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Trabajo Original

Obesidad y síndrome metabólico

Cardiometabolic risk factors and hypovitaminosis D in adolescents with overweight from a sunny region in northeast Brazil: a cross-sectional study

Factores de riesgo cardiometabólico e hipovitaminosis D en adolescentes con sobrepeso de una región soleada del noreste de Brasil: un estudio transversal

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Abstract

Background: obesity can influence vitamin D levels, which in turn might be associated with cardiometabolic risk factors.

Objectives: this study assessed the association between 25-hydroxyvitamin D [25(OH)D] levels and cardiometabolic risk factors in adolescents with overweight living in a region of northeastern Brazil.

Material and methods: a cross-sectional study was carried out by non-probabilistic sampling in adolescents diagnosed with overweight or obesity. The subjects were divided according to their 25(OH)D status into two groups: sufficient vitamin D and hypovitaminosis D. Biodemographic, lifestyle, cardiometabolic, and biochemical factors were evaluated. A logistic regression model was applied to determine the predictors of hypovitaminosis D.

Results: we found a high frequency of hypovitaminosis D (45.6 %) in adolescents. Weekly sun exposure was negatively associated with hypovitaminosis D (OR = 0.96; 95 % CI: 0.92-0.99), while significant positive associations were observed between hypovitaminosis D and blood pressure above the 95th percentile (OR = 4.00; 95 % CI: 1.19-13.37), body weight (OR = 1.04; 95 % CI: 1.01-1.07), and fasting insulin (OR = 1.13; 95 % CI: 1.05-1.22).

Conclusion: hypovitaminosis D showed a high prevalence in adolescents with overweight living in a sunny region of northeastern Brazil, and cardiometabolic risk factors such as systemic arterial hypertension, high body weight, and hyperinsulinemia are predictors of hypovitaminosis D.

Keywords:

Adolescent. Overweight. Obesity. Vitamin D. Vitamin D deficiency. Risk factors.

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Resumen

Introducción: la obesidad puede influir en los niveles de vitamina D, lo que a su vez podría estar asociado con factores de riesgo cardiometabólico.

Objetivos: este estudio evaluó la asociación entre los niveles de 25-hidroxivitamina D [25(OH)D] y los factores de riesgo cardiometabólico en adolescentes con sobrepeso que viven en una región del noreste de Brasil.

Material y métodos: se realizó un estudio transversal mediante muestreo no probabilístico con adolescentes diagnosticados de sobrepeso u obesidad. Los sujetos se dividieron según su estado de 25(OH)D en dos grupos: suficiente vitamina D e hipovitaminosis D. Se evaluaron factores biodemográficos, de estilo de vida, cardiometabólicos y bioquímicos. Se aplicó un modelo de regresión logística para determinar los predictores de la hipovitaminosis D.

Resultados: encontramos una alta frecuencia de hipovitaminosis D (45,6 %) en los adolescentes. La exposición semanal al sol se asoció negativamente a la hipovitaminosis D (OR = 0,96; IC 95 %: 0,92-0,99), mientras que se observaron asociaciones positivas significativas entre hipovitaminosis D y presión arterial por encima del percentil 95 (OR = 4,00; IC 95 %: 1,19-13,37), peso corporal (OR = 1,04; IC del 95 %: 1,01-1,07) e insulina en ayunas (OR = 1,13; IC del 95 %: 1,05-1,22).

Conclusión: la hipovitaminosis D mostró una alta prevalencia entre los adolescentes con sobrepeso que viven en una región soleada del noreste de Brasil, y los factores de riesgo cardiometabólico, como hipertensión arterial sistémica, peso corporal elevado e hiperinsulinemia, son predictores de hipovitaminosis D.

Palabras clave:

Adolescente. Exceso de peso. Obesidad. Vitamina D. Deficiencia de vitamina D. Factores de riesgo.

INTRODUCTION

The growing epidemic of obesity has been the most important metabolic disorder reported in many populations and age groups (1,2). In adolescents as well, the prevalence of overweight/obesity is increasing exponentially, with an estimated 25.5 % of adolescents in Brazil being overweight (3). Obesity in general can result in the appearance of several cardiovascular risk factors such as glycemic changes, dyslipidemia, high blood pressure, and metabolic syndrome (MS) (4). In addition, in adolescents, if not controlled, these risk factors can persist and cause adverse health events later in adulthood (5).

