LITERATURE REVIEW
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Is Excess Sodium Intake a Risk Factor for Overweight?: A Systematic Review

Apakah Asupan Natrium Berlebih Merupakan Faktor Risiko Overweight?: Tinjauan Sistematis

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ABSTRACT

Background: World salt consumption exceeds 200% of the daily recommendation. Obesity is the third largest health problem in the world. Various studies have begun to explore potential association mechanisms between sodium intake and weight gain, the risk of being overweight, and obesity.
Objective: To analyze the relationship between sodium intake and the risk of being overweight regarding nutritional status, central obesity, and body composition in the adult population.
Methods: This research was a systematic review. The data collection process used Pubmed and Science Direct databases with the keywords "obese" OR "overweight" OR "adiposity" AND "sodium" OR "salt intake" AND "adult." Articles were selected through title and abstract, which were re-selected according to inclusion and exclusion criteria.
Discussion: There are 11 kinds of literature related to nutritional status, 10 to central obesity, and 3 to body composition. Sodium intake was associated with an increase in body weight and the risk of being overweight, an increase in body weight of up to 2.75 kg, an increase in waist circumference of up to 2.15 cm, and an increase in fat mass up to 0.91 kg. Potential mechanisms underlying this relationship include energy intake, increased extracellular volume, increased adiposity, and changes in plasma leptin.
Conclusion: There is a relationship between excessive salt consumption and increased body weight and risk factors for being overweight regarding nutritional status, central obesity, and body composition in the adult population. However, the mechanism of this relationship still needs to be studied further.

INTRODUCTION

Weight gain is a phenomenon that is currently a significant problem related to the increase in non-communicable diseases. Based on the Asia Pacific World Health Organization (WHO) standards, obesity is defined as body mass index (BMI)≥25kg/m2[1]. Assessment of nutritional status based on BMI does not reflect the distribution of fat mass and body composition. Measuring fat mass distribution and body composition can use anthropometric measurements such as waist circumference, abdominal circumference, and bioimpedance analysis[2–4].

Obesity is one of the world's top three causes of health problems. Various factors behind obesity, including genetic factors, excess intake, physical activity, environment, and emotional[5]. Meanwhile, health problems caused by obesity include cardiovascular disease, chronic kidney disease, type 2 diabetes mellitus, hypertension, and hyperlipidemia.[6]. Between 1975 and 2016, the prevalence of obesity has nearly tripled[7]. Over 1.9 billion adults are overweight, of which 650 million are obese[8].

Improper food intake is the main factor causing weight gain[9]. Not only is it always closely related to macronutrients, but in recent years, obesity has been associated with an imbalance of micronutrients such as sodium[10]. The WHO recommendation for salt consumption in adults is less than 2,000 mg/day of sodium or the equivalent of 5 g of salt[11]. The American Heart Association recommends a maximum sodium intake for adults of 2,300 mg/day, equivalent to 6 grams of salt per day[12]. Salt consumption globally ranges from 9 to 12 g/day[13].

Table salt is the most significant contributor to sodium because the main component of table salt is sodium (NaCl). Sodium can be found in daily foodstuffs such as chicken, fish, milk, and soybeans. The use of daily seasonings such as sweet soy sauce, soy sauce, and Tauco also increases sodium intake. In addition, processed foods such as bread, biscuits, and chips also contain high enough sodium, which, if not balanced with sufficient consumption of vegetables and fruit, can disrupt the

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balance of sodium in the body.

The relationship between sodium and obesity has been investigated in recent years. Obesity and sodium are associated with an increased risk of chronic disease, one of which is cardiovascular[9]. Various studies have shown that an increase in sodium consumption is related to an increase in obesity[9]. The relationship between sodium intake and obesity is associated with increased calorie intake through the consumption of carbohydrates and fats, so there is also an increase in sodium intake[14]. Recently, various studies have suggested that sodium intake contributes to the incidence of obesity regardless of energy intake[15]. High salt intake is also associated with increased fluid intake due to excessive thirst, so it can increase the intake of sweet drinks. In adults, reduced sodium intake is associated with reduced fluid intake[14]. The mechanism that might occur is an increase in extracellular volume, disruption of leptin balance[3], genetic predisposition, and salt sensitivity[9]. The use of sodium in processed and commercial foodstuffs that contribute to daily sodium intake and various findings on the relationship between sodium intake and obesity have made researchers interested in conducting a systematic review regarding the mechanism of the relationship between sodium intake and hypertension.

