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ORIGINAL RESEARCH

Childhood Obesity and Essential Micronutrients: Insights from India's Comprehensive National Nutrition Survey (2016–18)

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ABSTRACT

Introduction: Based on the long-term impact of childhood obesity, there is a compelling need to assess the burden of obesity and micronutrient deficiency and the interactions between the two. Thus, the aims of the study were to estimate the prevalence of overweight and obese children and adolescents to compare micronutrient levels in these children with normal and underweight categories and explore the factors affecting overweight and obesity in the presence of micronutrient deficiencies.

Methods: Secondary data analysis of the Comprehensive National Nutrition Survey-India (2017–2018) was done. The survey recorded information from 112,245 preschool children (6–60 months), school age children (5–9 years), and adolescents (10–19 years). Half of these participants were invited for biochemical testing and were included in our analysis. The presence of overweight or obesity and micronutrient (serum erythrocyte folate; vitamin B12, A, and D; ferritin; zinc; and urinary iodine) deficiencies were the primary outcomes. The secondary outcome included the mean serum levels and predictors of overweight and

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obesity in the presence of micronutrient deficiencies.
Results: Of the 38,060, 38,355, and 35,830 preschool, school-age, and adolescent study participants, about 2.69, 4.18, and 4.99% were overweight or obese. We observed significant variations in the mean folate and vitamin B12 levels among the overweight and obese preschool and school-age children compared to the normal weight group. School-age children exhibited significant differences in all micronutrient levels. In contrast, adolescents only showed substantial differences in vitamin D and A and serum ferritin levels. The predictors of overweight and obesity included geographical locations, wealth quintiles, and societal castes. Iron, folate, vitamin D, and zinc levels significantly affect the odds of developing childhood overweight and obesity.
Conclusions: It is vital to halt the growing burden of childhood overweight and obesity. Addressing micronutrient deficiencies can help us bring a sustainable and feasible approach to managing this menace.

Keywords: Childhood obesity; Micronutrition; Social disparities; CNNS-India

Key Summary Points
Why carry out this study?
Childhood overweight and obesity is a growing public health issue, with huge morbidity and economic implications
Obese micronutrient deficiency contributes to childhood overweight and obesity but is not supported by enough evidence from India
What was learned from the study?
The present study estimate the prevalence of overweight and obesity in children and adolescents using a national dataset and compares the micronutrient levels among overweight/obese and normal/underweight participants
There was a significant difference in folate and vitamin B12 levels among the overweight and obese preschool and school-age children compared to the normal weight group
Overweight and obese adolescents exhibited substantial differences in vitamin D and A and serum ferritin levels

INTRODUCTION

Positive energy balance, most commonly attributed to overweight and obesity, is widely prevalent worldwide in all strata of society. It has paved the way for a new pandemic across genders and ages, and the burden among children and adolescents is rapidly escalating. As per the latest estimates by the World Health Organization (WHO), the prevalence of childhood and adolescent overweight and obesity escalated from 4 to 18% between 1975 and 2016 [1]. The situation is more worrisome for India, as the fifth wave of the National Family Health Survey (2019–2021) reported a 3.4% prevalence of overweight in under-5 children, which is 61% higher than the fourth wave (2015–2016) [2]. Children's obesity is rising, and multifactorial causation contributes to this trend [3]. Due to economic transition, there is an abundance of calorie-rich food that lacks critical micronutrients such as vitamins and minerals [4]. These micronutrients are vital for appropriate growth and development. They enable the body to produce enzymes, hormones, and other essential substances, which facilitate energy metabolism, and deficiency may promote obesity [5]. Obese children and adolescents are at greater risk of having lower levels of vitamins and minerals, which reduce or impede leptin expression, than those with normal weight [6–9].

The effects of childhood obesity are detrimental. Children with obesity experience breathing difficulties, sleep disorders like obstructive sleep apnea, hypertension, increased fracture risk, insulin resistance, metabolic syndrome, early cardiovascular problems, non-alcoholic fatty liver disease markers, and several psychologic effects [10]. They are also prone to increased risks of premature mortality and disability [11, 12]. Furthermore, the negative consequences of micronutrient deficiencies on development have been proven in previous studies [13, 14]. Micronutrient deficiency synergizes with obesity, leading to fat deposition and chronic inflammation [15]. Hence, coexisting overweight or obesity and micronutrient deficiencies can have catastrophic effects on the health and well-being of children and may have economic and social repercussions for society in the future. Based on the long-term impact of childhood obesity, there is a compelling need to not only assess the burden of obesity and micronutrient deficiency but also analyze whether they contribute to each other in any way. Despite the need, monitoring of micronutrient deficiencies faces hurdles due to the requirement of population-based data on micronutrient status. Even with a paucity of data, available evidence data indicate that micronutrient deficiencies are widespread.

Within this context, the Comprehensive National Nutrition Survey (2016–2018) implemented by the Indian Government has collected comprehensive data regarding childhood malnutrition and micronutrient deficiency following a robust methodology. It allows us to explore the relationship between the two grave problems [16]. Therefore, the present study aimed to estimate the prevalence of overweight and obese children and adolescents across different strata of socio-demographic characteristics, to compare micronutrient levels in overweight and obese children with normal and underweight categories, and to explore the factors affecting overweight and obesity in children in the presence of micronutrients deficiencies.