In this context, evidence has shown that vitamin D plays an important role in the pathogenesis of chronic non-communicable diseases such as obesity (6). Vitamin D belongs to a group of liposoluble secosteroids and is responsible for promoting the intestinal absorption of calcium, magnesium, and phosphate. To perform its functions, it needs to be converted into its active form, 1.25-dihydroxyvitamin D, also known as calcitriol or 1.25$(OH)_2$D (7). However, recently, its extra-skeletal role and the expression of more than 2,000 genes involved in the regulation of several mechanisms associated with cardiometabolic disorders have been discussed (8).

A study carried out in Norway demonstrated that serum concentrations of 25(OH)D below 50.0 nmol/L were associated with a significantly increased odds ratio (OR) for the incidence of obesity during follow-up (adjusted OR = 1.73, 95 % CI, 1.24-2.41) (9). In Brazil, a recent cohort study found that body weight, body mass index (BMI), and waist circumference increased over time in obese patients with low serum 25(OH)D concentrations, regardless of dietary vitamin D intake (10). The observed lower bioavailability of vitamin D in individuals with obesity is attributed, among other factors, to sequestration of this pre-hormone in adipose tissue (6).

Hypovitaminosis D can influence the homeostasis of the renin-angiotensin-aldosterone system and interfere with the pathogenesis of systemic arterial hypertension (SAH), compromising vascular health and culminating in elevated blood pressure (11). In a cohort of Iranian adolescents, low concentrations of 25(OH) D were reported to correlate negatively with SAH (12), whereas in American adolescents they were associated negatively with elevated systolic blood pressure and hyperglycemia (13).

Hypovitaminosis D is also associated with unfavorable outcomes related to atherogenic dyslipidemia, which affect high-density lipoprotein cholesterol concentrations (14). In addition, the presence of the vitamin D receptor in β-pancreatic cells demonstrates vitamin D activity in calcium-parathyroid hormone (PTH) homeostasis, with adequate concentrations of calcitriol preventing the development of insulin resistance (IR) and diabetes *mellitus* type 2 (15).

Given that vitamin D deficiency has become a global health problem in all age groups, monitoring vitamin D insufficiency/deficiency and its associated conditions in adolescents can optimize health in this cohort and prevent health issues in adulthood. Our aim was to evaluate the association between vitamin D status and cardiometabolic risk factors in adolescents with overweight living in a sunny urban region in northeastern Brazil.

MATERIALS AND METHODS

STUDY DESIGN

The cross-sectional study was approved by the Federal University of Rio Grande do Norte (UFRN) Research Ethics Committee (protocol number 1.614.945; CAAE 56763716.7.0000.5292), which complies with the Declaration of Helsinki. All participants completed and signed an informed consent form.

A total of 125 adolescents, of both sexes, diagnosed as overweight or obese, and who attended for the first time the Pediatric Clinic of a Federal University Hospital in Natal, RN, between September 2016 and November 2018, were enrolled (Fig. 1).

CLINICAL EVALUATION

During clinical evaluation, data on family, personal pathological antecedents, and sexual maturation were collected. The study included adolescents who 1) were between 10 and 19 years old, 2) had normal physical and cognitive functions, and 3) presented with a nutritional status classified as overweight or obese. The exclusion criteria were 1) presence of genetic syndromes associated with obesity or other diseases, 2) pregnant and lactating women, 3) use of vitamins and mineral supplements, 4) use of drugs to treat insulin resistance or type-2 diabetes *mellitus,* and 5) adolescents presenting with some pathology impairing vitamin D metabolism (e.g., chronic renal failure, cancer, and heart failure).

Participants were classified in two groups: prepubertal (stage 1) and pubertal (stages 2 to 5) (16). Systolic and diastolic blood pressure was determined according to the protocols established by the 7th Brazilian Guideline on Hypertension (17).