METHODS

This study used a systematic review method in observational studies (cross-sectional, case-control, cohort). The results of the primary research search were described using the 2020 Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) method. The database used includes Pubmed and Science Direct. The search was carried out in May-September 2022. Research identification using Boolean Operators includes OR/AND/NOT. The keywords used were "obese" OR "overweight" OR "adiposity" AND "sodium" OR "salt intake" AND "adult." Search criteria were limited to articles with observational research designs, other full text, English-language articles, and research published in the last ten years(2013-2022). Article inclusion criteria included in the review were among adults aged >19 years, having measures of sodium intake and markers of obesity. Article exclusion criteria have the same content as other articles.

Based on the search results from the electronic database, it was found that as many as 7,926 articles were relevant to keywords. After eliminating article applications spanning more than ten years, not full text or research articles, 309 articles were obtained, filtered by looking at the suitability of the title and abstract. In the title and abstract selection stages, 22 relevant articles were obtained. The relevant articles then entered the Critical Appraisal stage, carried out by two independent researchers using JBI critical appraisal tools for cross-sectional and cohort studies. The assessment was carried out by giving a value of "YES," "NO," "IS NOT CLEAR," or "NO ANSWER." Each criterion rated "YES" gets 1 point, while the other answer points are 0. Total questions Articles with a final score of <50% were excluded from the review to avoid bias. After adjusting for the inclusion criteria, 11 articles that met Critical Appraisal were obtained.

The next stage is data extraction by collecting crucial information in the article. The information collected was then presented in tabular form as the result of a systematic review. The preparation of the table contains the following: 1) name of the researcher, 2) title, 3) subject, 4) method, 5) results and conclusions, and 6) JBI score.

RESULTS AND DISCUSSION

The United States dietary guidelines recommend limiting salt consumption to under 6g or the equivalent of 2,300 milligrams of sodium daily[1]. According to the American Heart Association, the ideal target for adults is no more than 1,500 milligrams per day[12]. However, most adults consume excess sodium. *Central Disease Control* and Prevention (CDC)estimates that the average American adult eats 3,400 grams each day. The primary food source of sodium is salt[1]. For a long time, salt has been a risk factor for hypertension through salt and fluid retention. Recently, various studies have linked salt intake with risk factors for being overweight/obese[16]. A meta-analysis shows that high sodium intake contributes to increased triglycerides, hypocholesterolemia, HDL, risk of being overweight, waist circumference, body mass index, abdominal obesity, blood pressure, and body fat percentage[17]. Sodium intake can increase food's delicacy, increasing energy intake from fat and carbohydrates[18]. Some foods high in sodium and energy density include chips, crackers, fried foods, and fast food.

In the past, salt consumption was assessed using the semi-quantitative food frequency questionnaire (SQ-FFQ). However, the gold standard for measuring sodium intake is 24-hour urinary sodium excretion[3]. Meanwhile, determining nutritional status, especially in determining overweight and obesity, is generally used by body mass index (BMI). Central obesity can be determined through waist circumference (WC) or better indicators using the waist-to-height ratio (WHtR)[4]. Another adipocyte assessment indicator has begun to be developed to support BMI and WC, namely by measuring body composition to determine fat distribution in the body.

Eleven articles discuss the relationship between sodium intake and overweight through indicators determining obesity in general (BMI), central obesity (WHtR/WC), and assessment of fat distribution with body composition, as seen in Table 1.

