U.PORTO

Association between Urinary Sodium Excretion and Body Fat in School-Aged Children: Insights from the ARIA Study

Associação entre a Excreção Urinária de Sódio e Gordura Corporal em Crianças em Idade Escolar: Conclusões do estudo ARIA

Ana Patrícia Ruivo Soares

ORIENTADO POR: MESTRE MÓNICA CAROLINA RODRIGUES
COORIENTADO POR: DR.ª TERESA MARIA DA SILVA THEMUDO

TRABALHO DE INVESTIGAÇÃO
1.º CICLO EM CIÊNCIAS DA NUTRIÇÃO | UNIDADE CURRICULAR ESTÁGIO
FACULDADE DE CIÊNCIAS DA NUTRIÇÃO E ALIMENTAÇÃO DA UNIVERSIDADE DO PORTO

TC

Porto, 2024

Abstract

Childhood obesity has been associated with increased sodium intake. Nonetheless, evidence linking sodium intake to Body Mass Index (BMI) and Body Fat Mass Percentage (%BF) remains limited, especially in pediatric age. Therefore, this study aims to investigate whether there is an association between 24-hour urinary sodium excretion with BMI and %BF in a sample of school-aged children. This cross-sectional analysis included 303 children aged 7 to 12 from 20 public schools in Porto, Portugal. Weight and %BF were assessed using the Tanita™ BC-418 Segmental Body Analyzer. Total Energy Intake (TEI) of the children was estimated through a single 24-Hour Food Recall Questionnaire, and urinary sodium and potassium excretion was estimated by 24-hour urine collection. The association between 24-hour sodium excretion with %BF and BMI was estimated by binary logistic regression adjusted for sex, age, physical activity, TEI, parental education, and 24-hour urinary excreted potassium. There is a significant positive association between higher levels of urinary sodium excretion and higher %BF values, even after adjusting for confounders. However, the same is not observed for BMI. Our findings suggest that higher sodium intake is associated with higher values of %BF among children, regardless of TEI and potassium intake.

Keywords: Children; Sodium; Energy Intake; Body Fat Mass Percentage; Body Mass Index

Resumo

A obesidade infantil tem sido associada ao aumento da ingestão de sódio. No entanto, a evidência que associa a ingestão de sódio ao Índice de Massa Corporal (IMC) e à Percentagem de Massa Gorda (%MG) permanece limitada, especialmente em idade pediátrica. Assim, este estudo tem como objetivo investigar se existe uma associação entre a excreção urinária de sódio de 24 horas com o IMC e a %MG em uma amostra de crianças em idade escolar. Esta análise transversal incluiu 303 crianças com idades entre os 7 e 12 anos de 20 escolas públicas no Porto, Portugal. O peso e a %MG foram avaliados usando a Balança Corporal Segmentar Tanita™ BC-418. A Ingestão Energética Total (IET) das crianças foi estimada através de um questionário alimentar às 24 horas anteriores, e a excreção urinária de sódio e potássio foi estimada pela colheita de urina de 24 horas. A associação da %MG e do IMC com a excreção de sódio de 24 horas foi estimada por regressão logística binária ajustado para o sexo, idade, atividade física, IET, educação dos pais e excreção urinária de potássio de 24 horas. Existe uma associação positiva significativa entre níveis mais elevados de excreção de sódio urinário e valores mais elevados de %MG, mesmo após o ajuste para os confundidores. No entanto, o mesmo não é observado para o IMC. Os nossos resultados sugerem que uma maior ingestão de sódio está associada a valores mais elevados de %MG em crianças, independentemente da IET e da ingestão de potássio.

Palavras-chave: Crianças; Sódio; Ingestão de energia; Percentagem de Massa Gorda Corporal; Índice de Massa Corporal

List of Abbreviations, Acronyms, and Initialisms

aOR – adjusted Odds Ratio

%BF - Body Fat Mass Percentage

BIA - Bioelectrical Impedance Analysis

BMI – Body Mass Index

CDC – Centers for Disease Control and Prevention

CI – Confidence Interval

DEXA - Dual-energy x-ray absorptiometry

EFSA- European Food Safety Authority

OR – Odds Ratio

TEI – Total Energy Intake

Contents

Introduction

Childhood obesity is a complex public health issue affecting most developed countries and can be characterized by an excessive or abnormal accumulation of body fat[1, 2]. This chronic disease is responsible for a series of complications that contribute to increased morbidity and premature mortality, with inadequate nutrition and physical inactivity being the main contributors to its cause[2].

Sodium intake has emerged as a critical aspect of childhood nutrition, and numerous studies have been conducted in different countries showing that children and adolescents tend to consume more sodium than recommended[3]. This trend is particularly concerning given the well-established association between high sodium intake and elevated blood pressure, a significant precursor to the development of cardiovascular diseases[4, 5]. Furthermore, there has been a notable escalation in childhood obesity rates[6, 7], concomitant with heightened sodium intake within this age group[8]. Based on the COSI Portugal 2022 study, despite a reversed trend in the prevalence of childhood overweightedness and obesity in Portugal from 2008 to 2019, the same was not observed in 2022. In fact, between 2019 and 2022, there was an increase of 2.2 and 1.6 percentage points in the prevalence of childhood overweightedness and obesity, respectively[9].

Evidence shows that it is highly recommended to estimate sodium intake from 24h urinary excretion, as it is a more precise marker of sodium intake[10], which appears to be associated with adiposity[11] and an increased risk of obesity[12, 13]. It has been demonstrated that an increase in salt intake by 1 g/day is associated with a 27 g/day increase in the consumption of sugary sodas in children and adolescents[14]. Therefore, this association between salt and obesity may be partly explained by the excessive consumption of energy-rich and salty processed foods[15]. However, growing evidence suggests that there may be a direct relationship between salt intake and obesity, independent of energy intake[16-21].

