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Review

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# The association between dietary sodium intake and obesity in adults by sodium intake assessment methods: a review of systematic reviews and re-meta-analysis

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## ABSTRACT

**BACKGROUND/OBJECTIVES:** The scientific evidence of a sodium-obesity association is limited by sodium intake assessments. Our specific aim is to synthesize the association between dietary sodium intake and obesity across the sodium intake assessments as evidenced by systematic reviews in adults.

**SUBJECTS/METHODS:** A systematic search identified systematic reviews comparing the association of dietary sodium intakes with obesity-related outcomes such as body mass index (BMI), body weight, waist circumference, and risk of (abdominal) obesity. We searched PubMed on October 24, 2022. To assess the Risk of Bias in Systematic Reviews (ROBIS), we employed the ROBIS tool.

**RESULTS:** This review included 3 systematic reviews, consisting of 39 unique observational studies (35 cross-sectional studies and 4 longitudinal studies) and 15 randomized controlled trials (RCTs). We found consistently positive associations between dietary sodium intake and obesity-related outcomes in cross-sectional studies. Studies that used 24-h urine collection indicated a greater BMI for those with higher sodium intake (mean difference = 2.27 kg/m$^2$; 95% confidence interval [CI], 1.59–2.51; $P < 0.001$; $I^2 = 77\%$) compared to studies that used spot urine (mean difference = 1.34 kg/m$^2$; 95% CI, 1.13–1.55; $P < 0.001$; $I^2 = 95\%$) and dietary methods (mean difference = 0.85 kg/m$^2$; 95% CI, 0.1–1.51; $P < 0.05$; $I^2 = 95\%$).

**CONCLUSIONS:** Quantitative synthesis of the systematic reviews has shown that cross-sectional associations between dietary sodium intake and obesity outcomes were substantially different across the sodium intake assessments. We need more high-quality prospective cohort studies and RCTs using 24-h urine collection to examine the causal effects of sodium intake on obesity.

**Keywords:** Sodium; obesity; systematic review; meta-analysis; association

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**Conflict of Interest**

The authors declare no potential conflicts of interests.

**Author Contributions**

Conceptualization: Lee M, Sohn C, Kim OY, Lee J; Data curation: Lee YM, Lee J; Formal analysis: Lee J; Funding acquisition: Lee M; Investigation: Lee YM, Lee J; Methodology: Lee M, Lee J; Project administration: Yoon MO; Supervision: Lee M; Writing - original draft: Lee YM, Lee J; Writing - review & editing: Lee M, Sohn C, Kim OY, Lee YM, Yoon MO, Lee J.

# INTRODUCTION

Obesity is one of the world's major epidemic challenges. The global prevalence of obesity approximately tripled between 1975 and 2016 [1]. Adult obesity has been associated with various complications such as cardiovascular disease, type 2 diabetes mellitus, coronary heart disease, certain types of cancer, and obstructive sleep apnea [2]. Obesity is a multifactorial disease affected by: (1) dietary factors (e.g., energy intake that exceeds energy needs, high consumption of calorie-dense, nutrient-poor food); (2) low physical activity; and (3) unhealthy psychological conditions (e.g., depression, stress) [3]. Although high energy intake is the major factor leading to obesity, evidence is emerging that high sodium intake leads to additional weight gain in adults [4-6]. Therefore, research is needed to systematically review individual studies and examine associations between dietary sodium intake and obesity.

Multiple methods were utilized to estimate dietary sodium intake, such as dietary methods, 24-h urine, spot urine, and overnight urine. While 24-h urine collection is considered the gold standard for assessing dietary sodium intake, the studies often employed other methods that were less time-consuming or burdensome. However, these other methods are known to be less accurate with regard to reflecting the sodium intake of individuals [7]. Some methods of measuring dietary sodium intake could underestimate or overestimate obesity outcomes. Consequently, it is critical to determine how sodium intake methods could differ when it comes to associations between dietary sodium intake and obesity.

We conducted a review of systematic reviews to identify and synthesize the scientific evidence regarding the association between dietary sodium intake and obesity in adults. Additionally, we performed subgroup analyses of primary studies in the included systematic reviews to examine whether the association of sodium and obesity differs by dietary sodium intake assessment method.

# SUBJECTS AND METHODS

## Data sources and searches

The search strategy was developed based on a protocol of the earlier systematic review [8]. We conducted the data searches for systematic reviews with or without meta-analysis in the PubMed database (from inception to October 24, 2022) (**Supplementary Table 1**). Obesity-related outcomes were included in the search terms, such as body mass index (BMI), body weight, waist circumference, and abdominal obesity.

