Review

Association between nutritional status, deficiency of protein, iron and vitamins, caloric intake and food security in Mexican school children

Fatima Ezzahra Housni[1], Erika Saenz-Pardo-Reyes[1], Madeline de Jesús López Larios[1], Claudia Llanes Cañedo[1], Virginia Gabriela Aguilera Cervantes and Mariana Lares-Michel[1]*

[1]Research Institute in Feeding Behavior and Nutrition. University Center of the South. University of Guadalajara. Address: Av. Enrique Arreola Silva 883, Col. Centro. Zip code 49000. Ciudad Guzmán, Jalisco. México.

Abstract. The double burden of malnutrition, characterized by prevalence of undernutrition that coexist with overweight and obesity, affects more than a third of the Mexican child population. These conditions are linked to problems related to energy, macro, and micronutrient deficiencies and in the contexts of poverty in Mexico, they are also related to Food Insecurity (FI). Therefore, the objective of this study is to explore the association between nutritional status, protein, iron and vitamin deficiency, caloric intake, and Food Security (FS) in Mexican school children. 719 children between 5 and 12 years old from Chihuahua, Mexico were evaluated. Body Mass Index (BMI), weight for age (W/A), weight for height (W/H), height for age (H/A) and arm circumference (AC) were used. Two 24-hour recalls (R24h), a Food Consumption Frequency Questionnaire (FQFC) and the Mexican Food Security Scale (EMSA) were applied. In addition, clinical evaluation of macro and micronutrient deficiencies was carried out. To examine the association between the variables, binary logistic regression models were performed reporting Odds Ratios (OR). Dietary protein and micronutrient deficiencies were associated with the risk of both undernutrition and overweight and obesity. 71.4% of the overweight and obese children presented some degree of FI. Exceeding the consumption of fruits, vegetables, and soft drinks was associated with the risk of developing overweight and obesity. Micronutrient deficiencies and FI are not exclusive to undernutrition and are strongly associated with overweight and obesity problems. Exceeding the consumption of foods, even if they are healthy, is related to the risk of developing overweight and obesity.

Key words: Overweight and obesity, Malnutrition, Micronutrients, Proteins, Mexican schoolchildren.

Background

Obesity is defined as the increase of body weight at the expense of fatty tissue, caused by a chronic imbalance between energy intake and consumption (1). The International Obesity Task Force (IOTF) reports that, worldwide, at least 155 million school-age children are overweight or obese (2); which coincides with other studies that have shown similar results (3,4). Mexico presents a prevalence of overweight and obesity of 26.3% in the group aged from 2 to 18 years, stratified by regions, socioeconomic status, urban and rural areas, and ethnic group using the IOTF (5). The growth and development of children is the result of the genetic characteristics and the environmental conditions to which they are exposed, in a process that is not uniform, in which there are stages of higher speed where children are more susceptible to present nutritional problems such as malnutrition and being overweight or obese (6). For this reason, it is important to evaluate the nutritional status of children using indicators such as the weight/age (W/A), height/age (H/A) and weight / height (W/H), and in recent years it has been additionally use the Body Mass Index (BMI =

weight [kg] / height^2 [m]) (7). The problem of malnutrition, understood as the deficiencies, excesses and imbalances of a person's caloric and nutrient intake, is frequently associated with micronutrient deficiencies, and especially protein-caloric malnutrition (8). In general, micronutrient deficiencies during the first years of life have adverse effects on the growth, development, and health of children. At school age (5-11 years), some of these deficiencies have effects on learning, which together have long-term repercussions on the acquisition of individual capacities and on social development (9). However, vitamin deficiency is always related to limited access to healthy food and poverty (10), a condition in which overweight and obese children are also exposed.

Inadequate access to healthy food in a context of poverty exposes children to degrees of Food Insecurity (FI). FI is defined as: "the limited or uncertain availability of nutritionally adequate and safe food; or the limited and uncertain ability to acquire adequate food in socially acceptable ways" (11), presents a complex and contrasting panorama in Mexico. Recent information from the National Health and Nutrition Survey (ENSANUT) reported that almost one in three households suffers from FI in its moderate or severe form (12). The objective of this study is to explore the association between nutritional status, protein, iron and vitamin deficiency, caloric intake, and Food Security (FS) in Mexican school children.