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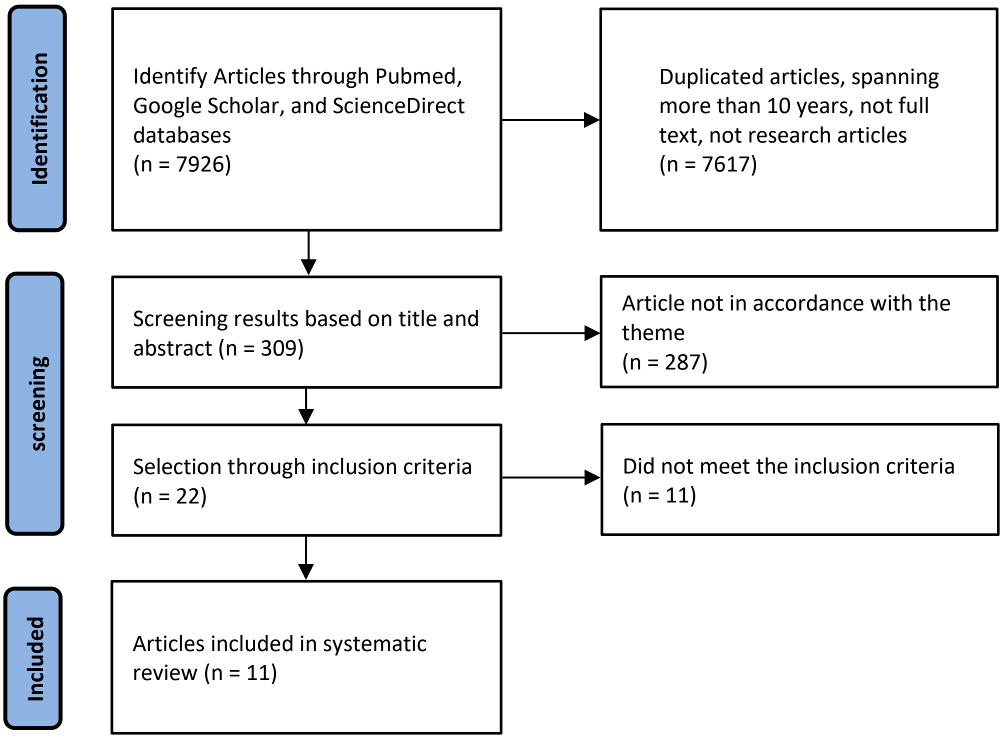

Figure 1. PRISMA flowchart for 2020 to identify the risk factors of excessive salt intake

Nutritional status

Body Mass Index (BMI) is a standard assessment for determining nutritional status. Body mass index is the result of dividing body weight in kilograms (kg) and height in meters (m) by the square of (kg/m^2)[19]. Various studies state that BMI > 25 increases the risk of developing cardiovascular disease[20]. According to Siburian (2007), the lowest risk for a person experiencing cardiovascular disease is with a BMI of 21-25. The risk increases when a person has a BMI of 25 to 27 kg/m^2, a high risk if a person's BMI is 27 to 30 kg/m^2, and a very high risk if a person's BMI reaches >30kg/m^2[20]. BMI is a measure to determine a person's nutritional status but cannot describe body composition and body fat distribution specifically.

The findings from the literature review are that ten studies have a positive relationship between urinary sodium intake/excretion and overweight[2–4,6,21–25]. Analysis using NHANES data showed that a difference of 1 g of sodium per day was associated with a higher BMI of 1.03 kg/m^2 regardless of energy intake[2]. Studies among diverse US Hispanic/Latino populations found that each 500 mg (approximately 21.75 mmol) increase in sodium intake was significantly associated with 0.07 kg/m^2 higher BMI (95% CI: 0.00, 0.15)[26]. In line with the study using INTERMAP data among the populations of China, Japan, UK, and USA after adjusting for confounding factors, it was stated that there were differences in the increase in the subject's BMI in each country[22]. Higher 1g/day salt intake was associated with higher BMI increases of 0.10 kg/m^2 in China, 0.28 kg/m^2 in Japan, 0.42 kg/m^2 in the UK, and 0.52 kg/m^2 in the United States (p-value 0.001)[22]. The risk of being overweight/obese also increased by 21% in Japan, 4% in China, 29% in the UK, and 24% in the US, and an increase of 1g/day of sodium intake[22].

Central Obesity

One of the determinants of central obesity is waist circumference. The limit for determining central obesity for men is a waist circumference > 90 cm, while for women, it is > 80 cm (WHO, 2014). Central obesity is one of the causes of degenerative diseases, including type 2 diabetes mellitus, dyslipidemia, coronary heart disease, hypertension, cancer, and metabolic syndrome.[27]. Findings from a literature review consisting of 10 studies measuring central obesity using waist circumference (WC), waist-to-height ratio (WHtR), and waist-to-hip ratio (WHR)[2–4,6,21,23–25,28,29]. Anthropometry can predict the distribution of body fat, especially in the abdomen. The results of a review of ten journals, eight of which showed that high sodium intake is associated with an increased risk of central obesity[2–4,6,21,24,25,29].