METHODS

Data Source

We did a secondary data analysis of a nationally representative dataset from the CNNS. The Ministry of Health and Family Welfare (MoHFW), Government of India, conducted the survey in 2016–2018, and it is considered the world's most extensive micronutrient study.

Sample Selection

The CNNS offers a thorough picture of the nutritional status of pre-schoolers (0–4 years), school-age children (5–9 years), and teenagers (10–19 years). The study gathered thorough data on participants' anthropometric measurements, dietary intake, nutritional status, and micronutrient levels. The intended sample size for the survey was 40,700 participants in each of the three age groups for the household survey and anthropometric measures. Half of this sample (20,350 participants in each group) was invited for biologic samples. For our study, we only included the survey participants with biochemical parameters. For this study, a total of 112,245 preschool children (6–60 months), school age children (5–9 years), and adolescents (10–19 years) were included in the analysis.

Sampling Technique

The CNNS used a multi-stage sampling design to select a representative sample of households and individuals aged 0–19 across the 30 states [16]. In each state, the rural sample was selected in two stages as per the survey report. The first stage was the selection of Primary Sampling Units (PSU) using probability proportional to size (PPS) sampling. In rural areas, the 2011 census list of villages (village was PSU in rural areas) served as the sampling frame. All villages with fewer than ten households were removed from the CNNS sampling frame. To ensure a sufficient number of households in selected PSUs, villages with $<$ 150 households in the sampling frame were linked to neighboring villages to create 'linked PSUs' with a minimum of 150 households. The second stage was a systematic random selection of households within each PSU. In large PSUs, the sampling design involved three stages, with the addition of a segmentation procedure to reduce enumeration areas to manageable sizes. A household listing was completed immediately before data collection. The listing was conducted in each PSU, or segment of PSU, to create an up-to-date frame for selecting households.

In urban areas, the sampling frame for the first stage was a list of all the wards in the state obtained from the 2011 PCA stratified by geographical region. Urban wards were selected from this stratified list using PPS random sampling. Every ward consists of several census enumeration blocks (CEBs), each comprising approximately 100–150 households. For the second stage of sampling, a list of all the CEBs in each selected ward was used to select one CEB from each selected ward randomly. To ensure a sufficient number of households in the selected sampling unit, smaller CEBs were linked to neighboring CEBs to create a sampling unit with a minimum of 150 households. Subsequently, in each selected CEB, a household listing was carried out similar to that conducted for rural PSUs. In the third stage, households were randomly selected from these lists.

Study Variables

Dependent Variables

Overweight and obesity were our primary dependent variables and were defined as per the CNNS report. Weight-for-height $> +2$ standard deviations (SD) and $> +3$ SD above the WHO Child Growth Standards median were used to define overweight and obesity in under-5 children (WHO, 2010). Body mass index (BMI) was used to categorize overweight and obese children and adolescents between 5 and 19 years. Overweight and obese were defined as BMI-for-age $> +1$ SD and $> +2$ SD above the WHO Child Growth Standards median (WHO, 2007).

Independent Variables

Micronutrient deficiency was our primary independent variable. The phlebotomists collected the blood, urine, and stool samples in the morning from the selected children and adolescents. Eight milliliters (ml) of blood was collected from children 1–4 years and 10 ml from children 5–19 years. The details about the sample collection, packing, transportation, and assays standardization are given in the survey report [16]. Information regarding the levels of micronutrients like ferritin; vitamins A, D, and B12; folate; and urinary iodine was collected in the survey.

1. Folate: 151 ng/ml of serum erythrocyte folate was considered deficient (WHO, 2008).
2. Vitamin B12: deficiency was defined as serum vitamin B12 $<$ 203 pg/ml.
3. Vitamin D: As per Institute of Medicine standards, vitamin D deficiency was recognized in the three age groups using a cutoff of 12 ng/ml (30 nmol/l).
4. Vitamin A: deficit was identified in accordance with WHO recommendations. The definition of vitamin A deficiency in children and adolescents aged 1 to 19 years was set at a cutoff of 20 g/dl.
5. Zinc: to identify zinc deficiency, morning fasting blood zinc concentration values of 65 g/dl in boys and females $<$ 10 years and 70 g/dl in males, and 74 g/dl in females $>$ 10 years, were utilized.
6. Iron: deficiency was diagnosed using serum ferritin levels < 12 μg/l and < 15 μg/l among children aged 1 – 4 years and children aged ≥ 5 years as per WHO protocols.
7. Iodine: Suboptimal intake at the population level was defined according to WHO/ UNICEF/ICCIDD guidelines; a cutoff level of ≤ 50 μg/l was used for classification.

Covariates

The variables were chosen following a literature review, and the variables that may affect the epidemiology of childhood obesity were included in the study. We had residence (rural and urban), religion (Hindu, Muslim, and others), caste [schedule cast (SC), schedule tribe (ST), other backward class (OBC), and none of the above], education status (ever attended school: yes, no), wealth index (poorest, poorer, middle, richer, and richest), completed mother's schooling—mothers having completed ≥ 12 years of education, regions of India (North, Central, East, Northeast, West, and South as per the original survey plan), and duration of breastfeeding.