Methods

Data and study population

The study was cross-sectional and the study population was made up of school children from 7 public schools in the southern state of Chihuahua, Mexico. All school-age children between 5 and 11 years old were included in the study. A total of 982 children were included. Children who did not attend school on the days of anthropometric measurements were discarded, as were children whose parents did not sign the informed consent. Anthropometric measurements and clinical evaluation of dietary protein, iron and vitamin deficiency were performed in 719 children. 310 children completed the food safety questionnaire and 159 children completed the two 24-hour recalls (R24h) and the Food Consumption Frequency Questionnaire (FCFQ) of vegetables, fruits, and soft drinks validated for the Mexican population (13). Figure 1 schematically shows the distribution of the studied sample.

Data collection

Nutritional status evaluation of the schoolchildren was made up following the parameters: a) anthropometric, b) clinical and c) dietary.

Anthropometric parameters

The anthropometric parameters measured were: weight, height, BMI and AC. Subsequently, the W/A, H/A, BMI for age (BMI/A) and AC for age (AC/A). The interpretation of the former was performed with the cut-off points proposed by the World Health Organization in 2007 and 2008 in standard deviation; and the AC with the 1990 Frisancho tables in percentiles (14, 15, 16).

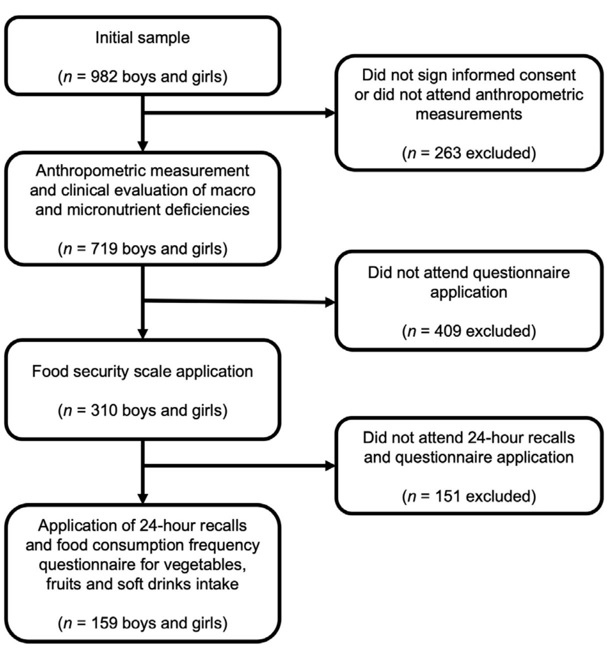

Figure 1. Schematic representation of study design

Clinical parameters

Physical signs of possible deficiencies of the following macro and micronutrients were identified: (a) protein, (b) iron, (c) riboflavin, niacin, and pyridoxine; (d) vitamin A and (e) vitamin C. The following are the physical signs that were looked for during the evaluation:

Protein deficiency: Weight loss, muscle, and fat; depigmentation of the skin or nails, cracks in the skin or nails, thinning of hair, flag sign and moon face.

Iron deficiency: Paleness of the skin, tongue, or conjunctiva, and koilonychia.

Riboflavin, niacin, and pyridoxine deficiency: Nasolabial seborrhea, redness, or fissures at the corners of the lips, glossitis, magenta tongue, papillary atrophy, angular stomatitis, and cheilosis.

Vitamin A deficiency: Conjunctival and corneal xerosis, bitot spots, brittle or scaly skin, and follicular hyperkeratosis.

Vitamin C deficiency: Swollen or bleeding gums.

It was interpreted as a nutrient deficiency when at least one of the physical signs mentioned above was observed (17,18,19).

Dietary parameters

A weekly FCFQ of fruits, vegetables, junk food and soft drinks was applied. In addition, the number of meals and the intake of natural water per day were asked. Also, energy and protein intake were evaluated by means of two R24h in schoolchildren in the fifth and sixth year of primary school and in the parents of the other children. The R24h were applied by previously trained nutrition students, who asked the questions and filled out the forms based on the answers provided. Energy intake was calculated in calories per kilogram per day (kcal/kg/day) and protein in grams per kg per day (g/kg/day). These data were compared with the requirements for school age suggested by FAO/WHO through the percentage of adequacy, considering deficient intake at values lower than 90% and excessive intake at values higher than 110% (20,21,22).