Body mass index (BMI) has been widely used in large-scale population research and public or clinical health screenings as a surrogate measure for fat mass content[22, 23]. However, BMI may not be the most effective indicator for measuring adiposity[24], as evidenced in a meta-analysis where BMI showed high specificity but low sensitivity in detecting excess adiposity in children[25]. For this reason, the body fat mass percentage (%BF) has been commonly used as a more reliable index of adiposity[22]. Moreover, for %BF, which is a better predictor of adverse health effects such as cardiovascular risk factors[26], obesity[27], and unfavorable lipid profile[28], research remains scarce.

Thus, despite only a few studies demonstrating a direct association between sodium intake and BMI and %BF, independently of energy intake[15, 18], these are inexistent using more precise measures of sodium and potassium intake in children.

Objectives

This study aimed to examine the association between 24-hour urinary sodium excretion, BMI, and %BF, independently of total energy intake, in a sample of school-aged children from the ARIA study.

Methodology

Ethics

The study was approved by the Ethics Committee of the University Hospital São João (ARIA 248-13), and written consent was obtained from the legal guardian of each child. Furthermore, the research was conducted in accordance with the Helsinki Declaration.

Participants and Study Design

The population sample for this study was drawn from a cross-sectional survey carried out between January 2014 and March 2015. Specifically, 1602 children, aged between 7 and 12 years old, enrolled in the 3rd and 4th grades across 20 public schools situated in Porto, Portugal, were extended invitations to participate[(29)]. Of the 1602 children, 686 (42.8%) did not provide signed consent, and 58 (3.6%) did not authorize clinical procedures. Among the remaining 858 children (53.6%), 348 (21.7%) had a valid urine sample, but only 303 (18.9%) were included in the analysis, as only those had a valid 24-hour food recall questionnaire (Figure 1).

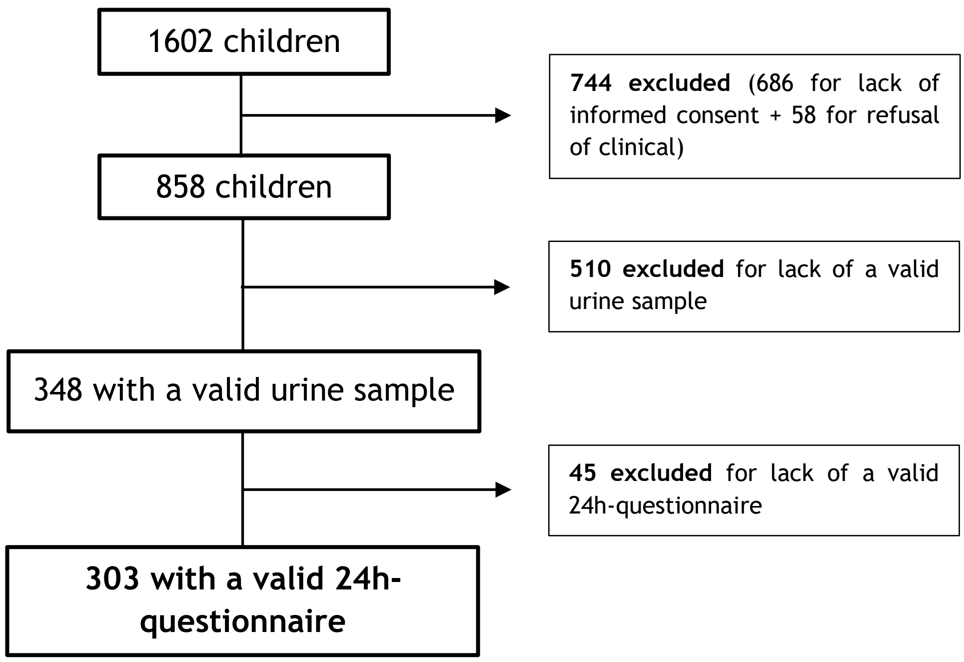

Figure 1. Summary of the participant inclusion process.

Material and Methods

Total Energy Intake Assessment

The collection of dietary and nutritional information from the children was conducted by a trained interviewer through a single 24-Hour Food Recall Questionnaire, using well-established procedures and a photographic atlas to assist in estimating portion sizes(30). This questionnaire included detailed questions about the foods and beverages consumed during this period, including information on quantities and brands(30). Food Processor® software, manufactured by ESHA Research in the United States, SQL®, V3, which integrates detailed data on the nutritional composition of Portuguese foods, was used to estimate total energy intake (TEI). Subsequently, for the validation of the 24-Hour Food Recall Questionnaires, the Goldberg criteria was employed to detect and exclude "misreporters", children with inaccurate reports in the questionnaire(31).

24-Hour Urine Collection

Regarding the 24-hour urine collection, verbal and written instructions were provided to caregivers or parents to assist in collecting the 24-hour urine sample from the children, along with a sterile urine collection container. On the first morning of collection, they were instructed to discard the initial sample and subsequently collect all samples, including the first sample of the next day, over a 24-hour period. The collected samples were then sent for analysis to certified laboratories, where testing was conducted for 24-hour creatinine (mg/day), 24-hour urine volume (ml), 24-hour potassium excretion (mEq/day), and 24-hour sodium excretion (mEq/day). The values of sodium and potassium in urine were converted to mg/day using the following formulas, respectively: 23 mg of Na^+ = 1 mmol of Na^+ or 1 mEq of Na^+(32), and 39.1 mg of K^+ = 1 mmol of K^+ or 1 mEq of

K^{+}[33]. To assess the validity of the 24-hour urine collections, creatinine coefficients were used, such as creatinine excretion in relation to weight, with creatinine coefficients above 0.1 mmol/kg/day classified as acceptable[34].

Urinary sodium levels were categorized into two distinct groups based on the median value observed within our sample. Specifically, individuals were categorized as either having lower urinary sodium levels (≤2507) or higher urinary sodium levels (>2507). Additionally, for estimating sodium consumption, it was assumed that approximately 90% of consumed sodium is excreted in the urine[35].