Statistical Analysis

The statistical analysis was done using STATA 16. The association between childhood overweight/obesity and sociodemographic variables in children and adolescents was examined using bivariate analysis. We compared the mean levels of micronutrients among normal/underweight study participants using a *t*-test, further categorized the micronutrient deficiencies into dichotomous variables, and compared them between the two study groups using the chi-square test. After that, we built an adjusted binary logistic regression model to predict childhood overweight/obesity in the presence of micronutrient deficiency and other covariates. The primary sampling units, sample weights, and strata were incorporated into the models to account for the CNNS 2016–2018's complicated sampling design when adjusting the population prevalence estimates of children overweight/obesity and all regression models. Prevalence estimates were exhibited using weighted % and 95% confidence intervals (CI). P values < 0.05 were considered statistically significant.

Ethics and Consent/Assent Procedure

As a secondary data analysis, ethical approvals were not deemed necessary. However, for the original survey, ethical approvals were obtained from the International ethical approval from the Population Council's Institutional Review Board (IRB) in New York. Federal approval was obtained from the ethics committee of PGIMER in Chandigarh. Ethics approvals were obtained before initiating survey activities. More details regarding the approval can be obtained from: https://nhm.gov.in/WriteReadData/l892s/1405796031571201348.pdf. This study was performed in accordance with the Helsinki Declaration of 1964 and its later amendments.

As per the survey, consent/assent was requested before conducting the interviews. For children aged 0–10 years, informed consent was obtained only from parents/caregivers, while both informed consents from parents/caregivers for adolescents aged 11–17 years and assent from adolescents aged 11–17 years were obtained, and only informed consent was obtained from adolescents aged 18–19 years [16].

RESULTS

We segregated the 38,060, 38,355, and 35,830 preschool, school-age, and adolescent study participants per socio-demographic characteristics (Table 1). Most participants were from the country's east region, while the northeastern part had the minimum representation. There was a higher proportion of males in preschool and school-age children, while females were more in the adolescent age group. A higher proportion of mothers of preschool children had completed their education compared to the mothers of school-age and adolescent study participants. There was a higher representation from the rural areas, but they were equally distributed across different wealth quintiles. Most of the preschool children were breastfed for 6–11 months.

Table 2 further segregates the overweight and obese study participants per their socio-demographic characteristics. Overall, the prevalence of overweight and obesity in the three age groups was 2.69, 4.18, and 4.99%, respectively. The proportion of overweight and obese preschool children was highest in western India, while the other two age groups had the maximum representation from South India. There was a higher proportion of overweight and obese male participants in the preschool and school age group, while no gender disparity was seen among the adolescents. The highest proportion was observed among the urban participants, following Hinduism, and belonging to the OBC category. The prevalence increased with the order of wealth quintile.

Table 1 Sample characteristics of the preschool, school-age children, and adolescents who participated in the Comprehensive National Nutrition Survey, India

	Pre-school *N* **(weighted %)**	**School age** *N* **(weighted %)**	**Adolescents** *N* **(weighted %)**
Total	38,060	38,355	35,830
Region			
North	5249.3(13.8)	5109 (13.3)	4898.8 (13.7)
Central	11,528.7(30.3)	11,732 (30.6)	11,702.9 (32.7)
East	9402.4(24.7)	9660 (25.2)	8399.7 (23.4)
West	4614.9(12.1)	4666 (12.2)	4180.9 (11.7)
South	6013.7(15.8)	5963 (15.5)	5560.8 (15.5)
Northeast	1251(3.3)	1225 (3.2)	1087 (3)
Gender			
Male	19,739.8(51.9)	19,321 (50.4)	17,864.9 (49.9)
Female	18,320.2(48.1)	19,035 (49.6)	17,965.1 (50.1)
Mother's schooling			
No schooling	81.8 (0.27)	133.1 (0.47)	102.6 (0.5)
< 5 years completed	6184.1 (20.09)	3587.1 (12.6)	3146.8 (14.2)
5–7 years	3294.5 (10.7)	7586 (26.65)	6439.1 (29)
8–9 years	7301.6 (23.72)	6776 (23.81)	5705.3 (25.7)
10–11 years	5080.1 (16.5)	4607.2 (16.19)	3585.2 (16.1)
Completed	8838.9 (28.72)	5772.4 (20.28)	3232 (14.6)
Locality			
Rural	29,043.2(76.3)	29,065 (75.8)	26,966.8 (75.3)
Urban	9016.8(23.7)	9290 (24.2)	8863.2 (24.7)
Religion			
Hindu	29,893.1(79.5)	30,252.6 (78.88)	28,512.1 (80.5)
Muslim	6080.9(16.2)	6238.5 (16.27)	5407.5 (15.3)
Others	1629(4.3)	1864 (4.86)	1510.4 (4.3)
Caste			
Scheduled caste	8534.8(24.4)	8621 (24.4)	32,099.6 (89.6)
Scheduled tribe	4880.4(14)	4893 (13.8)	2699.1 (7.5)
Other backward classes	14,757.6(42.2)	14,985 (42.4)	742.9 (2.1)
Others	6771.2(19.4)	6859 (19.4)	288.5 (0.8)
Wealth index			