Food security

To collect FS data, the Mexican Food Safety Scale (EMSA) was used (23). This instrument addresses the dimension of access to food in twelve questions that consider the quality and sufficiency of food through the report of experiences lived by the population. EMSA gives an account of the degree of FI in households and is the instrument with which the indicator of lack of access to food used in the official measurement of poverty in Mexico is constructed. More insecure or more deprived households would be expected to have less varied diets than safe households. Four levels of FS/insecurity are considered: FS, mild FI, moderate FI and severe FI (23). For statistical analysis purposes in this study, two FS classifications were considered. Children with FS and children with FI (mild, moderate and severe).

Data analysis

All statistical analyzes were performed in STATA 12 version. First, descriptive statistics, including frequency and percentage, were used to describe age, anthropometric measurements of children, and FS. The chi-square test was extended to explore the relationships between BMI and AC, weight according to W/A, H/A, BMI/A, and AC/A, between gender. In addition, a student's t-test was performed to explore the relationship of mean age between gender. A frequency and percentage were also made for the classification of FS in the 310 children. The chi-square test was also extended to explore the relationship between FS in children with normal BMI and in children with overweight and obesity.

Second, binary logistic regression models reporting Odds ratio (OR) were used to examine the relationship between nutritional status and vitamin deficiency. For model 1 and 2 the 2007 WHO BMI classifications (14) were used. In model 1, the relationship between thinness and low weight and the deficiency of dietary proteins, iron and vitamins was evaluated, for this model low weight, thinness and severe thinness were considered as exposed and normal weight as not exposed or control. Model 2 relates to overweight/obesity and vitamin deficiency. Here, overweight and obesity were considered as exposed and normal weight as control. In model 3 and 4, data from the 2008 WHO weight-for-height assessment were used (15). Data from model 3 relate low weight, growth problems, and dietary protein, iron, and vitamin deficiencies. Low weight, severe underweight and growth problems were considered as exposed cases and normal weight as controls. For model 4, the relationship between overweight/overweight risk and dietary protein, iron and vitamin deficiency was examined. For this model, the risk of overweight/overweight were considered as exposed and normal weight as control. For models 5 and 6, the weight-for-height classification data were used (15). Model 5 expresses the relationship between emaciated/severely emaciated and vitamin deficiency, considering emaciated and severely emaciated children as cases and those with normal weight as controls. Model 6 examines the relationship between risk of being overweight, overweight/obese, and dietary protein, iron, and vitamin deficiencies. For this model, overweight, risk of overweight and obesity were considered as exposed or case and weight for normal height as control. For the H/A and A/C evaluations, the models generated were not statistically significant, therefore they were not considered.

The relationship between FS and dietary protein, iron and vitamin deficiencies and the BMI of school children was then examined. A binary logistic regression adjusted for age was used.

For the fourth analysis, age-adjusted binary logistic regression models were used to explore the risk factors of consumption above the recommended servings of fruits, vegetables and soft drinks in school children who developed overweight and obesity. To do this, we rely on the dietary and physical activity guidelines of Bonvecchio et al. 2015 (24). According to this guide, the recommended serving of fruits and vegetables for Mexican school children is 3 servings for vegetables and 2 servings for fruits per day. For sugary drinks, the consumption of any drink with sugar and low nutrient content was considered not recommended.

Finally, and to explore the relationship between total energy and protein consumption and overweight and obesity in school children, a linear regression model was used. The analysis was carried out by age ranges, since consumption in ages 6-8 years is different than consumption in ages 9-11 years.

For the binary logistic regression models, a p value lower than 0.001 and lower than 0.05 was considered statistically significant for the significance between variables.

Ethical considerations

This project was carried out under the guidelines of the Declaration of Helsinki, in addition, it was approved by the Research Committee of the Institute for Research in Food Behavior and Nutrition. Likewise, it is registered in the Postgraduate and Research Coordination of the Southern University Center, of the University of Guadalajara, with the code SAC/CI/010/19.

Results

Anthropometric characteristics of the study sample

The descriptive results showed that the 719 children were made up of 353 boys and 366 girls. The average age in boys was 8.94 years and 9.23 in girls. For BMI, 63% of 719 children were normal weight (212 boys and 241 girls), 16.83% and 10.99% were overweight and obese, respectively; the majority were boys. 49% presented low weight and only 11 and 6%, respectively, presented thinness and severe thinness. Girls presented more normal BMI data than boys, who presented a higher rate of overweight/obesity and underweight and thinness.