Anthropometric Measurements and Body Fat Mass Percentage

In terms of anthropometry, bioelectrical impedance analysis was applied using a digital scale (Tanita™ BC-418 Segmental Body Analyzer, Middlesex, UK) in order to obtain weight in kilograms and body fat percentage. A portable stadiometer (SECA® 214) was used to measure height in centimeters. This measure was done according to standardized procedures described elsewhere[36]. The BMI was calculated from weight and height data as the ratio of weight to height squared, in kilograms per square meter (kg/m^2). Participants were then divided into two groups: non-overweight/obese ($P<85^{th}$) and overweight/obese ($P\geq85^{th}$), based on specific BMI percentiles for sex and age from the Centers for Disease Control and Prevention (CDC)[37]. This definition was used following an evaluation of the level of agreement among various BMI classifications, including those from the CDC, World Health Organization, International Obesity Task Force, and Percentage of Body Fat. The analysis revealed that the BMI classification from the CDC demonstrated the strongest agreement with all other classification systems[38]. Moreover, individuals were characterized according to %BF using age- and sex-specific percentile curves for children's body fat[39]. Thresholds were established at the 85th percentile to delineate categories of under-fat/normal fat (<85th) and overfat/obese (≥85th), respectively[39].

Other Covariates

The children's physical activity level was assessed and categorized into three groups: <2 times/week, 2–3 times/week, or ≥4 times/week. The evaluation was conducted through a questionnaire on participation in sports activities, excluding physical education classes at school, distributed to each parent or guardian. Parental education level was also considered and categorized into three groups: ≤9 years, 10 to 12 years, and >12 years of education[40].

Statistical Analysis

The statistical analysis was performed using SPSS® software version 28.0. Initially, the normality of continuous study variables was assessed using skewness and kurtosis tests, considering the range of values from -1 to 1. Moreover, absolute and relative frequencies for all categorical variables were presented. For quantitative variables, the median and the 25-75 percentiles were chosen due to non-normal distribution.

Subsequently, to investigate differences between children without and with overweight/obesity, as well as with body fat percentage above or below the P85th, the Mann-Whitney test was used for quantitative non-normally distributed variables, and the Chi-square test for categorical variables.

Regarding the assessment of the association between urinary sodium excretion with BMI and %BF, a binary logistic regression models were employed (odds ratio (OR)), with a 95% confidence interval (CI), adjusting for confounders. Finally, the null hypothesis was rejected when the significance level was <0.05 (p<0.05).

Results

The characteristics of the participants included in the study are presented in Table 1, by the total number of participants (n=303) and the following groups: "non-overweight/non-obesity"(P<85th)/"overweight/obesity"(P≥85th) and %BF considered to be "under fat/normal fat"(P<85th)/%BF considered to be "overfat/obese"(P≥85th).

Table1. Main characteristics of the study sample according overweight/obesity and body fat mass percentage.

	Total, n=303 (100%)	**Non-overweight/ non-obese(P<85th), n=231**	**Overweight/ obese(P≥85th), n=72**	***p*-value**	**%BF (P<85th), n=209**	**%BF (P≥85th), n=90**	***p*-value**
Age (years), median (25th-75th)	8 (8-9)	8 (8-9)	8 (8-9)	0.911	8 (8-9)	8 (8-9)	0.153
Sex, n (%)							
Female	141 (46.50%)	110 (47.60%)	31 (43.10%)	0.498	103 (49.30%)	36 (40.00%)	0.140
Male	162 (53.50%)	121 (52.40%)	41 (56.90%)		106 (50.70%)	54 (60.00%)	
Total Energy Intake (kcal), Median (25th-75th)	2178.67 (1890.28-2510.45)	2173.15 (1864.01-2519.32)	2222.42 (1943.68-2491.09)	0.518	2175.19 (1873.54-2519.66)	2199.22 (1901.25-2507.39)	0.829
24-Hour Urinary Sodium Excretion (mg), Median (25th-75th)	2507.00 (1909.00-3151.00)	2392.00 (1886.00-3059.00)	2725.50 (2087.25-3680.00)	0.016*	2300.00 (1863.00-3024.50)	2760.00 (2236.75-3622.50)	0.001*
24-Hour Urinary Potassium Excretion (mg), Median (25th-75th)	1681.30 (1368.50-2111.40)	1642.20 (1290.30-2072.30)	1915.90 (1485.80-2189.60)	0.020*	1642.20 (1290.30-2052.75)	1720.40 (1466.25-2189.60)	0.057
Ratio Na/K	2.52 (1.99-3.29)	2.51 (2.00-3.26)	2.60 (1.91-3.38)	0.928	2.46 (1.98-3.21)	2.66 (2.00-3.54)	0.111
Physical Activity, n (%)							
<2 times/week	131 (47.00%)	100 (47.20%)	31 (46.30%)	0.985	85 (45.00%)	44 (51.20%)	0.622
2-3 times/week	108 (38.70%)	82 (38.70%)	26 (38.80%)		76 (40.20%)	30 (34.90%)	
≥4 times/week	40 (14.30%)	30 (14.20%)	10 (14.90%)		28 (14.80%)	12 (14.00%)	

Parental education, n (%)							
≤9 years	103 (37.30%)	71 (33.80%)	32 (48.50%)		64 (34.00%)	36 (42.90%)	
10-12 years	71 (25.70%)	54 (25.70%)	17 (25.80%)	0.054	49 (26.10%)	21 (25.00%)	0.336
>12 years	102 (37.00%)	85 (40.50%)	17 (25.80%)		75 (39.90%)	27 (32.10%)	

Note: * denotes a statistically significant association. To exist significant differences: p-value must be less than 5% with a 95% confidence interval.