## Study eligibility criteria

We included systematic reviews with randomized controlled trials (RCTs) and observational studies. To be included, systematic reviews had to contain information about adult subjects (over 18 yrs). Additionally, systematic reviews had to include dietary sodium intake with a quantitative assessment and different levels of sodium intake or compare the effect of dietary sodium intake based on different levels of intake. Systematic reviews describing a dietary pattern/index indicating a higher intake of sodium, but not indicating the specific levels of sodium intake, were ineligible. Systematic reviews had to have reported outcomes related to obesity (i.e., BMI, body weight, risk of overweight/obesity or abdominal obesity, and waist circumference). Finally, we included systematic reviews with or without meta-analysis, but excluded literature reviews, critical reviews, and review of systematic reviews.

### Study selection process

Two researchers independently screened the abstract of all citations according to the established inclusion and exclusion criteria. To conduct the abstract screening, 2 researchers used the online software Abstrackr separately. Then, 2 researchers independently implemented the full-text screening according to the study eligibility criteria.

### Data extraction and study quality assessment

We employed the Risk of Bias in Systematic Reviews (ROBIS) tool to assess the quality of the included systematic reviews. The ROBIS tool involves the assessment of 4 domains: study eligibility criteria; identification and selection of studies; data collection and study appraisal; and synthesis and findings [9]. Finally, an overall evaluation was rated as low, unclear, or high by considering the following issues: the interpretation of findings addressed all the concerns identified in the above domains; the relevance of the included studies to the review's research question; and the emphasizing of the results based on statistical significance. The risk of bias of each systematic review was independently evaluated by 2 researchers. Any discrepancies were resolved by discussion.

### Quantitative synthesis

We performed re-meta-analyses of the individual studies included in the earlier systematic reviews to examine the association between dietary sodium and obesity. Due to significant clinical and methodological heterogeneity (e.g., various levels of sodium intake, different characteristics of participants), we used a random effects model for the meta-analyses. To examine the degree of statistical heterogeneity, we utilized the $I^2$ index. The cut-off values were 25% for low, 50% for moderate, and 75% for high heterogeneity for the descriptive purpose [10]. Meta-analyses were conducted in STATA/SE 17 (Stata Corp., College Station, TX, USA). Less than 0.05 of 2-tailed *P*-values were considered statistically significant.

### Narrative synthesis

We narratively described the findings of the systematic review without meta-analysis in this research.

## RESULTS

### Characteristics of individual reviews

The initial search generated 1,069 citations. Then, we conducted the abstract screening and selected 21 possibly relevant articles for full-text screening. Finally, we selected 3 systematic reviews (2 systematic reviews with meta-analyses and 1 systematic review without meta-analysis) that met the inclusion criteria. The study selection process is shown in **Fig. 1**. Included 3 systematic reviews were published between 2016 and 2021 [11-13]. **Table 1** shows a summary of review characteristics. One systematic review included RCTs and observational studies [11], while 2 systematic reviews included only observational studies [12,13]. Moosavian *et al.* [12] performed a meta-analysis of studies with the inclusion of both children and adults, while Grimes *et al.* [11] implemented a meta-analysis among children and adults separately [11]. Because the specific aim of this study was to investigate the association between sodium intake and adiposity outcomes across sodium intake assessments, we analyzed subgroup analyses with the use of the individual studies only in adults included in the past 2 systematic reviews [11,12]. The risk of bias for observational studies was evaluated by a modified version of the Newcastle-Ottawa Scale in the included 2 systematic reviews


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**Table 1.** Characteristics of individual reviews

| Author/Year | Review aim | Search strategy | Included studies in meta-analysis or narrative synthesis for this review | PICOS | Risk of bias |
|---|---|---|---|---|---|
| Grimes *et al*. (2021) [11] | To investigate the association between dietary sodium intake and adiposity | MEDLINE Complete (EBSCO Host), CINAHL (EBSCO Host), Scopus, Embase and CENTRAL | · Cross-sectional studies (n = 25)<br>· Longitudinal studies (n = 4)<br>· RCTs (n = 15) | · Population: humans<br>· Intervention/exposure: high intake of sodium (observational study)/sodium-reduced diet (RCT)<br>· Comparator: low intake of sodium (observational study)/usual or control diet (RCT)<br>· Outcome: BMI, body weight, abdominal adiposity, body composition<br>· Study type: observational study, RCT | · A modified version of the NOS for observational studies<br>· A modified version of the Cochrane Collaboration risk of bias for RCTs |
| Moosavian *et al*. (2017) [12] | To examine the association between sodium intake and obesity | MEDLINE, Google Scholar, and Scopus | Cross-sectional studies (n = 14) | · Population: humans<br>· Intervention/exposure: high intake of sodium<br>· Comparator: low intake of sodium<br>· Outcome: weight, waist circumference, BMI, overweight, obesity, fat mass and adiposity<br>· Study type: observational study | A modified version of the NOS |
| Kang *et al*. (2016) [13] | To identify the association between sodium intake and obesity | KMbase, KoreaMed, NDSL, DBpia, RISS, KISS | Cross-sectional studies (n = 5) | · Population: Koreans<br>· Intervention/exposure: high intake of sodium<br>· Comparator: low intake of sodium<br>· Outcome: overweight/obesity, waist circumference, body fat<br>· Study type: observational study | NI |