Table 1 continued

	Pre-school *N* (weighted %)	School age *N* (weighted %)	Adolescents *N* (weighted %)
Poorest	7612.8(20)	7673 (20)	7170.1 (20)
Poorer	7621.7(20)	7671 (20)	7162.3 (20)
Middle	7601.7(20)	7672 (20)	7168.3 (20)
Richer	7611.9(20)	7672 (20)	7162.5 (20)
Richest	7611.9(20)	7668 (20)	7166.7 (20)
Type of diet			
Vegetarian	13,117.5 (35)	24,791.6 (64.64)	8335.3 (23.26)
Non-vegetarian	24,834.5 (65)	13,563.4 (35.36)	27,494.7 (76.74)
Duration of exclusive breast feeding (in months)			
0–5	11,681.7(33.2)	NA	NA
06–11	19,080.7(54.2)	NA	NA
> 12	4456.6(12.7)	NA	NA
Stunted			
No	23,754.5(64.2)	28,719 (77.8)	23,407.7 (72.1)
Yes	13,258.5(35.8)	8209 (22.2)	9045.3 (27.9)

We observed significant variations in the mean folate and vitamin B12 levels among the overweight and obese preschool and school-age children compared to the normal weight group (Table 3). School-age children exhibited significant differences in all the micronutrient levels. In contrast, adolescents only showed substantial differences in vitamins D and A and serum ferritin levels. We observed that overweight and obese preschool children exhibited higher mean values of vitamin B12, vitamin A, and iron, but these differences were not statistically significant. Further bivariate analysis of deficient and non-deficient study participants regarding being overweight/obese or not exhibited substantial differences in the distribution of folate in preschool children, where a higher proportion of the preschool children deficient in these vitamins were overweight or obese (Table 4). Similarly, we observed significant differences in the ratio of overweight/obese school-age children deficient in vitamins B12, A, and D; iron; and zinc. Notably, among school-age children and adolescents, vitamin A and iron had a negative association with overweight/obesity, with a lower proportion of this group deficient in these vitamins and minerals.

Table 5 highlights the predictors of overweight and obesity in the presence of micronutrient deficiency. Preschool children's chances of developing overweight and obesity increased significantly if they were from Northeast India or belonged to ST, OBC, or other social castes. Iron deficiency increased the chances of developing obesity by 50%, while the odds were 36% higher in the presence of folate deficiency. Similarly, in school-age children, chances of developing overweight and obesity were higher if the child was from urban areas of eastern, southern, and northeastern parts of the country and belonged to the rich or richest wealth quintiles. Vitamin D deficiency

Table 2 Distribution of overweight and obese children as per various socio-demographic characteristics

Region	Pre-school	School age	Adolescents
Total sample	38,060	38,355	35,830
Overall prevalence of overweight/obesity, *n* (weighted %)	1692 (2.69)	3086 (4.18)	2799 (4.99)
Regions of India			
North	15.1 (13.45, 16.92)	12.8 (11.68, 14.08)	15.1 (13.76, 16.45)
Central	20.6 (18.74, 22.65)	14.5 (13.31, 15.83)	15.2 (13.93, 16.63)
East	15.4 (13.72, 17.22)	17.6 (16.23, 18.95)	19.3 (17.86, 20.82)
West	21.3 (19.38, 23.34)	20.5 (19.13, 22.01)	17.7 (16.3, 19.17)
South	18.1 (16.25, 19.97)	28 (26.44, 29.64)	29.4 (27.73, 31.14)
North-East	9.5 (8.11, 10.96)	6.5 (5.66, 7.43)	3.3 (2.63, 3.98)
Gender			
Male	53.7 (51.27, 56.08)	56.7 (54.91, 58.44)	50 (48.1, 51.84)
Female	46.3 (43.92, 48.73)	43.3 (41.56, 45.09)	50 (48.16, 51.9)
Locality			
Urban	64.4 (62.09, 66.71)	54.4 (52.58, 56.12)	52.2 (50.33, 54.07)
Rural	35.6 (33.29, 37.91)	45.6 (43.88, 47.42)	47.8 (45.93, 49.67)
Religion			
Hindu	75.3 (73.2, 77.41)	89.2 (88.06, 90.28)	76.2 (74.53, 77.74)
Muslim	16.8 (15.03, 18.69)	6.7 (5.83, 7.62)	17.2 (15.79, 18.63)
Others	7.9 (6.6, 9.25)	4.1 (2.82, 4.14)	6.7 (5.76, 7.66)
Caste			
SC	20.9 (18.88, 23.02)	19.7 (18.19, 21.17)	91.5 (90.38, 92.48)
ST	16.9 (15.04, 18.87)	11.2 (10.1, 12.47)	4.3 (3.53, 5.07)
OBC	39.8 (37.32, 42.29)	39.5 (37.65, 41.31)	3.5 (2.87, 4.27)
Others	22.4 (20.36, 24.61)	29.6 (27.95, 31.36)	0.8 (0.47, 1.15)
Wealth index			
Poorest	12.2 (10.66, 13.84)	7.3 (6.39, 8.25)	3.4 (2.75, 4.13)
Poorer	15.7 (13.98, 17.5)	10 (9, 11.16)	9.6 (8.54, 10.76)
Middle	21.7 (19.73, 23.72)	16.6 (15.28, 17.94)	15 (13.69, 16.37)
Richer	21.8 (19.88, 23.88)	23 (21.55, 24.55)	26.1 (24.5, 27.79)
Richest	28.6 (26.48, 30.85)	43.1 (41.32, 44.84)	45.9 (44.03, 47.76)
Type of diet			
Vegetarian	34.6 (34.1, 35)	**64.6 (64.16, 65.12)**	23.3 (22.41, 24.14)
Non-vegetarian	65.4 (65, 65.9)	35.4 (34.88, 35.84)	76.7 (75.86, 77.59)