The median age of the children was 8 (8-9) years, and 53.50% (n=162) were male. There are no significant differences between children without overweight/obesity (P<85th) and those with overweight and obesity (P≥85th), except for 24-hour urinary sodium excretion values [2392.00 (1886.00-3059.00) vs 2725.50 (2087.25-3680.00)], and 24-hour urinary potassium excretion levels [1642.20 (1290.30-2072.30) vs 1915.90 (1485.80-2189.60)]. In the sense that children in the overweight/obesity group have higher values of sodium and potassium, children with higher %BF values exhibit significantly elevated 24-hour urinary sodium excretion values compared to children with underfat/normal fat values [2300.00 (1863.00-3024.50) vs 2760.00 (2236.75-3622.50)].

Regarding the relationship between excreted sodium with BMI, a significant positive association was observed in the crude model (OR=2.04, 95% CI 1.18-3.50), which did not persist after adjusting for sex, age, TEI, physical activity, parental education, and urinary excreted potassium (adjusted Odds Ratio (aOR)=1.56, 95% CI 0.82-2.96). However, in the case of body fat mass percentage, %BF (≥P85th), we can observe that children with increased urinary sodium excretion levels have higher odds of having higher %BF values in the crude model (OR=2.62, 95% CI 1.56-4.38), as well as after adjusting for previously referred confounders, (aOR=2.89, 95% CI 1.58-5.30). The results are presented in Table 2.

Table 2. Analysis of the association between overweight/obesity and body fat mass percentage (%BF) (P≥85th) with excreted sodium.

	Excreted sodium (>2507 mg), crude model, OR (95% CI)	*p*-value	Excreted sodium (>2507 mg), adjusted model, aOR (95% CI)	*p*-value
Overweight/obese (P≥85th)	2.04 (1.18-3.50)	0.010*	1.56 (0.82-2.96)	0.172
%BF (P≥85th)	2.62 (1.56-4.38)	<0.001*	2.89 (1.58-5.30)	<0.001*

Note: Logistic regression was adjusted for sex, age, total energy intake, physical activity, parental education, and excreted potassium. * denotes a statistically significant association.

Discussion

This study presents novel findings showing that higher urinary sodium excretion levels were associated with an increased %BF in children, considering potential confounding factors such as energy intake and potassium urinary excretion, a crucial factor in sodium balance regulation[(41)]. The relationship between obesity and sodium intake has been previously explained by increased liquid intake, particularly sugary drinks, and excessive consumption of energy and salt-rich processed products[(12, 15)]. Therefore, energy intake could act as a confounding factor[(42)]. However, in our results, the association between sodium and %BF is independent of TEI. This is consistent with a study by Ma et al., which showed that a 1 g/day increase in salt intake was associated with a 0.73 kg (*p*=0.001) increase in body fat mass in children, after adjusting for age, sex, ethnicity, and TEI[(15)].

The mechanisms for this positive association between sodium and %BF are not yet elucidated although some authors propose that excessive sodium intake may reflect unhealthy behaviours leading to adiposity[(43)], or even a direct contribution to an increase in body fat[(44)]. An experimental study in rats showed that the group attributed to the "high salt intake" exhibited higher plasma leptin concentration and excessive accumulation of white adipose tissue compared to the lower salt intake group[45]. These events in the "high salt intake" group could be explained by the improvement in insulin sensitivity of the adipocyte for glucose uptake, insulin-induced glucose metabolism, and lipogenic capacity of white adipose tissue in rats[45, 46]. Another possible mechanism is that if more salt is consumed, the volume of extracellular water increases, which will result in a small weight gain of <1 kg[47].

Similar results were observed in epidemiological studies[16, 18, 21, 44]. A cross-sectional study involving adolescents was conducted to explore the association between dietary sodium intake, assessed using a seven-day 24-hour dietary recall method, and various adiposity measures. Multiple linear regression analyses demonstrated independent associations between dietary sodium intake and adiposity measures, including body weight, BMI, waist circumference, percent body fat, fat mass, subcutaneous abdominal adipose tissue, as well as leptin levels[16]. Another study, in children and adolescents, investigating the associations between urinary sodium excretion and dietary sodium intake with adiposity measures (BMI, waist circumference, and total body fat percent) demonstrated that higher urinary sodium excretion, as measured by spot urine analysis, exhibited significant positive associations with all adiposity measures, independent of energy intake, physical activity, sugar-sweetened beverage intake, and socio-demographic variables. As for dietary sodium intake, estimated by 24-hour dietary recalls, increased Na consumption was consistently associated with increased odds of overweight and obesity, as indicated by BMI and waist circumference measures. Significant dose-response relationships were observed, indicating a linear trend of increasing adiposity with higher dietary sodium intake[44]. Additionally, prospective cohort studies conducted in children, adolescents, and adults revealed that the values of 24-hour urinary sodium excretion were associated with an increase in body fat percentage over time, independent of energy intake[18, 21]. Therefore, these observations suggest that salt intake may exert a regulatory influence on body fat metabolism, potentially contributing directly to increased fat deposition. Elevated salt consumption appears to impact adipose tissue metabolism, as it has been demonstrated that high-salt diets may elevate leptin concentration and lead to excessive accumulation of white adipose fat[15]. Furthermore, a pilot study showed that high sodium intake leads to cortisol production, and this increase in cortisol production appears to lead to obesity[48]. Such mechanisms align with the concept that dietary factors, beyond their caloric content, may intricately modulate metabolic pathways[15].

Despite our results not showing a significant association between BMI and urinary sodium excretion after adjusting for the mentioned confounders, a 2015 study found that BMI increased from the lowest to the highest tertile of salt intake (p<0.001) in both children, after adjusting for age, sex, ethnicity, family income, physical activity, TEI, and inaccurate reports, as well as in adults after additional adjustment for alcohol consumption, tobacco, and education level[15]. The absence of a statistically significant association between BMI and urinary sodium in our sample may potentially be attributed to the limitations of BMI in distinguishing between lean body mass and body fat mass[49]. BMI alone may not adequately capture the variability in body composition as an individual may exhibit a high BMI yet have low fat mass, or conversely, have a low BMI despite a higher proportion of fat mass. This discrepancy underscores the complexity of using BMI as a sole indicator of adiposity and highlights the importance of incorporating additional measures, such as body fat mass percentage or waist circumference, to more accurately assess adiposity[49-53].