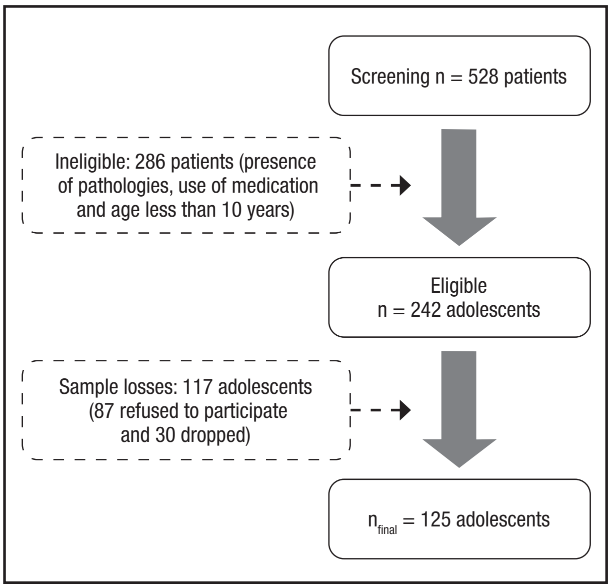

Figure 1.
Recruitment of participants.

ANTHROPOMETRIC EVALUATION

Anthropometric data on weight and height were collected according to Lohman et al. (1988) (18). BMI was calculated and the classification of anthropometric nutritional status was performed using the BMI-for-age anthropometric index (19). Abdominal circumference was measured to estimate cardiovascular risk based on the classification proposed by Taylor et al. (2000) (20) for adolescents (16). Neck circumference was measured and used to classify participants according to the cut-off points adapted for adolescents (21). All measurements were performed in duplicate by trained examiners.

BIOCHEMICAL ANALYSES

Blood samples were collected after fasting for 10 to 12 h. Fasting blood glucose, total cholesterol and its fractions, triglycerides, calcium, phosphorus, and C-reactive protein was analyzed using Wiener kits (Wiener Laboratories, Rosario, Argentina) following the manufacturer's instructions, and using the CMD-800 biochemical analyzer (Wiener Laboratories, Rosario, Argentina). Insulin and PTH were analyzed with the chemiluminescence method (Kit Liason XL, Diasorin, Stillwater, MN, USA).

Serum 25(OH)D was analyzed using the electrochemiluminescence method (COBAS 6000 Series Modular Analyzer, Mannheim, Germany). The 25(OH)D status was diagnosed according to the recommendation established by the Endocrine Society using the following reference values: deficiency, if 25(OH)D ≤ 20 ng/mL; insufficiency, if 25(OH)D between 21 and 29 ng/mL; and sufficiency, if 25(OH)D ≥ 30 ng/mL (22). Participants were stratified into two groups: 1) sufficiency, which included those with 25(OH)D ≥ 30 ng/mL, and 2) hypovitaminosis D, which included those with 25(OH)D deficiency and 25(OH)D insufficiency.

IR was assessed using the homeostasis model assessment for insulin resistance (HOMA-IR). A HOMA-IR cut-off point > 3.16 was established for the diagnosis of IR (23). To assess the lipid profile, we applied the reference values recommended by the Update of the Brazilian Dyslipidemia and Atherosclerosis Prevention Directive (2017) for adolescents (24); low-density lipoprotein cholesterol was calculated using Friedewald's formula.

MS diagnostic criteria for adolescents were used according to the International Diabetes Federation (2007) (25). Adolescents between 10 and 16 years of age with abdominal obesity (≥ 90th percentile) and the presence of two or more of the following factors are considered to have metabolic syndrome: triglycerides > 150 mg/dL, HDL < 40 mg/dL, fasting glucose > 100 mg/dL and PA > p95.

SUN EXPOSURE AND PHYSICAL ACTIVITY

We assessed the adolescents' exposure to sunlight using the questionnaire proposed by Hanwell (2010) (26). We also investigated the adolescents' frequency of sunscreen application on different parts of the body and the performance of physical activity in the sun. The skin phototype was classified from I to VI, as proposed by Toda et al. (1973) and referred to by Astner and Anderson (2004) (27). Physical activity was assessed using the questionnaire developed and validated by Florindo et al. (2006) (28).

STATISTICAL ANALYSIS

The distribution of variables was analyzed using the Kolmogorov-Smirnov test. The data are presented as average or median, when appropriate. The Shapiro-Wilk test was used for statistical analysis. The frequency of hypovitaminosis D [25(OH)D ≤ 30 ng/mL] was calculated based on the sample proportion, with a 95 % confidence interval (CI) and a 5 % margin of error. Student's *t*-test was performed for continuous variables with normal distribution in the groups.