PICOS, Population, Intervention/exposure, Comparator, Outcome, and Study type; NI, no information; RCT, randomized controlled trial; NOS, Newcastle-Ottawa Scale; BMI, body mass index; CINAHL, Cumulative Index to Nursing and Allied Health Literature; CENTRAL, Cochrane Central Register of Controlled Trials; NDSL, National Discovery for Science Library; RISS, Research Information Sharing Service; KISS, Korean Information Service System.

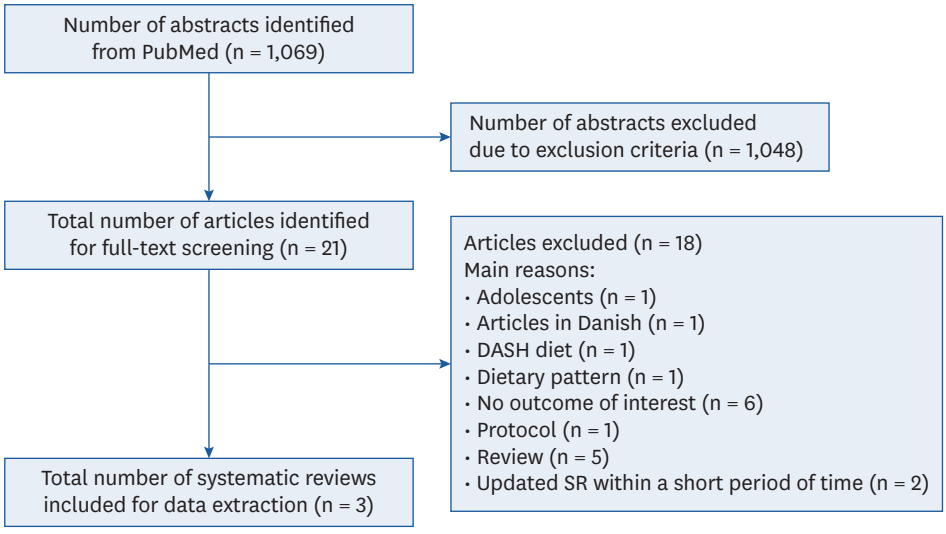


**Fig. 1.** Literature search and study selection process.
DASH, Dietary Approaches to Stop Hypertension; SR, systematic review.

[11,12]. The risk of bias for RCTs was evaluated using a modified version of the Cochrane Collaboration in one systematic review [11]. However, the remaining systematic review did not include information related to the risk of bias for the included studies [13].

The results of the ROBIS evaluation are shown in **Table 2**. Regarding study eligibility criteria (domain 1), a clear definition of the search criteria revealed that all included systematic reviews were at low risk [11,12]. However, concern regarding methods used to identify and select studies (domain 2) was considered by Kang *et al.* [13], who did not include methods beyond database searching to identify relevant studies [13]. In the domain of data


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**Table 2.** Risk of bias using the Risk of Bias in Systematic Reviews tool

| Author/Year | Study eligibility criteria | Identification and selection of studies | Data collection and study appraisal | Synthesis and findings | Risk of bias in the review |
|---|---|---|---|---|---|
| Grimes *et al*. (2021) [11] | Low | Low | Low | Low | Low |
| Moosavian *et al*. (2017) [12] | Low | Low | Low | Low | Low |
| Kang *et al*. (2016) [13] | Low | High | High | NA[1)] | High |

NA, not applicable.
[1)]Because the population of interest was limited to Koreans, there were not enough studies to implement quantitative synthesis.

collection (domain 3), 2 systematic reviews described sufficient study characteristics extracted by independent reviewers [11,12], while the remaining systematic review was not reported with regard to this [13]. Because an adequate tool to assess the risk of bias was used in only 2 systematic reviews, Kang *et al.* [13] raised an additional concern regarding quality assessment for the included studies. Overall, one systematic review was rated as being at high risk of bias [13].