A study among a diverse US Hispanic/Latino population found that each 500 mg (approximately 21.75 mmol) increase in daily dietary sodium was significantly associated with a 0.18 cm greater increase in waist circumference (95% CI: 0.00, 0). ,36)[29]. In contrast to the results of a study in Denmark using the MONICA study, which was attended by 215 subjects, it was found that there was no relationship between sodium excretion and waist circumference even though it had been adjusted for confounding factors. However, the sample in this study was relatively small compared to other studies, even though it was carried out with a cohort design[28].

A study in a Bangladeshi population revealed that a 100 mmol/24 h increase in sodium intake unadjusted for caloric intake was associated with an

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increase of 0.20 cm in waist circumference (95% Cl: 0.10, 0.30). However, this study found no correlation between sodium excretion, waist-to-hip ratio, and waist-height[23]. Data from the National Health and Nutrition Examination Survey (NHANES) in South Korea showed that adults who had a high sodium intake (3200 mg) had a 2.5-fold greater risk of developing central obesity compared to adults who had a sodium intake below 2200 mg. mg (determined by waist circumference)[30].

Body Composition

The percentage of body weight consisting of non-fat and adipose tissue is called body composition[31]. Body composition, including fat, muscle, and fluid, changes frequently. Weight gain and loss are associated with changes in the distribution of fat mass, fat-free mass, and fluid in the body. Body composition can be measured using the in vivo method using DXA, BIA, MRI, and dilution Techniques and measurements with anthropometric methods using skinfold calipers[32].

Based on the results of a literature study, it was found that three articles used body composition as an indicator of overweight/obesity together with BMI and WC indicators[3,4,28]. The three articles show differences in body composition, including fat and fat-free mass in subjects who consume excess sodium when viewed from sodium intake and excretion[3,4,28]. Based on studies, NHANES showed that a difference of 1 gram of sodium per day was associated with an increase of 0.91 kg of body fat mass and 0.32 kg of lean mass[4]. The results showed a significant association between salt intake and body fat in the unadjusted and energy intake adjusted models. However, other body compositions have no relationship between sodium intake and fat-free mass[3]. Supported by studies conducted in Denmark using the MONICA database, it was found that every 100 mmol increase in sodium excretion is associated with an increase in fat mass of 0.24 kg and a decrease in fat-free mass of 0.21 kg[28].

The short-term effect of a high-salt diet is associated with increased blood pressure. However, a high-salt diet in the long term is associated with obesity through several pathways[33]. Based on a literature review, sodium intake contributes to increased body weight, central obesity, and changes in body composition and nutritional status. Various mechanisms underlie this based on energy intake and regardless of energy intake.

The mechanism that can explain the relationship between sodium intake and excretion of sodium to the increase in fat mass is that high salt intake plays a role in increasing the intake of high-energy foods. Foods that have a high energy density tend to have a high salt content, such as cheese, crackers, chips, and fried foods, thereby increasing total energy intake.[28]. High salt intake is also related to increased intake of high-calorie drinks because salt has the property of attracting water, causing a feeling of thirst[14]. Intake with high energy density, such as fat, contributes to increased body fat mass, which manifests in increased body weight.

The following possible mechanism is an increase in extracellular volume. Higher salt intake results in transient hyperosmolality in the portal vein and liver. In the long term, high sodium intake changes serum osmolality[3,34]. An increase in osmotic pressure causes an increase in solutes, which attracts the extracellular solvent (water), thereby causing water retention. The study stated that if salt intake was reduced from the current average intake of about 10 g (160 mmol) to less than 5g (80 mmol), there was a loss of more than 1 kg in weight, consequently reducing extracellular volume. Therefore, it is unsurprising that high salt intake exacerbates sodium and water retention conditions and can lead to weight gain[3,35].