Table 2 continued

Region	Pre-school	School age	Adolescents
Duration of breast feeding			
0–5	37.8 (35.42, 40.31)	NA	NA
6–11 months	49.1 (46.55, 51.59)	NA	NA
12 +	13.1 (11.45, 14.87)	NA	NA
Stunting			
No	34.3 (32, 36.58)	76.4 (74.84, 77.87)	81.7 (80.21, 83.11)
Yes	65.7 (63.42, 68)	23.6 (22.13, 25.16)	18.3 (16.89, 19.79)

increased the chances of developing overweight and obesity by 26%, while zinc deficiency decreased the chances by 30%. Among the adolescents, chances of developing overweight and obesity were higher if the child was from the east, west, south, or northeast part of the country compared to the children from North India or those belonging to non-Hindu and non-Muslim religions and were from the rich or richest strata of the society. It was observed that iron deficiency was linked to decreased chances of developing overweight/obesity, while vitamin D and folate deficiency increased the stakes by up to 78% and 25%.

DISCUSSION

The contribution of micronutrient deficiency in childhood obesity has been long debated but has not been quantified in previous studies using generalizable data. The gap was filled through the robust datasets from the CNNS, providing us with one such opportunity to inspect this association. This is among the few studies from India that have provided such estimates. This study has produced some significant findings that deserve discussion. First, we observed substantial regional disparities in the proportion of overweight and obesity among all three age groups of the study participants. A higher prevalence of overweight/obesity was observed among males in the younger age groups, but the differences were negated in adolescent age groups. Higher socioeconomic status and residence in urban areas contributed more to overweight and obesity. Second, in preschool children, vitamin D and folate deficiency was significantly associated with overweight/obesity. Third, in the school-age group, vitamin D showed a significant association. Lastly, adolescent participants exhibited significant differences in vitamin A and D, serum ferritin, and urinary iodine levels.

The burden of being overweight and obese in childhood and adolescence has soared in the last decade [17, 18]. Data from the CNNS survey (2016–2018) suggest a much higher prevalence of overweight and obesity in Indian children and adolescents [16]. The highest prevalence of overweight and obesity is noted in preschool children from the central region, school-going children from the South and West, and adolescents from the South. The syndrome is least prevalent across all age groups in the Northeast region. Regional disparities in the prevalence of overweight and obesity has also been observed in adults and can be attributed to varying cultural practices and eating habits [19]. Male gender, urban residence, OBC background, and rich wealth index are associated with overweight and obesity as well. The rising prevalence is associated with the overall development of the country and increased availability of energy-dense food, leisure time, and decreased physical activity [20, 21]. Similar reasons

Table 3 Comparison of the micronutrients in underweight/normal and overweight/obese children

Concentrations of vitamins and minerals	Pre-school			School age			Adolescents		
	Normal Mean ± SE	Overweight/obese Mean ± SE	*P* value	Normal Mean ± SE	Overweight/obese Mean ± SE	*P* value	Normal Mean ± SE	Overweight/obese Mean ± SE	*P* value
S. erythrocyte folate (ng/ml)	308 ± 2.86	263.9 ± 8.11	< 0.001	281.4 ± 1.7	306.6 ± 6.56	< 0.001	223.6 ± 1.76	228.2 ± 6.26	0.454
S. vitamin B12 (pg/ml)	376.5 ± 1.92	397.5 ± 7.09	0.002	351.5 ± 1.52	379.5 ± 5.88	< 0.001	293 ± 1.43	290.4 ± 4.32	0.597
Vitamin A (μg/dl)	28 ± 0.39	29.4 ± 1.4	0.283	26 ± 0.36	30.2 ± 1.23	< 0.001	32.2 ± 0.35	34.8 ± 1.25	0.028
Vitamin D (ng/ml)	19.1 ± 0.12	18.8 ± 0.8	0.467	17.4 ± 0.11	15 ± 0.46	< 0.001	16.3 ± 0.13	13 ± 0.55	< 0.001
S. ferritin (μg /l)	28.5 ± 0.39	29 ± 1.26	0.743	39 ± 0.38	42.2 ± 1.01	0.025	41 ± 0.44	46 ± 1.46	< 0.001
S. zinc (μg /dl)	80.3 ± 0.17	79.8 ± 0.58	0.452	80.3 ± 0.15	81.5 ± 0.53	0.027	78.6 ± 0.16	77.7 ± 0.5	0.131
Urinary iodine (μg/l)	233.2 ± 1.63	223.3 ± 4.8	0.068	219.8 ± 1.43	236.8 ± 5.45	0.001	217.4 ± 1.53	229.2 ± 4.7	0.024

explain the higher prevalence in richer quintiles and urban areas.