Categorical variables were analyzed descriptively using absolute and relative frequencies and Pearson's chi-square test or Fisher's exact test were applied. Spearman's correlation was performed to assess the relationship between the dependent variable 25(OH)D and other continuous variables in the study. The binomial logistic regression model was applied to determine the effect of some of the tested variables in predicting hypovitaminosis D. Sexual maturation was used as an adjustment variable. The general statistical significance of the model was assessed by the Omnibus test. Interpretation of the adjusted models was based on the odds ratio (OR) and 95 % CI. The SPSS software version 20.0 (SPSS, Chicago, IL, USA) was employed, and a significance level of 5 % was adopted for all analyses.

RESULTS

GENERAL CHARACTERISTICS OF ADOLESCENTS WITH OVERWEIGHT ACCORDING TO 25(OH)D STATUS

We identified a high frequency of hypovitaminosis D (45.6 %) among adolescents with overweight. The average concentration of 25(OH)D was 32.73 (± 10.03) ng/mL in the total sample; however, the value was 39.39 (± 8.25) ng/mL in the sufficiency group and 24.38 (± 4.01) ng/mL in the hypovitaminosis D group. Table I lists the bio-demographic characteristics and lifestyle habits of adolescents with overweight and classifies them according to their 25(OH)D status. A statistically significant increase in hypovitaminosis D was recorded in all age groups (p = 0.024), except the first one (10-11 years). None of the other demographic parameters, such as exposure to sun, use of protective cream, skin color or sexual maturation were significantly different between the two groups.

Table I. Bio-demographic and lifestyle variables in adolescents with overweight grouped according to 25(OH)D status

Variable	25(OH)D Status		c^2	p-value
	Sufficiency > 30 ng/mL (n = 68)	Hypovitaminosis D ≤ 30 ng/mL (n = 57)		
	n (%)	n (%)		
Gender				
Male	40 (58.8)	25 (43.9)	2.78	0.095
Female	28 (41.2)	32 (56.1)		
Age (years)				
10–11	50 (73.5)	29 (50.9)	7.45	*0.024*[*a]
12–13	13 (19.1)	17 (29.8)		
≥ 14	5 (7.4)	11 (19.3)		
*Sexual maturation**				
Prepubertal	7 (17.1)	17 (34.0)	3.45	0.178
Initial pubertal	21 (51.2)	19 (38.0)		
Final pubescent	13 (31.7)	14 (28.0)		
Physical activity				
Active (≥ 300 min/week)	20 (29.4)	12 (21.1)	1.14	0.286
Inactive (< 300 min/week)	48 (70.6)	45 (78.9)		
Use of sunscreen				
Yes	11 (16.2)	6 (10.5)	0.84	0.359
No	57 (83.8)	51 (89.5)		
Exposure to sun during physical activity				
Yes	30 (44.1)	16 (28.1)	3.43	0.064
No	38 (55.9)	41 (71.9)		
Self-reported skin color				
White	14 (20.6)	10 (17.5)	0.58	0.966[b]
Black	9 (13.2)	7 (12.3)		
Brown	38 (55.9)	35 (61.4)		
Yellow	2 (2.9)	2 (3.5)		
Indigenous	5 (7.4)	3 (5.3)		
Skin phototype				
I	2 (3.0)	0 (0.0)	4.47	0.484[c]
II	10 (14.7)	5 (8.8)		
III	16 (23.5)	10 (17.5)		
IV	30 (44.1)	31 (54.4)		
V	9 (13.2)	9 (15.8)		

*Significance levels at *p < 0.05, based on the chi-square test. [a]Cramer's V = 0.24. [b]40 % of cells have an expected frequency below 5 according to Fisher's exact test. [c]33 % of cells have an expected frequency below 5 according to Fisher's exact test. *Multiple imputations for missing data.*

CLINICAL, ANTHROPOMETRIC, AND BIOCHEMICAL VARIABLES ASSOCIATED WITH 25(OH)D

The association between 25(OH)D status and the clinical, anthropometric, and biochemical variables of adolescents with overweight is shown in table II. Compared to the 25(OH)D sufficiency group, adolescents in the hypovitaminosis D group presented a higher incidence of elevated blood pressure according to the 95^{th} percentile (22.8 %; p = 0.006). In addition, there was a tendency for the group with hypovitaminosis D to include more adolescents diagnosed with MS (38,6 %; p = 0.068); neck circumference (61.4 %; p = 0.016) and elevated HOMA-IR (38.6 %; p = 0.016) were also significantly different between adolescents with hypovitaminosis D and the 25(OH)D sufficiency group.