The mechanism for weight gain that comes from increased sodium intake that is not mediated by energy intake in experimental animal studies is that a high-salt diet induces white adipose tissue (WAT) and plasma leptin concentrations. Increased WAT can be caused by food consumption, energy expenditure, cell hypertrophy, and hyperplasia. However, in the experimental animal studies, the experimental animals consumed the same amount of food during the trial period. The increase in adiposity in experimental animals is induced by glucose metabolism, contributing to an increase in fat mass. The increased capacity to incorporate glucose into lipids and higher lipogenic enzymatic activity may have driven adipocyte hypertrophy and excessive fat accumulation. Another mechanism for increased adiposity is excess salt, which increases the basal lipolytic response of visceral adipocytes and isoproterenol-stimulated lipolytic response without causing significant weight loss and adiposity. However, this study showed no significant increase in body weight in rats without salt, low salt, or high salt[36].

Changes in extracellular serum osmolality affect the increase in tonicity, activating the transcription factor tonEBP (NFAT5), which induces the protein aldose reductase (AR), thereby activating the polyol pathway[34]. The polyol pathway is an intracellular hyperglycemic pathway in which glucose is metabolized by aldose reductase to sorbitol. Increased sorbitol will reduce inositol levels, disrupting basement membrane osmolarity. The increase in sorbitol also affects the increase in endogenous fructose through the mechanism of sorbitol, which is converted to fructose by sorbitol-6-phosphate 2-dehydrogenase[37]. A high-salt diet in rats causes an independent increase in fructose (increased fructose metabolism), where salt increases fat accumulation[34]. Long-term fructose hypermetabolism causes a decrease in insulin sensitivity, causing hyperphagia[34]. In the short term, rats on a high-salt diet did not experience a significant increase in body weight, but entering the 13th week, there was a significant difference in body weight between mice that were given a low-salt diet and mice that were given a high-salt diet. Mice fed a high-salt diet had excess body weight[34].

This systematic review has several strengths. First, this systematic review analyzes various groups in different countries so that the subject is more heterogeneous and can describe the relationships in various countries. Second, sodium intake was assessed through standard gold measurements, namely urinary sodium excretion, and several articles were supported by reporting notes and diet recalls. Third, the determinants of obesity are reviewed from various indicators, namely

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changes in body weight, BMI, measurements of central obesity, and body fat distribution. Not only strengths this systematic review but, of course, also has various weaknesses. First, the lack of indicators determining obesity in each selected article has a different cut-off. Second, The database used in the article search is still limited to only two sources. Third, some of the articles retrieved still use secondary data, so confounding factors are difficult to control. Fourth, most of the articles retrieved were cross-sectional studies, so they cannot be used to conclude cause-and-effect relationships.

Table 1. Literature related to the relationship between sodium intake and overweight/obesity