The role of micronutrients in childhood obesity has been established, and our analysis adds to existing evidence. We observed that RBC folate levels were significantly lower in overweight/obese preschool children and higher in school-age children and adolescents (non-significant). The decrease in serum levels is in agreement with previous studies. The finding explains the increased utilization of folic acid in preschool children, with more urinary excretion and dilution of blood volume. Individuals with higher BMI have lower use of supplements and follow unhealthier diets with insufficient fruits and vegetables, which can cause a reduction in folate levels [22, 23]. Folic acid deficiency increases serum homocysteine levels and insulin resistance, aggravating obesity [24]. Another explanation might pertain to the influence of obesity on short-term folate pharmacokinetics, which affects the absorption of folic acid ingested orally. Adiposity also impairs the absorption of folate by the intestinal epithelium [25]. On the other hand, some studies explain the increased levels of RBC folate, and a positive correlation exists between BMI and RBC folate [24]. In obese people, low serum folate levels may promote red blood cell folate uptake. An animal model of dietary folate deficiency demonstrated a rise in the mRNA and protein concentrations of folate carriers, an increase in the activity of the enzyme folate hydrolase, and a significant upregulation of intestinal folate uptake, suggesting the potential involvement of a transcriptional regulatory mechanism [26]. Transepithelial folic acid transport in intestinal epithelial cells is upregulated during a folate deficit. When the serum folate concentration is low in obesity, this offers a speculative and plausible mechanism for increasing cellular folate concentrations in RBCs [27]. Elevated erythrocyte folate during pregnancy, which is connected with the increased fat mass of children at age 6, can be used to explain non-significant variations in the prevalence of overweight and obesity in school children observed in our study. Folate has been associated with weight increase in children during later stages of development [28, 29].

Table 4 Distribution of children as per their micronutrient deficiency status who participated in the CNNS-India

Indicators	Pre-school			School age			Adolescents		
	Normal	Overweight/ obese	*P* value	Normal	Overweight/ obese	*P* value	Normal	Overweight/ obese	*P* value
Folate									
No deficiency	97.83	2.17	< 0.001	96.72	3.28	0.281	95.6	4.4	0.059
Deficiency	97.65	2.35		94.73	5.27		93.74	6.26	
B12									
No deficiency	97.74	2.26	0.094	96.34	3.66	0.027	94.88	5.12	0.886
Deficiency	98.33	1.67		96.3	3.7		94.86	5.14	
Vitamin A									
No deficiency	97.78	2.22	0.470	95.73	4.27	0.014	94.25	5.75	0.016
Deficiency	97.85	2.15		97.32	2.68		96.23	3.77	
Vitamin D									
No deficiency	97.81	2.19	0.965	96.58	3.42	< 0.001	95.5	4.5	< 0.001
Deficiency	98.11	1.89		94.87	5.13		92.82	7.18	
Iron									
No deficiency	97.79	2.21	0.842	96.14	3.86	< 0.001	94.82	5.18	< 0.001
Deficiency	97.78	2.22		97.22	2.78		94.68	5.32	
Zinc									
No deficiency	98.07	1.93	0.123	95.97	4.03	0.009	94.77	5.23	0.422
Deficiency	95.75	4.25		96.1	3.9		93.26	6.74	
Urinary iodine									
Inadequate	99.05	0.95	0.522	96.83	3.17	0.009	96.43	3.57	0.007
Adequate	97.29	2.71		96.34	3.66		94.52	5.48	

No significant differences in the mean vitamin B12 level were observed between the two comparison groups in the three age categories. This coincides with previous studies from Brazil and Thailand that demonstrate non-significant differences [30, 31]. We observed a lower prevalence of overweight and obesity in the vitamin B12-deficient group of school-age children. Prior studies have demonstrated high rates of vitamin B12 deficiency in individuals aged 19 to 25, with an apparent increase in B12 concentration and increased BMI [32]. However, we see contrasting results in a study from Pakistan that demonstrated a negative association of vitamin B12 with BMI [33]. Deficiency of vitamin B12 is associated with hematologic, neurologic, and psychiatric manifestations, leading to hyper-homocysteinemia, an independent risk factor for atherosclerotic disease [34]. Moreover, a calorie-rich, nutritionally poor vegetarian diet may contribute to a deficiency of vitamin B12 but can very well contribute to obesity.