Regarding the evaluation of the W/H, it was identified that 445 children out of 719 presented normal or adequate W/H, more than half was presented in girls. 16.68% were children with growth problems, of which 61 were boys and 59 girls. 8.9% were children at risk of being overweight and 6.39% were children already overweight. Only 5.56% and 0.55% presented low and severe underweight that occurred in children. The H/A showed that 525 boys (73.02%) were normal height for their age, and only 271 girls were into this classification. 119 children (16.55%) were very tall, of which 60 were girls. 8.76% were short and only 1.67% were severely short.

The evaluation of the W/A showed that the majority presented obesity, 347 (48.94%) children of which 177 were boys and 170 girls. Followed by 269 children with normal weight for their age (37.94%), 144 girls and 125 boys. 5.08% of the children evaluated by W/H, presented emaciation, mostly girls, and 3.95% were overweight and 3.67% presented risk of developing overweight. The AC measurement showed that 94.16% of the children were normal, 248 are girls and 329 are boys and only 4.59% present malnutrition. The results are presented in Table 1. The difference between nutritional evaluation between boys and girls was significantly different in all evaluations, except for AC.

Table 1. Participant's characteristics

	Total (n = 719)	Boys (n = 353)	Girls (n = 366)	X^2 (p value)	t-student (p value)
Age		8.94 ± 0.97	9.23 ± 0.11		<0.001
BMI[1]					
Severe thinness	6 (0.83%)	4 (1.13%)	2 (0.55%)	<0.001	
Thinness	11 (1.53%)	4 (1.3%)	7 (1.91%)		
Underweight	49 (6.82%)	26 (7.37%)	23 (6.28%)		
Normal	453 (63%)	212 (60.6%)	241 (65.85%)		
Overweight	121 (16.83%)	66 (18.7%)	55 (15.03%)		
Obese	79 (10.99%)	41 (11.61%)	38 (10.38%)		
Weight for age[2]					
Normal	445 (61.89%)	207 (58.54%)	238 (65.03%)	<0.001	
Overweight risk	64 (8.9%)	43 (12.18%)	21 (5.74%)		
Underweight	40 (5.56%)	22 (6.23%)	18 (4.92%)		
Severe under weight	4 (0.55%)	3 (0.85%)	1 (0.27%)		
Growth problem	120 (16.68%)	61 (17.28%)	59 (16.12%)		
Overweight	46 (6.39%)	17 (4.82%)	29 (7.92%)		
Height for age[2]					
Normal	525 (73.02%)	254 (71.95%)	271 (74.04%)	<0.001	
Low height	63 (8.76%)	34 (9.63%)	29 (7.92%)		
Severe low height	12 (1.67%)	6 (1.70%)	6 (1.64%)		
Very high height	119 (16.55%)	59 (16.71%)	60 (16.39%)		
Weith for height[2]					
Emaciated	36 (5.08%)	16 (4.6%)	20 (5.54%)	<0.001	
Normal	269 (37.94%)	125 (35.92%)	144 (39.89%)		
Obese	347 (48.94%)	177 (50.86%)	170 (47.09%)		
Overweight risk	26 (3.67%)	12 (3.45%)	14 (3.88%)		
Severely emaciated	3 (0.42%)	2 (0.57%)	1 (0.28%)		
Overweight	28 (3.95%)	16 (4.5%)	12 (3.32%)		
Middle arm circumference[3]					
Uundernourishment	33 (4.59%)	21 (5.95%)	12 (3.28%)	0.963	
Normal	677 (94.16%)	329 (93.20%)	348 (95.08%)		
Uundernourishment risk	3 (0.42%)	1 (0.28%)	2 (0.55%)		
Obesity risk	6 (0.83%)	1 (0.57%)	4 (1.09%)		

Note: Classifications from: [1]WHO (2007). [2]WHO (2008). [3]WHO, (1997)

Food security

The results of the EMSA are presented in Table 2. Of the 310 children who completed the FS survey, 62.26% were children with FS and 37.37% are children with some degree of FI. Regarding the relationship between FS and nutritional status, it was identified that 117 (73.3%) of children with normal weight were in FS and 26.6% were in a degree of FI. Only 2 children with malnutrition suffered from FI, since of the initial sample, only 310 children responded to the EMSA. In contrast, it can be identified that 28.57% of children with overweight and obesity were children in FI and 71.4% were children with a degree of FI. The significance of the relationship was less than 0.001.