Authors	Title	Subject	Method	Results and Conclusions	JBI Score
Ma et al., 2015	High Salt Intake Independent Risk Factor for Obesity?	2,174 adults (19-64 years)	Cross-sectional	An increase in salt intake of 1 g/day was associated with an increased risk of obesity by 28% (p=0.0002), an increase in body fat mass of 0.91 kg (p=0.001), and an increased risk of central obesity by 20%	87.5%
Larsen et al., 2013	24h Urinary Sodium Excretion and Subsequent Change in Weight, Waist Circumference and Body Composition	215 Adults (25–64 Years)	Longitudinal study	There was no significant relationship between sodium excretion and changes in body weight or waist circumference, but there was a significant relationship between sodium excretion in fat mass (p = -0.015) and fat-free mass (p = 0.041). For every 100 mmol increase, there is a change in waist circumference of 0.35 cm, an increase in fat mass of 0.24 kg, and a decrease in fat-free mass of 0.21 kg.	81.8%
Yi et al., 2014	Independent Associations of Sodium Intake with Measures of Body Size and Predictive Body Fatness	4,613 Adults (>20 Years)	Cross-sectional	After adjustment, a difference of 1 g/day in sodium was associated with higher anthropometry at BMI 1.03 kg/m2; body weight 2.75 kg; waist circumference 2.15 cm; prediction of body fatness 1.18%. Differences in anthropometric measurements are more significant for women for every 1g/day increase in sodium.	75.0%
Lee et al., 2018	Associations of urinary sodium levels with overweight and central obesity in a population with a sodium intake	16,250 Adults (>19 Years)	Cohort	High levels of sodium excretion (≥ 3200 mg) indicated 2.17 times increased risk of overweight and central obesity 2.5 times compared with those with lower urinary sodium excretion rates (< 2200 mg).	75.0%
Crouch et al., 2018	Dietary sodium intake and its relationship to adiposity in young black and white adults: The African-PREDICT study	761 Adults (20-30 Years)	Cross-sectional	A single regression analysis shows a relationship between body weight, BMI, body surface area, waist circumference, waist-to-hip ratio, and waist-to-height ratio with sodium intake (p=0.008). Meanwhile, with multivariate adjustment, only body surface area had a relationship with sodium intake (p=0.039)	87.5%
Zhou et al., 2018	Salt intake and prevalence of overweight/obesity in Japan, China, the United Kingdom, and the United States: the INTERMAP Study	4680 Adult (40-59 Years)	Cross-sectional	After adjusting for potential confounders, 1 g/day higher salt intake was associated with higher BMI in Japan, China, the UK, and the USA by 0.28 kg/m2, 0.10 kg/m2, 0.42 kg/m2 m2, and 0.52 kg/m2 (p<0.001). Regarding the risk of being overweight/obese in Japan, China, England, and the United States, it was 21%, 4%, 29%, and 24% (p <0.05). Meanwhile, the prevalence of overweight/obesity in Japan, China, England, and the United States is 26.7%, 25.5%, 69.7%, and 71.8%.	100%
Rahman et al., 2022	Urinary Sodium Excretion and Obesity Markers among Bangladeshi Adult Population: Pooled Data from Three Cohort Studies	10,034 Adults (>19 Years)	Cohort	For every increase of 100 mmol/24 hours, the subject experienced an average increase in BMI of 0.10 kg/m2, an increase of 0.39 kg/m2 in underweight subjects, and an increase of 0.59 kg/m2 in overweight subjects. The waist circumference variable has a change of 0.20 cm, with a change of 0.18 cm in subjects with low body weight and an increase of 0.23 cm in overweight subjects.	81.8%
Elfassy et al., 2022	Associations of Sodium and Potassium with Obesity Measures Among Diverse US Hispanic/Latino Adults: Results from the Hispanic Community	16,415 Adults (18-74 Years)	Cross-sectional	Higher sodium intake of 500 mg/day was associated with an increase in BMI of 0.07 kg/m2 (p < 0.05) and waist circumference of 0.18 cm (p=0.04). In respondents born in the US, an increase in urinary sodium of 500 mg/day was associated with an increase in BMI of 0.27 kg/m2 (p<0.01) and an increase in	100%

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Authors	Title	Subject	Method	Results and Conclusions	JBI Score
	Health Study/Study of Latinos			body fat of 0.54 kg (p<0.01).	
Mukarami et al., 2015	The 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	1043 Adult Female (18-22 Years)	Cross-sectional	After adjustment for confounding factors, sodium intake was associated with a higher risk of obesity (BMI) (OR=2.49; p=0.04) and central (waist circumference) obesity (OR=1·77; p=0.04).	75.0%
Zeng et al., 2015	Are 24-hour urinary sodium excretion and sodium: potassium independently associated with obesity in Chinese adults?	1906 Adult (18-69 Years)	Cross-sectional	The odds of being overweight, obese, and abdominal obese increased significantly across all quartiles of increasing sodium (p<0.001). For every 100 mmol increase in sodium, the risk of overweight, obesity, abdominal obesity according to waist circumference, and abdominal obesity decreased waist-to-hip ratio by 46%, 39%, 55%, and 33%.	75.0%
Mohammadifard et al., 2020	Is urinary sodium excretion related to anthropometric indicators of adiposity in adults?	508 Adult (>19 Years)	Cross-sectional	After controlling for confounding factors, subjects with higher sodium intake had an increased risk of being overweight 1.004 (p=0.015), abdominal obesity 1.004 (p=0.031), and increased body fat 1.007 (p=0.001).	87.5%

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CONCLUSIONS

Most research results show a relationship between excess salt consumption from sodium intake and 24-hour urine sodium excretion with increased body weight and overweight risk factors seen from nutritional status, central obesity, and body composition in the adult population. However, the mechanism of this relationship still needs to be studied further. Restricting sodium consumption, especially in table salt, must be done to prevent the risk of cardiovascular disorders and the development of excess weight. Future studies are needed to (1) Assess other determinants of changes in body weight and body composition, (2) Take into account other confounding factors that may affect the results of the study, and (3) Conduct prospective studies to prove the relationship between sodium intake and overweight.

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