percentile between different education level groups, children with higher maternal education levels showed a higher weight percentile at 12–18 years, suggesting that mothers with higher educational attainment prioritize nutritional supplementation, positively impacting height levels. This beneficial effect often becomes more evident during adolescence, indicating that the impact of maternal education on children's height is a gradual and accumulative process, manifesting positively during the teenage years.

Vit D, a crucial nutrient for health, plays a key role in bone metabolism, muscle cell function, and immune regulation (Bouillon et al., 2019; Pludowski et al., 2013). It influences growth by promoting proper bone mineralization and quality, and regulates body growth and macronutrient metabolism by modulating the cell cycle and cell proliferation (Prasad & Kochhar, 2016; Samuel & Sitrin, 2008). Previous studies have indicated that Vit D deficiency can lead to short stature (Kuraoka et al., 2022; Xu et al., 2021). The findings from a randomized controlled trial revealed that daily supplementation with 800 IU of Vit D for six months led to increased growth (Ganmaa et al., 2017). In our study, children of mothers with higher educational backgrounds tended to have higher Vit D levels than those with lower educational levels, supporting this association. Moreover, mothers with higher education levels may provide more targeted care, incorporating factors such as exercise and sleep to optimize nutritional support for optimal height (Kong et al., 2018).

Contrary to expectations, our study revealed a negative correlation between bone markers' levels and height. Taller children exhibited lower levels of Vit D and higher levels of serum phosphorus and alkaline phosphatase, potentially due to their faster growth rate leading to increased nutrient consumption. Additionally, children with lower height percentiles might pay more attention to Vit D supplementation based on doctors' recommendations. However, a JAMA study questioned the impact of continuous Vit D supplementation on height. In this study, children with Vit D deficiency were randomly assigned to receive either 14,000 IU of Vit D or a placebo weekly. After three years, the group receiving Vit D supplements had significantly higher Vit D levels (31.0 ng/mL) compared to the placebo group (10.7 ng/mL). However, there was no significant difference in height changes between the two groups (Ganmaa et al., 2023). Similarly, in another study, a shorter trial of 300 IU of Vit D fortified milk daily for 7 weeks also did not lead to improvements in height (Ganmaa et al., 2017). This suggests that prolonged Vit D supplementation did not significantly affect various health indicators in children, including height. This raises questions about the appropriate range of Vit D levels, indicating that a relatively low concentration might be sufficient for meeting the demands of bone metabolism, while higher levels of Vit D may have effects in other aspects.

4.4. Maternal educational attainment shapes childhood height through diverse pathways

Mothers with higher educational attainment often have higher incomes, not only facilitating a healthier living environment and providing ample nutritional support but also granting access to superior healthcare resources (Chowdhury et al., 2018). This elevated awareness prompts children to prioritize health behaviors such as regular exercise and sufficient sleep, positively influencing height development (Mesquita et al., 2023). Furthermore, mothers with higher education levels create stimulating home environments that foster intellectual and emotional growth, further contributing to the overall development of the child (Quick et al., 2021).

In conclusion, our study highlights the substantial influence of weight percentile, BW, birth order, maternal education level, and bone marker levels on height, which means the groundwork for height is laid at birth, with maternal educational attainment profoundly impacting this developmental journey. Mothers with higher education levels exhibit an enhanced ability to navigate and optimize their children's growth potential, highlighting the lasting impact of educational empowerment. To fortify interventions for effective height development, our study advocates for a proactive, comprehensive approach prioritizing educational empowerment. These initiatives encompass a range of measures, including extending compulsory education, implementing nutrition knowledge training courses, offering nutritional supplements and dietary guidance for pregnant women, as well as organizing regular health lectures and maternal and child health services. However, our study is retrospective research. While it reveals correlations between maternal education level and children's height, it should be noted that this study identifies associations rather than establishing direct causal relationships. Besides, the manner in which maternal education level impacts children's height and how changes in height percentile affect health outcomes or quality of life are still not fully understood. A well-designed prospective study is still needed to further investigate these relationships.

Ethical statement

This study is approved by the Ethics Committee of the Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University (LCKY 2019-191). Written informed consents were obtained from the participants or their parents. All study performed associated with human participants met ethical standards of the 2013 Declaration of Helsinki.

5. Financial disclosures

None.

Sources of financial support

This work was supported by the Wenzhou Basic Medical and Health Technology Project [grant number Y20210310].

CRediT authorship contribution statement

Ruixue Cao: Writing – original draft, Investigation, Data curation, Conceptualization, Writing – review & editing. **Wenjing Ye:** Investigation, Conceptualization, Formal analysis. **Jinrong Liu:** Investigation, Conceptualization. **Lili Chen:** Investigation, Conceptualization. **Zhe Li:** Investigation, Conceptualization. **Hanshu Ji:** Investigation. **Nianjiao Zhou:** Investigation. **Qin Zhu:** Investigation. **Wenshuang Sun:** Investigation. **Chao Ni:** Investigation. **Linwei Shi:** Investigation, Conceptualization. **Yonghai Zhou:** Investigation, Conceptualization. **Yili Wu:** Writing – review & editing, Project administration, Validation. **Weihong Song:** Supervision, Project administration, Resources, Writing – review & editing. **Peining Liu:** Supervision, Project administration, Funding acquisition, Resources.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2024.101672.

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