We observe non-significant differences in the mean vitamin A levels in all three age groups analyzed in our study. However, there was a significant difference in the distribution of overweight/obese school-age children and

Table 5 Factors affecting overweight and obesity among pre-school and school-going children and adolescents; results of logistic regression

Indicators	Pre-school		School age		Adolescents	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Region						
North®	1		1		1	
Central	1 (1.00, 1.00)	1.0	0.41 (0.19, 0.88)	0.021	0.91 (0.54, 1.53)	0.722
East	1 (0.46, 2.19)	0.991	1.99 (1.39, 2.86)	< 0.001	2.08 (1.48, 2.92)	< 0.001
West	0.75(0.26, 2.12)	0.584	1.5 (0.99, 2.27)	0.057	1.51 (1.01, 2.25)	0.045
South	0.58 (0.24, 1.43)	0.239	1.55 (1.06,2.25)	0.023	2.09 (1.50, 2.92)	< 0.001
North-East	2.29 (1.07, 4.92)	0.034	2.7 (1.86, 3.91)	< 0.001	2.27 (1.61, 3.21)	< 0.001
Gender						
Male®	1		1		1	
Female	0.72 (0.45, 1.13)	0.152	0.8 (0.65, 0.98)	0.031	0.84 (0.69, 1.03)	0.096
Locality						
Rural®	1		1		1	
Urban	1.2 (0.73, 1.98)	0.468	1.37 (1.09, 1.71)	0.006	1.12 (0.91, 1.38)	0.284
Religion						
Hindu®	1		1		1	
Muslim	0.56 (0.25, 1.28)	0.167	0.99 (0.70, 1.40)	0.948	0.92 (0.68, 1.26)	0.619
Others	1.08 (0.55, 2.13)	0.82	0.86 (0.62, 1.19)	0.371	1.5 (1.11, 2.03)	0.008
Caste						
SC®						
ST	1.51 (0.63, 3.63)	0.361	1.24 (0.84, 1.83)	0.272	0.62 (0.42, 0.92)	0.018
OBC	1.64 (0.76, 3.52)	0.205	0.93 (0.68, 1.27)	0.638	1.02 (0.68, 1.53)	0.911
Others	2.35 (1.11, 4.99)	0.026	1.37 (1.00, 1.87)	0.047	0.57 (0.20, 1.61)	0.288
Wealth index						
Poorest®	1		1		1	
Poor	0.55 (0.19, 1.66)	0.291	1.29 (0.60, 2.77)	0.507	1.03 (0.50, 2.10)	0.943
Middle	0.78 (0.29, 2.06)	0.61	1.5 (0.74, 3.05)	0.264	1.72 (0.91, 3.28)	0.097
Rich	0.48 (0.17, 1.32)	0.153	1.86 (0.93, 3.73)	0.08	2.84 (1.52, 5.30)	0.001
Richest	0.68 (0.25, 1.89)	0.464	5.08 (2.55, 10.12)	< 0.001	5.18 (2.76, 9.72)	< 0.001
Type of food						
Non veg®	1		1		1	
Veg	0.65 (0.40, 1.05)	0.079	0.99 (0.77, 1.28)	0.944	0.89 (0.66, 1.20)	0.429

Table 5 continued

Indicators	Pre-school		School age		Adolescents	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Exclusive breastfeeding						
0–5 months®	1		1		1	
6–11 months	0.78 (0.46, 1.32)	0.35	NA	NA	NA	NA
12 + months	0.85 (0.45, 1.59)	0.611	NA	NA	NA	NA
Iron						
Non-deficient®	1		1		1	
Deficient	1.5 (0.91,2.47)	0.112	0.8 (0.60,1.08)	0.143	0.63 (0.49,0.81)	< 0.001
Vitamin A						
Non-deficient®	1		1		1	
Deficient	0.5 (0.25, 1.01)	0.054	0.92 (0.71, 1.21)	0.564	0.86 (0.64, 1.15)	0.311
Vitamin D						
Non-deficient®	1		1		1	
Deficient	0.68 (0.36, 1.30)	0.249	1.26 (1.00, 1.59)	0.049	1.78 (1.44, 2.19)	< 0.001
Zinc						
Non-deficient®	1		1		1	
Deficient	1.17 (0.67, 2.05)	0.589	0.72 (0.53, 0.97)	0.029	1.13 (0.90, 1.42)	0.294
Folate						
Non-deficient®	1		1		1	
Deficient	1.36 (0.76, 2.42)	0.301	1.14 (0.89, 1.46)	0.293	1.25 (1.00, 1.55)	0.048
Vitamin B12						
Non-deficient®	1		1		1	
Deficient	0.81 (0.32, 2.06)	0.662	1.09 (0.81, 1.45)	0.907	1.12 (0.90, 1.41)	0.306
Urinary iodine						
Sub-optimal®	1		1		1	
Adequate	1.14 (0.62, 2.10)	0.681	1.04 (0.90, 1.20)	0.58	1.13 (0.87, 1.46)	0.353