In the context of this cross-sectional investigation, our sample of school-aged children yielded a median sodium excretion of 2507 mg. This result goes according to other Portuguese studies that have demonstrated increased sodium excretions in similar age groups[54, 55]. Notably, the value of sodium intake presented in our sample (2786 mg) is significantly above the recommendations for the age range of the study participants. The European Food Safety Authority (EFSA) recommends a daily sodium intake of 1700 mg/day for ages 7-10 years and 2000 mg/day for that age onwards[56].

Excessive salt consumption is a risk factor for elevated blood pressure and consequently for the onset of cardiovascular diseases[57, 58], as well as other health complications, with obesity being one of them[59]. Although most prevention-oriented strategies are often conducted in adults, interventions aimed at reducing blood pressure over the lifespan are likely to have a greater impact if started early in childhood, when children's eating habits are forming[60]. There is sufficient evidence to recommend reducing sodium intake from pediatric age as an effective and well-tolerated approach in children to reduce their blood pressure[60], considering that salt intake in children is a risk factor for developing hypertension in the future[61]. To better delineate interventions to reduce salt intake, it is crucial to know the main sources of sodium and in another report from the ARIA study, it was found that the food groups with the highest contribution to participants' sodium intake were cereals and cereal-based products, soups and sauces, and meat products. Bread, vegetable soup, and red meats represented the major dietary sources in the mentioned groups respectively[(62)]. In fact, several interventions carried out in public institutions have shown their effectiveness in reducing salt intake[(63-65)]. An example is the Salt Control-C equipment, which allowed for a 30% reduction in added salt levels in canteen meals without a decrease in consumer satisfaction[(63)]. Furthermore, besides changes in food retail and food service settings, it is important to highlight that family may play a significant role in educating children about consuming an appropriate level of salt[(66)]. So it is crucial to consider multi-level interventions when aiming to reduce salt intake in this age group[(67, 68)].

It is crucial to highlight the limitations inherent in our study design. Firstly, the reliance on a single 24-hour urine collection may not fully capture an individual's habitual sodium intake[(36)]. Furthermore, the utilization of a sole 24-hour food recall questionnaire only permits assessment of short-term dietary intake, potentially overlooking seasonal fluctuations in food consumption[(36)]. Therefore, it would be more prudent to employ multiple urine collections and various 24-hour food recall questionnaires to obtain a more reliable assessment of dietary intake[(36)].

Dual-energy x-ray absorptiometry (DEXA) is considered one of the best methods to evaluate body composition[(69)]. Nonetheless, to assess body fat, bioelectrical impedance analysis (BIA) was used, which, despite its limitations and not being considered a gold standard for body fat mass percentage assessment, is considered a good alternative to DEXA for large-scale studies in children[(70-72)]. Additionally, BIA exhibited advantages related to its simplicity and quick procedure[70, 71]. However, another limitation is that children weren't asked to be on an empty stomach, which could affect the results. In the future, it would also be interesting to study other indicators of obesity such as waist circumference and waist-to-height ratio as there is evidence suggesting that these measures demonstrate a good correlation with visceral abdominal fat[73] and metabolic risk factors in children[74, 75].

It's also important to consider memory errors associated with the use of this type of questionnaire for dietary assessment as participants may experience difficulties accurately recalling their dietary intake of the previous day. Furthermore, it is necessary to recognize possible limitations of knowledge regarding specific brands and to accurately estimate portions sized in this age group[76]. Additionally, it is essential to recognize that the utilization of a cross-sectional design in our study restricts our ability to establish a causal relationship between %BF and 24-hour sodium excretion[36]. While our study and others suggest that high salt intake is likely a contributing factor to obesity, we cannot exclude the possibility that adiposity may predispose individuals to higher salt consumption independently of TEI[15].

However, it is important to underscore several strengths of our study methodology. Among these strengths is the utilization of 24-hour urine collection, regarded as the gold standard method for assessing sodium and potassium intake[35]. Furthermore, it is important to note the implementation of the creatinine coefficient as a measure to ensure the validity of urine samples. This approach helps mitigate potential inaccuracies and collection errors that may arise with the previously mentioned method[34]. The data collection for dietary assessment was conducted by trained interviewers, enabling the acquisition of information in an unbiased manner[77]. Additionally, the absence of potential modification of food intake due to the use of a quick and retrospective information collection method allows for a better characterization of children's eating habits[77, 78]. Furthermore, dietary assessment process encompassed a comprehensive evaluation of various factors, as a wide range of specific product brands, portion sizes, and components of mixed dishes which allowed to capture a detailed representation of participants' dietary food intake[77]. Finally, it is essential to highlight three additional strengths in our research methodology. Firstly, the validation of the 24-hour food recall questionnaires using the Goldberg Method which helps in assessing the accuracy and reliability of dietary intake data. Secondly, a substantial number of participants. Lastly, the consideration of possible confounding variables such as gender, age, TEI, physical activity, parental education, and excreted potassium values[15, 36].

Conclusions

This study indicates that higher values of %BF are associated with increased 24-hour urinary sodium excretion levels, independent of TEI and excreted potassium, in children from the ARIA study. These findings underscore the importance of promoting nutritional education from an early age to reduce the consumption of high-sodium food products and encourage less salt incorporation in meals.

Having these results into consideration, a collective commitment with the food industry and public awareness initiatives are essential to reduce sodium intake. This collective effort can play a crucial role in promoting healthier eating habits and preventing health issues associated with excessive sodium consumption.

References

1. Hassapidou M, Vlassopoulos A, Kalliostra M, Govers E, Mulrooney H, Ells L, et al. European Association for the Study of Obesity Position Statement on Medical Nutrition Therapy for the Management of Overweight and Obesity in Adults Developed in Collaboration with the European Federation of the Associations of Dietitians. Obes Facts. 2023; 16(1):11-28.