Dietary protein, iron and vitamin deficiency and nutritional status in school children, using binary logistic regression reporting Odds Ratios

The results of the binary logistic regression models reporting the OR to associate nutritional status and vitamin deficiency are presented in Table 3. Model 1 presents an R^2 of 0.45 and it was shown that low weight in children is related to dietary protein deficiency, the OR was 19.03 (7.52 - 48.16). In model 2, a coefficient of determination R^2 of 0.73 with p <0.001 was identified. Children who were overweight and obese presented iron deficiency with an OR of 164 (41.66 - 647.11) and vitamin B complex deficiency, with an OR of 23.48 (6.49 -84.91). Although the coefficient of determination was low (0.38), a relationship was identified in model 3 between growth problems with respect to underweight with riboflavin, niacin, and pyridoxine deficiency, with an OR of 12.55 (5.57-28.25) and deficiency of vitamin C (OR of 13.44, 5.42 - 33.30).

In model 4, the coefficient was very low, however, found p value was significant (<0.001). The risk of being overweight/overweight is related to the deficiency of B complex vitamins and vitamin A. Similarly, for model 5 the coefficient of determination was 0.078 but statistically significant (p <0.001). In this same model, an association between emaciation and severe thinness with vitamin A deficiency was identified, with an OR of 0.57 (0.17 - 1.84). In model 6, the determination coefficient was 0.64 (p <0.001) and the relationship between the risk of overweight, overweight/obesity and vitamin deficiency was found to be a risk of iron deficiency, with an OR of 0.30 (0.31 - 0.71), the risk of vitamin A deficiency was OR of 0.30 (0.07 - 0.50) and for vitamin C, the OR was 6.4 (1.99 - 10.77).

Food security, nutritional status, and vitamin deficiency

The multiple binary logistic regression model between overweight/obesity, vitamin deficiency and FS (Table 4), presented a coefficient of determination (R^2) of 0.76. The results showed that there is a very low risk between overweight/obesity in school children and the difference of iron with an OR of 0.003 (0.006 - 0.164) and the deficiency of riboflavin, niacin and pyridoxine had an OR of 0.04 (0.12 - 0.19). However, the relationship between overweight/obesity and FS was 7.2 (1.7-29.62) with p <0.05.

Total energy consumption, fruits, vegetables and soft drinks and the risk of overweight and obesity in school children

The relationship of the binary logistic regression between the consumption of fruits, vegetables and sugary drinks is shown in table 5. The regression model presented a coefficient of determination of 0.23 with a significance p <0.001. It can be identified that the con-

Table 2. Food security and its relationship with nutritional status in school children

Food security	Total n = 310 (100%)	Normal n = 233 (100%)	Overweight and obesity n = 77 (100%)	X^2 (p-value)
No	117 (37.74%)	62 (26.61%)	55 (71.43%)	<0.001
Yes	193 (62.26%)	171 (73.39%)	22 (28.57%)	

Note: Classification from BMI. *p<0.001

Table 3. Vitamin deficiency and nutritional status in school children, using binary logistic regression reporting Odds Ratios

Nutrient	Model 1 (n = 336)		Model 2 (n = 310)		Model 3 (n = 422)		Model 4 (n = 391)		Model 5 (n = 253)		Model 6 (n = 344)	
	OR (95%CI)	*p*	OR (95%CI)	*p*	OR (95%CI)	*p*	OR (95%CI)	*p*	OR (95%CI)	*p*	OR (95%CI)	*p*
Proteins	19.03 (7.5-48.16)	<0.001*	0.05 (0.001-2.81)	0.151	1.15 (0.45-2.96)	0.760	1.16 (0.52-2.57)	0.700	0.49 (0.10-2.26)	0.367	1.18 (0.72-3.76)	0.206
Iron	8.45 (1.80-39.65)	0.007**	164.20 (41.6-647.1)	<0.001*	0.77 (0.32-1.83)	0.557	0.59 (0.29-1.19)	0.143	1.56 (0.57-4.23)	0.379	0.30 (0.31-0.71)	0.006**
Riboflavin, Niacin and Pyridoxine	4.95 (1.36-17.99)	0.187	23.48 (6.49-84.91)	<0.001*	12.55 (5.57-28.25)	<0.001*	3.08 (1.20-7.89)	0.018**	6.26 (1.80-21.68)	0.349	1.17 (0.35-3.88)	0.787
Vitamin A	0.42 (0.11-1.51)	0.015**	0.26 (0.049-1.45)	0.128	0.32 (0.12-0.89)	0.029**	0.34 (0.14-0.80)	0.014**	0.57 (0.17-1.84)	0.004**	0.30 (0.07-0.50)	<0.001*
Vitamin C	0.18 (0.03-0.83)	0.028**	3.17 (0.63-15.95)	0.161	13.44 (5.42-33.30)	<0.001*	1.84 (0.69-4.90)	0.219	2.82 (0.56-14.02)	0.204	6.4 (1.99-10.77)	0.002**
	R^2= 0.4516*		R^2= 0.7389*		R^2= 0.3874*		R^2= 0.0291*		R^2= 0.0786*		R^2= 0.6431*	