Table II. Association between 25(OH)D status and cardiometabolic risk factors in adolescents with overweight

Variable	25(OH)D Status		c^2	p-value
	Sufficiency > 30 ng/mL (n = 68)	Hypovitaminosis D ≤ 30 ng/mL (n = 57)		
	n (%)	n (%)		
Blood pressure (mmHg)				
< 95^{th} percentile	64 (94.1)	44 (77.2)	7.56	*0.006*[*b]
> 95^{th} percentile	4 (5.9)	13 (22.8)		
Arterial pressure (mmHg)				
< 130 × 85	64 (94.1)	44 (77.2)	7.56	*0.006*[*b]
> 130 × 85	4 (5.9)	13 (22.8)		
Metabolic syndrome				
< 3 criteria	52 (76.5)	35 (61.4)	3.33	0.068
≥ 3 criteria	16 (23.5)	22 (38.6)		
BMI (kg/m²)				
Overweight	19 (28.0)	14 (24.6)	3.58	0.167
Obesity	46 (67.6)	35 (61.4)		
Severe obesity	3 (4.4)	8 (14.0)		
Abdominal circumference (cm)				
< 80^{th} percentile	4 (5.9)	4 (7.0)	0.07	1.00[b]
> 80^{th} percentile	64 (94.1)	53 (93.0)		
Neck circumference (cm)				
Men < 35,5; Women < 32	41 (60.3)	22 (38.6)	5.84	*0.016*[*a]
Men > 35,5; Women > 32	27 (39.7)	35 (61.4)		
Fasting blood glucose (mg/dL)				
≤ 99	53 (77.9)	47 (82.5)	0.39	0.530
> 99	15 (22.1)	10 (17.5)		
Fasting insulin				
< 23	67 (98.5)	54 (94.7)	1.44	0.330[c]
> 23	1 (1.5)	3 (5.3)		
HOMA-IR index				
< 3.16	55 (80.9)	35 (61.4)	5.84	*0.016*[*a]
> 316	13 (19.1)	22 (38.6)		
Total cholesterol (mg/dL)				
< 170	33 (48.5)	29 (50.9)	0.07	0.794
≥ 170	35 (51.5)	28 (49.1)		
LDL-cholesterol (mg/dL)				
< 110	39 (57.4)	33 (57.9)	0.004	0.951
≥ 110	29 (42.6)	24 (42.1)		

(Continues on next page)

Table II (Cont.). Association between 25(OH)D status and cardiometabolic risk factors in adolescents with overweight

Variable	25(OH)D Status		c^2	p-value
	Sufficiency > 30 ng/mL (n = 68)	Hypovitaminosis D ≤ 30 ng/mL (n = 57)		
	n (%)	n (%)		
HDL-cholesterol (mg/dL) > 45 ≤ 45	 22 (32.4) 46 (67.6)	 10 (17.5) 47 (82.5)	3.57	0.059
Triglycerides (mg/dL) < 90 ≥ 90	 29 (42.6) 39 (57.4)	 17 (29.8) 40 (70.2)	2.19	0.139
Serum calcium (mg/dL) ≤ 11 > 11	 52 (76.5) 16 (23.5)	 44 (77.2) 13 (22.8)	0.009	0.924
PTH (pg/mL) < 67 > 67	 55 (91.7) 5 (8.3)	 42 (89.4) 5 (10.6)	0.16	0.746[c]
Phosphorus (mg/dL) ≥ 4.5 < 4.5	 58 (85.3) 10 (14,7)	 45 (78.9) 12 (21.1)	0.86	0.353
C-reactive protein (mg/L) < 5 > 5	 55 (80.9) 13 (19.1)	 50 (87.7) 7 (12.3)	1.08	0.299

*BMI: body mass index; HDL: high-density lipoprotein; HOMA-IR: homeostasis model assessment for insulin resistance; LDL: low-density lipoprotein; PTH: parathyroid hormone. Significance levels at *p < 0.05, based on the chi-square test. [a]Φ = 0.22. [b]Φ = 0.25. [c]Fisher's test was applied.*

CORRELATIONS BETWEEN VITAMIN D STATUS AND DIFFERENT PARAMETERS

Table III shows correlations between vitamin D status and different parameters. Significant positive correlations were found between 25(OH)D status, weekly sunlight exposure (score) (p = 0.000; r = 0.321), and physical activity (weekly score) (p = 0.034; r = 0.189), indicating a low sun exposure and physical inactivity for the adolescents in this study. In addition, we identified negative correlations between 25(OH) D status and body weight (p = 0.008; r = -0.236), neck circumference (p = 0.025; r = -0.200), fasting insulin (p = 0.000; r = - 0.375), HOMA-IR index (p = 0.000; r = -0.386), and PTH (p = 0.020; r = -0.229).