2. Smith JD, Fu E, Kobayashi MA. Prevention and Management of Childhood Obesity and Its Psychological and Health Comorbidities. Annu Rev Clin Psychol. 2020; 16:351-78.

3. Wójcik M, Kozioł-Kozakowska A. Obesity, Sodium Homeostasis, and Arterial Hypertension in Children and Adolescents. Nutrients. 2021; 13(11):4032.

4. He FJ, Li J, Macgregor GA. Effect of longer term modest salt reduction on blood pressure: Cochrane systematic review and meta-analysis of randomised trials. Bmj. 2013; 346:f1325.

5. He FJ, MacGregor GA. Salt reduction lowers cardiovascular risk: meta-analysis of outcome trials. Lancet. 2011; 378(9789):380-2.

6. Swinburn BA, Kraak VI, Allender S, Atkins VJ, Baker PI, Bogard JR, et al. The Global Syndemic of Obesity, Undernutrition, and Climate Change: The Lancet Commission report. Lancet. 2019; 393(10173):791-846.

7. Puma A, Pecoraro L, Salvottini C, Carbonare LD, Piacentini G, Pietrobelli A. Parental Perceptions and Concerns Related to the Consequences of Pediatric Obesity: Feeling or Real Problem? Endocr Metab Immune Disord Drug Targets. 2023; 23(11):1380-91.

8. He FJ, MacGregor GA. A comprehensive review on salt and health and current experience of worldwide salt reduction programmes. Journal of Human Hypertension. 2009; 23(6):363-84.

9. Rito A, Mendes S, Figueira I, Faria MdC, Carvalho R, Santos T, et al. Childhood Obesity Surveillance Initiative: COSI Portugal 2022. Lisboa: Instituto Nacional de Saúde Doutor Ricardo Jorge; 2023. [citado em: 2024]. Disponível em: http://hdl.handle.net/10400.18/8630.

10. Lucko AM, Doktorchik C, Woodward M, Cogswell M, Neal B, Rabi D, et al. Percentage of ingested sodium excreted in 24-hour urine collections: A systematic review and meta-analysis. J Clin Hypertens (Greenwich). 2018; 20(9):1220-29.

11. Golpour-Hamedani S, Rafie N, Pourmasoumi M, Morteza Safavi S, Mohammadifard N. Sodium and potassium intakes and adiposity among Iranian pre-adolescents and adolescents: a cross-sectional study. Nutr J. 2022; 21(1):23.

12. Grimes CA, Riddell LJ, Campbell KJ, Nowson CA. Dietary salt intake, sugar-sweetened beverage consumption, and obesity risk. Pediatrics. 2013; 131(1):14-21.

13. Rahman MJ, Parvez SM, Rahman M, He FJ, Cunningham SA, Narayan KMV, et al. Urinary Sodium Excretion and Obesity Markers among Bangladeshi Adult Population: Pooled Data from Three Cohort Studies. Nutrients. 2022; 14(14):3000.

14. He FJ, Marrero NM, MacGregor GA. Salt intake is related to soft drink consumption in children and adolescents: a link to obesity? Hypertension. 2008; 51(3):629-34.

15. Ma Y, He FJ, MacGregor GA. High salt intake: independent risk factor for obesity? Hypertension. 2015; 66(4):843-9.

16. Zhu H, Pollock NK, Kotak I, Gutin B, Wang X, Bhagatwala J, et al. Dietary sodium, adiposity, and inflammation in healthy adolescents. Pediatrics. 2014; 133(3):e635-42.

17. Murakami K, Livingstone MB, Sasaki S, Uenishi K. Ability of self-reported estimates of dietary sodium, potassium and protein to detect an association with general and abdominal obesity: comparison with the estimates derived from 24 h urinary excretion. Br J Nutr. 2015; 113(8):1308-18.

18. Libuda L, Kersting M, Alexy U. Consumption of dietary salt measured by urinary sodium excretion and its association with body weight status in healthy children and adolescents. Public Health Nutr. 2012; 15(3):433-41.

19. Yoon YS, Oh SW. Sodium density and obesity; the Korea National Health and Nutrition Examination Survey 2007-2010. Eur J Clin Nutr. 2013; 67(2):141-6.

20. Ellison RC, Sosenko JM, Harper GP, Gibbons L, Pratter FE, Miettinen OS. Obesity, sodium intake, and blood pressure in adolescents. Hypertension. 1980; 2(4 Pt 2):78-82.

21. Larsen SC, Ängquist L, Sørensen TI, Heitmann BL. 24h urinary sodium excretion and subsequent change in weight, waist circumference and body composition. PLoS One. 2013; 8(7):e69689.

22. Lahti-Koski M, Gill T. Defining childhood obesity. In: W. Kiess, C. Marcus, M. Wabitsch, editores. Obesity in childhood and adolescence. Karger Publishers; 2004. 9, p. 1-19.

23. Gray DS, Fujioka K. Use of relative weight and Body Mass Index for the determination of adiposity. J Clin Epidemiol. 1991; 44(6):545-50.

24. Wells JC. Commentary: The paradox of body mass index in obesity assessment: not a good index of adiposity, but not a bad index of cardio-metabolic risk. Int J Epidemiol. 2014; 43(3):672-4.

25. Javed A, Jumean M, Murad MH, Okorodudu D, Kumar S, Somers VK, et al. Diagnostic performance of body mass index to identify obesity as defined by body adiposity in children and adolescents: a systematic review and meta-analysis. Pediatr Obes. 2015; 10(3):234-44.

26. Zeng Q, Dong SY, Sun XN, Xie J, Cui Y. Percent body fat is a better predictor of cardiovascular risk factors than body mass index. Braz J Med Biol Res. 2012; 45(7):591-600.

27. Romero-Corral A, Somers VK, Sierra-Johnson J, Thomas RJ, Collazo-Clavell ML, Korinek J, et al. Accuracy of body mass index in diagnosing obesity in the adult general population. Int J Obes (Lond). 2008; 32(6):959-66.