Note: Model 1: Relationship between thinness/severe thinness/underweight and vitamin deficiency. Model 2: Overweight/obesity relationship and vitamin deficiency. Model 3: Relationship between underweight/growth problems and vitamin deficiency. Model 4: Risk ratio of overweight/ overweight and vitamin deficiency. Model 5: Relationship between wasted / severely wasted and vitamin deficiency. Model 6: Relationship between risk of being overweight / overweight / obesity and vitamin deficiency.
*<0.001; **<0.05

Table 4. Risk of overweight and obesity and its relationship with protein consumption, vitamins deficiency and food security

Nutrient/Aspect	Total (n = 310)	
	OR (95%CI)	p value
Proteins	12 (0.28-497.96)	0.191
Iron	0.0031 (0.006-0.164)	<0.001
Riboflavin, Niacin, and Pyridoxine	0.04 (0.12-0.19)	<0.001
Vitamin A	3.30 (0.47-23.09)	0.228
Vitamin C	2.45 (0.95-3.43)	0.343
Food insecurity	7.2 (1.7-29.62)	0.005**
		R^2= 0.7646*

**$p<0.05$; *$p<0.001$

sumption above the recommended servings of fruits, vegetables and soft drinks was significantly associated with overweight and obesity in children. The OR was 3.90 (1.42 - 10.74) for fruits, 5.59 (2.24 - 13.91) for vegetables and 2.91 (1.10 - 7.71) for soft drinks. For caloric intake and protein consumption with the BMI of children by age ranges (Table 6), a statistically significant association of 0.4273 was found. The greatest association was presented mostly in children from 6 to 8 years old, with R^2 of 0.6885 and p <0.001. For children from 9 to 12 years old, there was an effect of caloric intake on the BMI of children with lower R^2 strength of 0.1726 but significant p <0.000 (Table 5).

Discussion

Regardless of the type of anthropometric evaluation, whether by BMI, W/A, H/A or AC, the results of this study showed that a high percentage of the school

Table 5. Consumption of fruits, vegetables and sugary drinks and risk of overweight and obesity in school children using binary logistic regression reporting Odds Ratios

Consumption	n = 159	
	OR (95%CI)	*p* value
Fruits	3.9(1.42-10.74)	0.008**
Vegetables	5.59(2.24-13.91)	<0.001*
Soft drinks	2.91(1.10-7.71)	0.031**
		R^2= 0.2331*

**$p<0.05$; *$p<0.001$

Table 6. Association between energy and protein consumption with BMI of school children by age ranges using linear regression

Intake	Total (n = 159)		Age 6-8 years (n = 36)		Age 9-11 years (n =123)	
	Coefficient (95%CI)	*p*	Coefficient (95%CI)	*p*	Coefficient (95%CI)	*p*
Energy	1.178	0.005**	0.0035	<0.001*	0.0024	0.002**
Protein	0.0348	0.002**	0.0701	<0.001*	-0.0311	0.012**
	R^2= 0.4273*		R^2= 0.6885*		R^2= 0.1726*	

**$p<0.05$; *$p<0.001$

population was of normal weight. However, they also showed an important prevalence of overweight and obesity, as well as undernutrition, especially chronic undernutrition. These results agree with those reported by researchers in many regions in Mexico (25, 26). The prevalence of overweight and obesity in those under 19 years of age in Mexico between 2012 and 2016 is still high, reaching more than a third of those over five years of age. This problem can be attributed to the fact that during the last 30 years, Mexico has suffered from several demographic, economic, environmental, and cultural changes that have had a negative impact on the lifestyle and well-being of its population, where the incidence of obesity has reached proportions almost epidemic, with behaviors on the rise in recent years affecting more than a third of children and adolescents by 2012 (27). The prevalence of malnutrition in Mexico is in accordance with what the Department of Nutrition of the World Health Organization (WHO) has published where it refers that at present, the world faces a double burden of malnutrition, which includes undernutrition and excessive feeding (28).