Table III. Correlations between 25(OH)D status and different parameters in adolescents with overweight

	25(OH)D status	
Variable	**R**	**p-value**
Sun exposure (weekly score)	0.321	0.000*
Physical activity practice (weekly score)	0.189	0.034*
Body weight (kg)	-0.236	0.008*
Systolic blood pressure (mmHg)	-0.288	0.001*
Neck circumference (cm)	-0.200	0.025*
Fasting insulin (µIU/mL)	-0.375	0.000*
Homa-IR index	-0.386	0.000*
PTH (pg/mL)	-0.229	0.020*

*Data were analyzed using Spearman's correlation. Statistical significance was determined for *p < 0.05.*

PREDICTING HYPOVITAMINOSIS D IN ADOLESCENTS WITH OVERWEIGHT

Table IV shows the logistic regression model as adjusted to predict hypovitaminosis D in adolescents with overweight. We recorded a significant negative association between weekly sunlight exposure (OR = 0.960; 95 % CI, 0.923-0.999) and hypovitaminosis D, and significant positive associations between body weight (OR = 1.040; 95 % CI, 1.012-1.069) and fasting insulin (OR = 1.133; 95 % CI, 1.049-1.224) as predictors of hypovitaminosis D. Specifically, adolescents with blood pressure > 95th percentile and those with arterial hypertension (diagnostic criterion for MS) exhibited a four times greater chance of hypovitaminosis D (OR = 4.005; 95 % CI, 1.199-13.375 and OR = 4.727; 95 % CI, 1.446-15.455, respectively). Finally, the linear regression model confirmed the association between elevated blood pressure and hypovitaminosis D observed by the classification of the 95th percentile and MS criteria.

Table IV. Logistic regression model adjusted to predict hypovitaminosis D in adolescents with overweight

Variable	B	SE	p-value	OR	IC 95 % for OR	
					Inferior	Superior
Weekly sun exposure	-0.041	0.020	0.045*	0.960	0.923	0.999
Constant	0.292	0.381	0.443	1.339	0.292	
Body weight (kg)	0.039	0.014	0.006*	1.040	1.012	1.069
Constant	-2.624	0.901	0.004*	0.073		
Fasting insulin (µIU/mL)	0.125	0.039	0.002*	1.133	1.049	1.224
Constant	-1.577	0.479	0.001*	0.207		
Blood pressure[a]	1.388	0.615	0.024*	4.005	1.199	13.375
Constant	0.292	0.381	0.443	1.339	0.292	
Blood pressure[b]	1.553	0.604	0.010*	4.727	1.446	15.455
Constant	-0.375	0.196	0.056*	0.688		

*B: regression coefficient; SE: standard error; OR: odds ratio = Exp (B); CI: confidence interval. *p < 0.05. [a]Reference category: < 95th percentile. [b]Reference category: MS < 130 × 85. Sexual maturation was a control variable.*

DISCUSSION

Our study identified a high prevalence of hypovitaminosis D among adolescents with excess weight and consequent metabolic changes, such as higher percentages of blood pressure, higher prevalence of metabolic syndrome, greater body weight, higher neck circumference, hyperinsulinemia, and insulin resistance.

We identified an association between individual nutritional status and vitamin D concentrations in the adolescents evaluated. Although our population was composed only of individuals with overweight, after the adjusted analysis high body weight augmented by 1.04 times the chance of adolescents presenting with hypovitaminosis D. This relationship of vitamin D with excess weight and a greater deposition of body fat can be explained by its fat-soluble nature, which can favor uptake by the adipose tissue, decreasing bioavailability and activation of the hypothalamus to develop a cascade of reactions that results in an increased feeling of hunger and decreased energy expenditure (6). Similar results were also confirmed in the study by Oliveira et al. (2014) (29), who evaluated a population of adolescents aged 15 to 17 years and demonstrated that vitamin D levels were lower in adolescents with overweight and abdominal obesity.