28. Oliosa PR, Zaniqueli D, Alvim RO, Barbosa MCR, Mill JG. Body fat percentage is better than indicators of weight status to identify children and adolescents with unfavorable lipid profile. J Pediatr (Rio J). 2019; 95(1):112-18.

29. Mendes FC, Paciência I, Cavaleiro Rufo J, Farraia M, Silva D, Padrão P, et al. Higher diversity of vegetable consumption is associated with less airway inflammation and prevalence of asthma in school-aged children. Pediatr Allergy Immunol. 2021; 32(5):925-36.

30. Walker JL, Ardouin S, Burrows T. The validity of dietary assessment methods to accurately measure energy intake in children and adolescents who are overweight or obese: a systematic review. Eur J Clin Nutr. 2018; 72(2):185-97.

31. Black AE. Critical evaluation of energy intake using the Goldberg cut-off for energy intake:basal metabolic rate. A practical guide to its calculation, use and limitations. Int J Obes Relat Metab Disord. 2000; 24(9):1119-30.

32. Bernstein AM, Willett WC. Trends in 24-h urinary sodium excretion in the United States, 1957-2003: a systematic review. Am J Clin Nutr. 2010; 92(5):1172-80.

33. Preuss HG, Clouatre DL. Sodium, Chloride, and Potassium. In: John W. Erdman Jr., Ian A. Macdonald, Steven H. Zeisel MD, editores. Present Knowledge in Nutrition. ILSI Press; 2012. p. 475-92.

34. Remer T, Neubert A, Maser-Gluth C. Anthropometry-based reference values for 24-h urinary creatinine excretion during growth and their use in endocrine and nutritional research. Am J Clin Nutr. 2002; 75(3):561-9.

35. Chen SL, Dahl C, Meyer HE, Madar AA. Estimation of Salt Intake Assessed by 24-Hour Urinary Sodium Excretion among Somali Adults in Oslo, Norway. Nutrients. 2018; 10(7):900.

36. Rodrigues M, Castro Mendes F, Padrão P, Delgado L, Barros R, Rufo JC, et al. Does the Mediterranean Dietary Pattern Promote Lower Sodium Urinary Excretion in Children? Children (Basel). 2023; 10(9):1478.

37. Kuczmarski RJ, Ogden CL, Grummer-Strawn LM, Flegal KM, Guo SS, Wei R, et al. CDC growth charts: United States. In: Advance Data from vital and health statistics. Hyattsville, Maryland: National Center for Health Statistics; 2000. p. 1-27.

38. de Castro Mendes F, Paciência I, Rufo JC, Farraia M, Silva D, Padrão P, et al. Increasing Vegetable Diversity Consumption Impacts the Sympathetic Nervous System Activity in School-Aged Children. Nutrients. 2021; 13(5):1456.

39. McCarthy HD, Cole TJ, Fry T, Jebb SA, Prentice AM. Body fat reference curves for children. Int J Obes (Lond). 2006; 30(4):598-602.

40. Elsenburg LK, Rieckmann A, Nguyen TL, Bengtsson J, Andersen AN, Taylor-Robinson D, et al. Mediation of the parental education gradient in early adult mortality by childhood adversity: a population-based cohort study of more than 1 million children. Lancet Public Health. 2022; 7(2):e146-e55.

41. Kim BS, Yu MY, Shin J. Effect of low sodium and high potassium diet on lowering blood pressure and cardiovascular events. Clin Hypertens. 2024; 30(1):2.

42. Yi SS, Kansagra SM. Associations of Sodium Intake with Obesity, Body Mass Index, Waist Circumference, and Weight. Am J Prev Med. 2014; 46(6):e53-e55.

43. Yoo BM, Kim M, Kang MJ. Association between childhood obesity and familial salt intake: analysis of data from Korean National Health and Nutrition Examination Survey, 2014-2017. Endocr J. 2021; 68(9):1127-34.

44. Lee SK, Kim MK. Relationship of sodium intake with obesity among Korean children and adolescents: Korea National Health and Nutrition Examination Survey. Br J Nutr. 2016; 115(5):834-41.

45. Fonseca-Alaniz MH, Brito LC, Borges-Silva CN, Takada J, Andreotti S, Lima FB. High dietary sodium intake increases white adipose tissue mass and plasma leptin in rats. Obesity (Silver Spring). 2007; 15(9):2200-8.

46. Fonseca-Alaniz MH, Takada J, Andreotti S, de Campos TB, Campaña AB, Borges-Silva CN, et al. High sodium intake enhances insulin-stimulated glucose uptake in rat epididymal adipose tissue. Obesity (Silver Spring). 2008; 16(6):1186-92.

47. Antonios TF, MacGregor GA. Salt--more adverse effects. Lancet. 1996; 348(9022):250-1.

48. Nowell A, Torres SJ, Hall SJ, Keske MA, Torpy DJ, Parker L, et al. Is high salt intake inducing obesity via production of cortisol? A novel working hypothesis and pilot study. Eur J Nutr. 2024; 63(4):1315-27.

49. Wellens RI, Roche AF, Khamis HJ, Jackson AS, Pollock ML, Siervogel RM. Relationships between the Body Mass Index and body composition. Obes Res. 1996; 4(1):35-44.

50. Strain GW, Zumoff B. The relationship of weight-height indices of obesity to body fat content. J Am Coll Nutr. 1992; 11(6):715-8.

51. Romero-Corral A, Somers VK, Sierra-Johnson J, Korenfeld Y, Boarin S, Korinek J, et al. Normal weight obesity: a risk factor for cardiometabolic dysregulation and cardiovascular mortality. Eur Heart J. 2010; 31(6):737-46.