Another interesting finding of this study is that vitamin deficiency, in addition to being related to underweight children, is also related to children who are overweight and obese. Underweight children are at risk of protein deficiency and iron, vitamin B, vitamin A and C deficiency. This is due to protein-energy malnutrition that manifests with low weight (low body weight compared to healthy peers), delay in growth (poor linear growth), emaciation (acute weight loss), or edematous malnutrition (kwashiorkor) (29). In our study, the model with the highest coefficient of determination was model 2, which explains a relationship between the overweight/obese population to vitamin and mineral deficiency, especially iron, vitamin B1, and A. This shows that micronutrient deficiency is prevalent in both underweight and obese populations (30). Many studies link this problem to poor nutrition. According to studies in the United States and Canada, many people do not reach the recommended levels of micronutrients through diet (31, 32). This can be attributed to a greater availability of cheap foods that are high in calories and deficient in nutrients (33-34). In addition, the metabolic changes that occur in people with obesity can also increase the requirements of certain nutrients (35). Obesity has been increasingly recognized as a risk factor for several nutrient deficiencies, which may seem surprising given the likelihood of excessive calorie intake in these individuals (36). However, many of these extra calories do not come from nutritional sources. In Mexico, this can be explained by the nutritional transition that urban localities are going through, where there is a high availability of processed foods and beverages, with a high content of salt, refined sugars and fats, and low availability of vitamins, minerals, and fiber, coupled with a decrease in physical activity and low water consumption due to the low availability of this or the preference for other beverages (27).

Although undernutrition was the most common reason for vitamin and mineral deficiencies, the evidence that suggests that obesity is related to nutritional deficiencies is growing (37). In this sense, our findings of iron deficiency in overweight and obese children coincide with the study of Ghadimi et al. (38) where a negative association was found between waist circumference and serum iron in Iranian children. Even though we did not measure waist circumference, the overweight and obesity indicators we used, especially BMI, match with those findings. Another's nutrients with an important risk of deficiency in malnutrition are B complex vitamins. One of the most common kinds of deficiency in this regard is vitamin B12, however, this type of vitamin is difficult to measure using only clinical indicators (39). Regarding riboflavin, niacin, and pyridoxine deficiency, a study showed that these specific vitamins are related to weight disorders (40). However, the findings of that study identified a positive relationship between intake of vitamin B1, B3, and B6 with weight gain. This could be explained by the biochemical role that these vitamins play in the process called AMP-activated protein kinase (AMPK) (40). However, our findings differ from that statement, since we identified deficiencies, not overconsumption of these vitamins. The principal explanation of our results could be related to inadequate intake through an unhealthy diet. However, further studies are needed to clear up these mechanisms.

Regarding vitamin A deficiency and its relationship with overweight and obesity, the evidence of this relation is considerably scarcer than studies relating this deficiency with undernutrition (41). However, some studies have highlighted an interesting relationship between obesity and vitamin A deficiency, since adequate levels of this vitamin promote an anti-inflammatory effect, for what, a deficiency of this nutrient can be related to an inflammatory status that can help to explain our findings (42). However, is important to mention that this analysis has been performed principally on animal models, for which further studies in human, and especially in children, are needed. In the case of vitamin C, its deficiency in overweight and childhood obesity is also related to mechanisms similar to vitamin A, since vitamin C also plays an important role in inflammation, and adequate and even high levels of vitamins C are related to low levels of inflammations, that can also be linked with less predisposition to obesity development (43). Also, deficiency of vitamin C is an important nutritional problem since it can also have implications on iron absorption, which can also lead to anemia, considering the already existing risk due to iron deficiency in the diet of Mexican children (44).

Malnutrition and inadequate diet are often associated with other aspects such as poverty, FI, low levels of awareness and education (30). In this study, it was found that some children who are overweight and obese are food insecure (3%). In addition, a relationship was found between FI, overweight and obesity, and iron and vitamin B deficiency (OR of 7.2). This is consistent with research that states that the prevalence of overweight is consistently high among food insecure youth (45). However, this result cannot be conclusive, given that other research examining the association between FI and youth overweight and obesity has shown inconsistent results, with findings differing according to age, race or ethnic origin, sex and poverty level (45-51).