Although the high prevalence of hypovitaminosis D has been evident throughout the world, the determinants of this phenomenon are not yet fully understood. It is known that the major part of vitamin D synthesis in the body is due to exposure to the sun (80 %); hence, places that remain sunny for most of the year, such as the northeastern region of Brazil, should have a low prevalence of hypovitaminosis D. However, we identified significant positive correlations between the 25(OH)D status and weekly sun exposure or the participation in physical activity (weekly score). This indicates that in spite of living in a sunny region all year round, these adolescents have adopted life habits of sedentary individuals that predispose them to hypovitaminosis D. These findings corroborate the study by Araújo et al. (2016) (30), who also identified a high prevalence of hypovitaminosis D in adolescents in a sunny capital of northeastern Brazil.

Other anthropometric parameters, in addition to weight and BMI, have been studied in the adolescent population as indicators of cardiometabolic risk. In our study, a large neck circumference was more frequent in adolescents with hypovitaminosis D. Neck perimeter has been used as a simpler but more reliable anthropometric indicator than waist circumference, and its increase is associated with cardiometabolic risks as strongly as is abdominal visceral fat (31). The BCAMS study, involving a cohort of individuals aged 14 to 28 years, found that concentrations of 25(OH)D were negatively correlated with neck circumference and body fat percentage, and that levels of 25(OH)D were significantly lower in participants with obesity or MS compared to their respective counterparts (32). Such data reinforce that vitamin D deficiency is more common in the population of young people who are at risk of MS; however, the mechanisms that justify this relationship still need to be elucidated in additional studies.

In general, changes in weight and body composition are associated with the appearance of complications such as hypertension and insulin resistance. The tested sample confirmed an association between being overweight and HOMA-IR. Such relationship may be linked to the increased anabolic effect of insulin and growth hormone during puberty (33). In addition, our findings agree with reports of a high prevalence of IR in female adolescents (34,35). The different prevalence of IR between the sexes can be explained, in part, by differences in the distribution of body fat or pubertal stage, as girls usually enter puberty about two years before boys, this justifying the investigation of the relationship between puberty as a control variable (36).

The negative correlation between low vitamin D concentrations and high insulin values shown in our study was also found by Gul et al. (2017), demonstrating the influence of vitamin D on the mechanisms underlying IR and hyperinsulinemia (37). The latter is a predictor of hypovitaminosis D in adolescents, which confirms the influence of hypovitaminosis D on the calcium-PTH axis and its role in the pathogenesis of diabetes *mellitus* type 2 (38).

It is worth noting that hyperinsulinemia contributes also to increased blood pressure, meaning that primary prevention measures for cardiometabolic risk factors should be implemented in adolescents (34). Morais et al. (2016) observed a significant association between IR and blood pressure and the impact of IR on blood pressure (34). Other studies also indicate that adolescents with IR are at higher risk of having altered blood pressure (13,15).

We confirmed the results of the association between hypovitaminosis D and presence of SAH in the adjusted analysis of the linear regression model. In our population, adolescents with blood pressure higher than the 95^{th} percentile were about four times more likely to develop hypovitaminosis D when compared to others. Some evidence shows that vitamin D can participate in the regular renin-angiotensin-aldosterone system at clinical, pathophysiological, and molecular levels in animal and human studies (39).

The present study has also some limitations. First, it is a cross-sectional study carried out without continuous monitoring of participants, which prevented further clarification of how some risk factors impacted on vitamin D status. Second, the questionnaire used to assess the sun exposure score had not been validated for adolescents. Third, even though diet has a negligible impact on the concentration of 25(OH)D, the study did not assess the influence of food and dietary intake on vitamin D status. Finally, memory bias could influence the recollection of weekly physical activity and sun exposure supplied in the questionnaires.

CONCLUSIONS

Taken together, the present results indicate a high prevalence of hypovitaminosis D in adolescents, and important associations between cardiometabolic risk factors such as SAH, high body weight, and hyperinsulinemia with hypovitaminosis D. Such correlations emphasize the urgent need for public policies aimed at preventing and treating adolescents with overweight, as well as monitoring cardiometabolic risk factors and hypovitaminosis D in this age group.

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