52. Norgan NG. Relative sitting height and the interpretation of the body mass index. Ann Hum Biol. 1994; 21(1):79-82.

53. Flegal KM, Shepherd JA, Looker AC, Graubard BI, Borrud LG, Ogden CL, et al. Comparisons of percentage body fat, body mass index, waist circumference, and waist-stature ratio in adults. Am J Clin Nutr. 2009; 89(2):500-8.

54. Cotter J, Cotter MJ, Oliveira P, Cunha P, Polónia J. Salt intake in children 10–12 years old and its modification by active working practices in a school garden. Journal of Hypertension. 2013; 31(10):1966-71.

55. Gonçalves C, Abreu S, Padrão P, Pinho O, Graça P, Breda J, et al. Sodium and potassium urinary excretion and dietary intake: a cross-sectional analysis in adolescents. Food Nutr Res. 2016; 60:29442.

56. Turck D, Castenmiller J, de Henauw S, Hirsch-Ernst KI, Kearney J, Knutsen HK, et al. Dietary reference values for sodium. EFSA J. 2019; 17(9):e05778.

57. Cappuccio FP. Cardiovascular and other effects of salt consumption. Kidney Int Suppl (2011). 2013; 3(4):312-15.

58. He FJ, MacGregor GA. Importance of salt in determining blood pressure in children: meta-analysis of controlled trials. Hypertension. 2006; 48(5):861-9.

59. World Health Organization. Guideline: Sodium intake for adults and children. Geneve: World Health Organization; 2012.

60. Appel LJ, Lichtenstein AH, Callahan EA, Sinaiko A, Van Horn L, Whitsel L. Reducing Sodium Intake in Children: A Public Health Investment. J Clin Hypertens (Greenwich). 2015; 17(9):657-62.

61. Mazzuca G, Artusa S, Pietrobelli A, Di Cara G, Piacentini G, Pecoraro L. The Future for the Children of Tomorrow: Avoiding Salt in the First 1000 Days. Children (Basel). 2024; 11(1):98.

62. Tânia Marisa da Silva Santos. Ingestão e Fontes Alimentares de Sódio em Crianças [dissertação de mestrado]. FCUP; 2015.

63. Faria AP, Padrão P, Pinho O, Silva-Santos T, Oliveira L, Esteves S, et al. Pilot Study to Reduce Added Salt on a University Canteen through the Use of an Innovative Dosage Equipment. Foods. 2022; 11(2):149.

64. Gonçalves C, Monteiro S, Padrão P, Rocha A, Abreu S, Pinho O, et al. Salt reduction in vegetable soup does not affect saltiness intensity and liking in the elderly and children. Food Nutr Res. 2014; 6:58.

65. Cohen JF, Smit LA, Parker E, Austin SB, Frazier AL, Economos CD, et al. Long-term impact of a chef on school lunch consumption: findings from a 2-year pilot study in Boston middle schools. J Acad Nutr Diet. 2012; 112(6):927-33.

66. Matsuzuki H, Muto T, Haruyama Y. School children's salt intake is correlated with salty taste preference assessed by their mothers. Tohoku J Exp Med. 2008; 215(1):71-7.

67. Silva-Santos T, Moreira P, Rodrigues M, Padrão P, Pinho O, Norton P, et al. Interventions That Successfully Reduced Adults Salt Intake-A Systematic Review. Nutrients. 2021; 14(1):6.

68. Ide N, Ajenikoko A, Steele L, Cohn J, C JC, Frieden TR, et al. Priority Actions to Advance Population Sodium Reduction. Nutrients. 2020; 12(9):2543.

69. Martin-Calvo N, Moreno-Galarraga L, Martinez-Gonzalez MA. Association between Body Mass Index, Waist-to-Height Ratio and Adiposity in Children: A Systematic Review and Meta-Analysis. Nutrients. 2016; 8(8):512.

70. Chen M, Liu J, Ma Y, Li Y, Gao D, Chen L, et al. Association between Body Fat and Elevated Blood Pressure among Children and Adolescents Aged 7-17 Years: Using Dual-Energy X-ray Absorptiometry (DEXA) and Bioelectrical Impedance Analysis (BIA) from a Cross-Sectional Study in China. Int J Environ Res Public Health. 2021; 18(17):9254.

71. Hosking J, Metcalf BS, Jeffery AN, Voss LD, Wilkin TJ. Validation of foot-to-foot bioelectrical impedance analysis with dual-energy X-ray absorptiometry in the assessment of body composition in young children: the EarlyBird cohort. Br J Nutr. 2006; 96(6):1163-8.

72. Chula de Castro JA, Lima TR, Silva DAS. Body composition estimation in children and adolescents by bioelectrical impedance analysis: A systematic review. J Bodyw Mov Ther. 2018; 22(1):134-46.

73. Brambilla P, Bedogni G, Moreno LA, Goran MI, Gutin B, Fox KR, et al. Crossvalidation of anthropometry against magnetic resonance imaging for the assessment of visceral and subcutaneous adipose tissue in children. Int J Obes (Lond). 2006; 30(1):23-30.

74. Savva SC, Tornaritis M, Savva ME, Kourides Y, Panagi A, Silikiotou N, et al. Waist circumference and waist-to-height ratio are better predictors of cardiovascular disease risk factors in children than body mass index. Int J Obes Relat Metab Disord. 2000; 24(11):1453-8.

75. Kelishadi R, Gheiratmand R, Ardalan G, Adeli K, Mehdi Gouya M, Mohammad Razaghi E, et al. Association of anthropometric indices with cardiovascular disease risk factors among children and adolescents: CASPIAN Study. Int J Cardiol. 2007; 117(3):340-8.

76. Foster E, Bradley J. Methodological considerations and future insights for 24-hour dietary recall assessment in children. Nutr Res. 2018; 51:1-11.

77. Shim JS, Oh K, Kim HC. Dietary assessment methods in epidemiologic studies. Epidemiol Health. 2014; 36:e2014009.

78. Ortega RM, Pérez-Rodrigo C, López-Sobaler AM. Dietary assessment methods: dietary records. Nutr Hosp. 2015; 31 Suppl 3:38-45.