For macronutrients, it was found that total caloric and protein intake is related to the increase in BMI in school children, especially in children between 6-8 years old. Many studies around the world agree with these findings. In the UK for example, one study reported that young children have energy and protein intakes that are higher than recommended levels and potentially increase the risk of obesity (52). Many attribute this relationship to caloric intake density, for example, a 2001–2004 NHANES analysis (53) found a positive association between high caloric intake density and children's BMI, in the same way longitudinal studies have shown positive associations between caloric intake density and fat mass, but not BMI (54,55). In Mexican school-age children, a study provided evidence of a positive association between caloric density and excess body weight (56).

Few studies have evaluated the association of fruits and vegetables consumption and BMI in children. A study of health behavior in school-age children 2001–2002 reported that being overweight was not associated with the intake of fruits or vegetables (57). Others reported that vegetarian diets or dietary patterns that are rich in vegetables, whole grains, nuts, and legumes have shown consistent protective effects of these diets on the risk of overweight (58). However, a recent study found a small association between increasing BMI and consuming fruits and vegetables, three or more times a week (59). This agrees with the findings of this study, where the intake of fruits and vegetables higher than recommended influences the increase in BMI in children. Another important point is the consumption of soft drinks was significantly associated with the increase in BMI. This can be explained by international statistics where Mexico is identified as the second largest consumer of soft drinks in the world and the proportion of families that buy soft drinks has increased over the years, as well as the milliliters consumed per capita (60). In addition, the excessive consumption of added sugars, especially soft drinks, contributes to the high prevalence of childhood and adolescent obesity (61-63). Mexican preschoolers and school-age children consume the highest documented levels of calories from beverages as a proportion of total energy intake (27.8 and 20.7%, respectively). Beverage calories increased significantly from 1999 to 2006, while non-drink food calorie energy remained constant (64).

Study limitations

Although our study found interesting trends in regard of the nutritional status of Mexican children, as well as about dietary intake and FS, it is important to mention that our study has some limitations. In the first place, it is important to say that we did not assess biochemical parameters, since it resulted invasive for children. However, serum levels of vitamins could have provided a more precise analysis. Also, there are other vitamins which deficiency cannot be measure by clinical exploration, such as vitamin D, which has been reported as deficient in obese children (65). This opens the necessity to perform other studies in the context of Mexico, to understand more deeply all the implications that obesity has on nutritional status.

Another important aspect to consider is that although the anthropometric indicators used have shown well efficacy to determine nutritional status in children, nowadays it is recognized the importance of measuring other adiposity indicators, such as body fat percentage and waist circumference (38, 66). This is another limitation that indeed if considering it could have reflected a more serious problem regarding overweight and obesity since it has been reported that although some children maintain adequate levels of BMI, body fat percentage or waist circumference can be elevated (38, 66). Finally, it is important to consider that this was a cross-sectional study, and we cannot prove causal relationships between malnutrition and deficiency of dietary protein, vitamins, and iron. However, the associations found provided interesting information for expanding knowledge in this regard. Also, we must bring to attention that dietary evaluation by means of R24h and FCFQ can also present variations regarding actual consumption, which is important to analyze the results of this study carefully.

Conclusions and future perspectives

The present study represents an approach to expand knowledge about nutrient deficiencies in children with malnutrition, besides only undernutrition, which used to be one of the principal public health problems in Mexico but has been accompanied by overweight and obesity. Also, FI was found as an important problem that not only affects underweight children but also the overweight and obese child population. One of the most important findings of this study is that not only excessive consumption of ultra-processed foods or sugary drinks lead to overweight and obesity, but excessive consumption of fruits and vegetables can also lead to a positive energy balance that could lead to excess adiposity. Therefore, this study shows the importance of policy regulations about nutrition in the country, and that establishing number and size of portions, even in healthy foods, is a very important aspect to promote a healthy lifestyle in Mexican children. For this reason, education and behavioral modification programs are urgent in the country. Also, we exhort health professionals to start considering nutrient deficiencies not only in undernourished children but also in overweight and obese children. Since, maintaining low consumption of dietary protein, vitamins from the B complex, and vitamin A and C, could have an important role in undernourishment (protein), energy utilization (B complex vitamins), and on inflammation including obesity (vitamin A and C).

Conflict of Interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article

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Correspondence
Erika Saenz-Pardo-Reyes
Av. Enrique Arreola Silva 883, Col. Centro. C.P. 49000. Cd. Guzmán, Jalisco. México.
Phone: (+52) 341 5752222 ext. 46142
E-mail: erika.saenzpardo@gmail.com