## Meta-analysis findings

*BMI: cross-sectional studies*

We performed a subgroup analysis for 28 cross-sectional studies that reported an association between dietary sodium intake and BMI (**Fig. 2**). The included unique studies utilized: (1) 24-h urine in 11 studies [14-24]; (2) spot urine in 9 studies [25-33]; (3) dietary methods in 7 studies [34-40]; and (4) overnight urine in 1 study [41].The results from this pooled analysis (38 effect sizes) indicated that BMI was significantly greater among adults in the highest intake group of sodium compared to those in the lowest intake group of sodium (BMI mean difference = 1.52 kg/m$^2$; 95% confidence interval [CI], 1.24–1.80; $P < 0.001$; $I^2 = 97\%$), presenting considerable heterogeneity. When we implemented the subgroup analysis by sodium intake assessment method, the greatest BMI was seen in studies that used 24-h urine to examine sodium intake (BMI mean difference = 2.27 kg/m$^2$; 95% CI, 1.59–2.51; $P < 0.001$; $I^2$

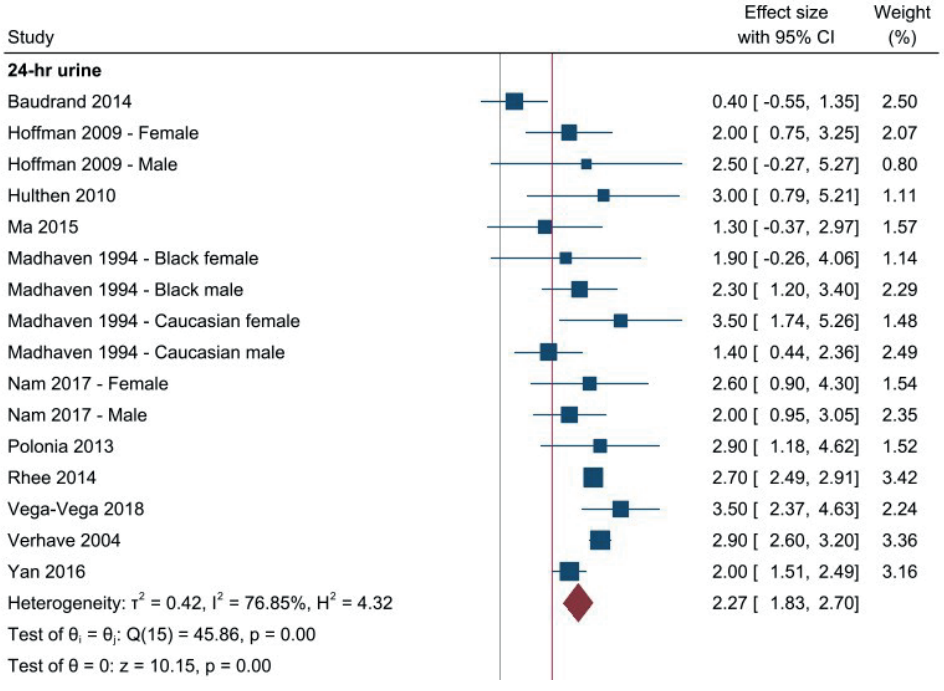


**Fig. 2.** Pooled mean difference in body mass index by sodium intake assessment.
CI, confidence interval; REML, Restricted Maximum Likelihood.