adolescents between the vitamin A deficient and non-deficient groups. The latter group showed a larger proportion of overweight and obesity than the others. According to studies, obesity may result in lower plasma concentrations of liposoluble vitamins due to decreased consumption of these micronutrients and considerable storage in adipose tissue, lowering their bioavailability in the body [35]. Similarly, we observed that vitamin D deficiency was associated with overweight and obesity in children across all groups. Previous studies have exhibited a similarly reciprocal relationship between vitamin D and body fat mass [36, 37]. A lack of vitamin D affects musculoskeletal development and exercise capacity, which may lead to a decrease in physical activity and involvement in games and sports. It makes sense that these children's predilection for an indoor and/or sedentary lifestyle may put them at risk for weight gain and vitamin D insufficiency. As an alternative, it has been suggested to increase the generation of 1,25(OH)2D, the active vitamin D metabolite. As a result, a more significant quantity exerts negative feedback control on the synthesis of 25(OH)D by the liver. Additionally, it has been proposed that obesity may result in a greater metabolic clearance of vitamin D, presumably due to increased adipose tissue uptake [38]. Wortsman et al. demonstrated that it is likely that the subcutaneous fat, which stores vitamin D3, sequesters more of the cutaneously produced vitamin D3 in obese than nonobese participants since more fat is available for this process, resulting in the lower serum levels in overweight/obese individuals [37].

Our results showed non-significant differences in the mean ferric levels in overweight/obese and other groups in the pre-school and school-age groups of study participants. In contrast, ferric levels were lower in the overweight/obese group of adolescents. However, the prevalence of obesity was lower in the iron-deficient groups of school-age and adolescent groups. Iron deficiency may be attributed to raised demand due to increased growth and development as well as bodily changes like attainment of menarche at this age, worsened by poor environmental hygiene leading to intestinal infestations, and inappropriate consumption of green leafy vegetables may reduce physical activity in children, thus predisposing them to weight gain. It is also possible that intake of calorie-dense but nutrient-poor beverages and foods may lead to a combination of obesity and iron deficiency. However, another theory about the low prevalence of obesity in iron-deficient groups points to the role of an inflammatory state caused by obesity. Obese individuals are at an increased risk of developing non-alcoholic fatty liver disease with steatohepatitis, which leads to elevated serum ferritin levels [39]. This also leads to underestimation of iron deficiency; hence, it has been suggested to raise the threshold of ferritin values in overweight/obese individuals [40]. Similar observations were made among obese youth from France and Canada [41, 42]. However, the raised iron levels, termed dysmetabolic iron overload syndrome, may facilitate the evolution to type 2 diabetes by altering beta-cell function, the progression of cardiovascular disease, and malignant transformation by promotion of cell growth and DNA damage in later stages [39].

Zinc deficiency protects against obesity in school-aged children. One of the common sources of zinc is cereals, and a lower intake of cereals may explain the association between zine deficiency and normal weight. The finding that diet diversity is not related to the prevalence of overweight and obesity goes against this conjecture, however [43]. Urinary iodine adequacy was seen to have a protective effect against overweight and obesity. This, too, is reasonable, given that urinary iodine concentration can be taken as a marker of overall nutritional health. However, since both higher and lower urine iodine excretion levels have been seen in overweight and obese children compared to normal-weight controls, information on this topic is conflicting. Hence, more studies are needed to reach robust conclusions [44].

Particular strengths and limitations of the study need acknowledgment. The secondary data set analysis we report is based on a methodologic assessment of national-level data collected robustly. The data cover the country's entire geographical and socioeconomic spectrum and is representative of the nation's nutritional status. However, cross-sectional data limit us from making any causal inferences. Also, as reported by previous studies, the present study is limited by the lack of detailed reporting of quality assurance data for the micronutrients and inflammatory markers. As overweight and obesity is an inflammatory state, other better inflammatory makers besides CRP were not available to be adjusted for our estimates [45]. Lastly, the survey provided crude estimates of deficiency based on recalled dietary intakes like breastfeeding, complementary feeding, and dietary diversity, and not actual estimates of micronutrient intake that can affect our estimates.

CONCLUSIONS

The present findings significantly affect our approach to overweight and obesity. We reiterate our stress on the management of micronutrient deficiencies in both underweight and overweight children. Furthermore, macro- and micronutrient adequacy should be viewed as part of the same spectrum of health and not as different entities. We have already seen the benefits of national-level vitamin A and zinc supplementation programs in reducing childhood morbidity and mortality. Now it is time to take a step towards micronutrient adequacy, especially iron and vitamin D, which must be addressed in child health initiatives and obesity prevention programs. We must systematically synthesize and generate more estimates from interventions to decrease micronutrient deficiencies in children. Simultaneoulsy, we must keep the cost of the chosen interventions to a minimum to ensure sustainability. Nutritional supplementation programs should now look beyond calories to fulfill the micronutrient deficiency gaps and help us realize our goals towards better child health soon.

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Compliance with Ethics Guidelines. As a secondary data analysis, ethical approvals were not deemed necessary. However, for the original survey, ethical approvals were obtained from the International Ethical Approval of the Population Council's Institutional Review Board (IRB) in New York. Federal approval was obtained from the ethics committee of PGIMER in Chandigarh. Ethical approvals were obtained before initiating survey activities. More details regarding the approval can be obtained from: https://nhm.gov.in/WriteReadData/l892s/1405796031571201348.pdf. This study was performed in accordance with the Helsinki Declaration of 1964 and its later amendments.

Data Availability Statement. The data can be obtained by reasonable request to the population Council website: https://www.popcouncil.org/uploads/pdfs/2019RH_CNNSreport.pdf.

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