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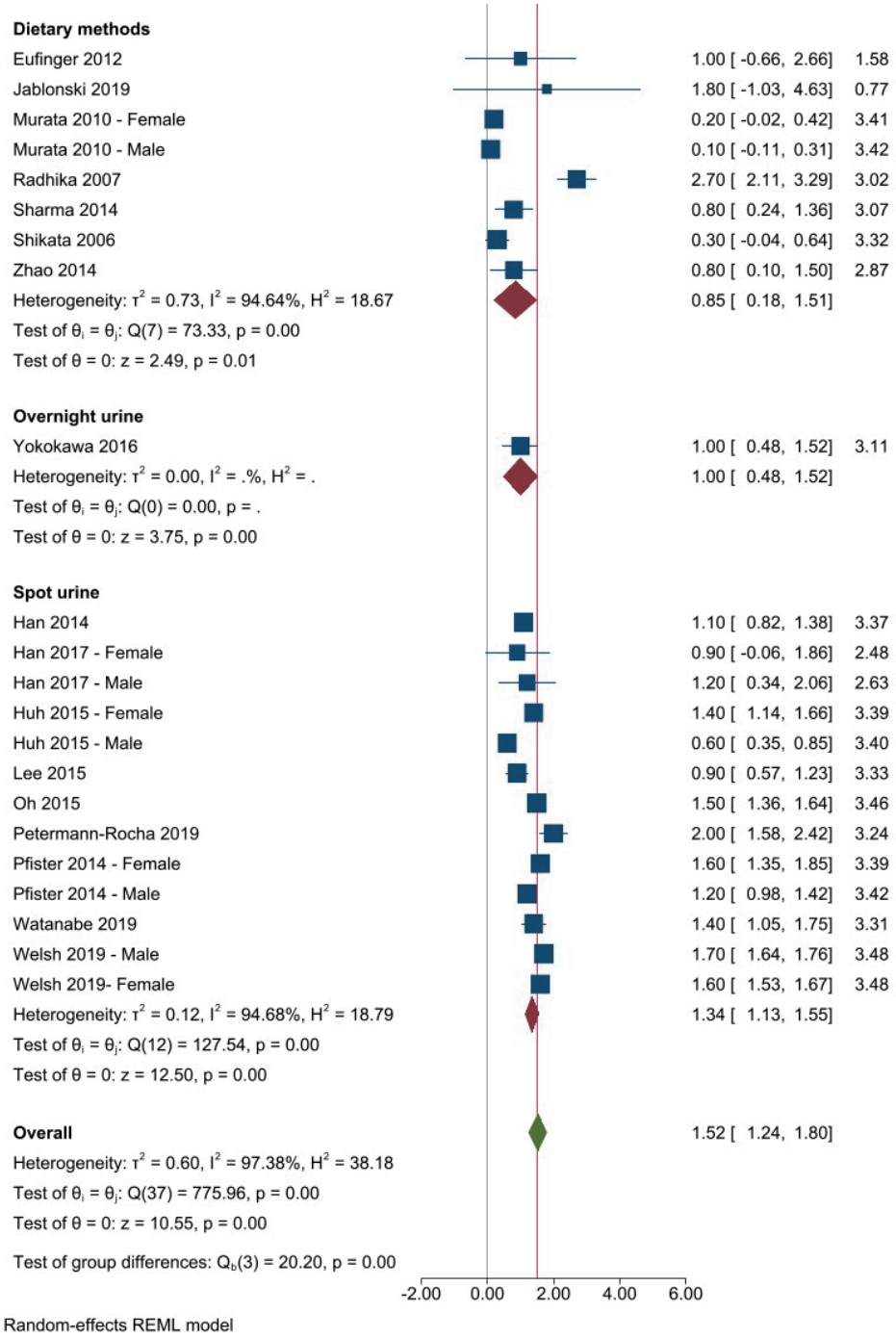


**Fig. 2.** (Continued) Pooled mean difference in body mass index by sodium intake assessment.
CI, confidence interval; REML, Restricted Maximum Likelihood.

= 77%), followed by: (1) spot urine (BMI mean difference = 1.34 kg/m$^2$; 95% CI, 1.13–1.55; $P$ < 0;001; $I^2$ = 95%); (2) overnight urine (BMI mean difference = 1.00 kg/m$^2$; 95% CI, 0.48–1.52; $P$ < 0.001); and (3) dietary methods (BMI mean difference = 0.85 kg/m$^2$; 95% CI, 0.18–1.51; $P$ < 0.05; $I^2$ = 95%).


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*Risk of overweight/obesity: cross-sectional studies*

We implemented a meta-analysis of 5 cross-sectional studies (8 effect sizes) (**Fig. 3**) [19,26,31,42,43]. The findings from this pooled analysis show that higher sodium intake was significantly associated with an increased risk of overweight or obesity (odds ratio [OR], 1.75; 95% CI, 1.40–2.18, $P < 0.001$; $I^2 = 72\%$), presenting substantial heterogeneity. In a subgroup analysis by the sodium intake assessment, the risk of overweight/obesity was not significantly different across the group. A higher level of dietary sodium intake was significantly associated with a risk of overweight/obesity in studies that used the 24-h urine (OR, 2.44; 95% CI, 1.67–3.56; $P < 0.001$; $I^2 = 59\%$) [19,42] and dietary methods (OR, 1.48; 95% CI, 1.17–1.88; $P < 0.001$; $I^2 = 16\%$) [43]. However, in studies that used spot urine, there was no association between dietary sodium intake and the risk of overweight/obesity [26,31].

*Body weight: cross-sectional studies*

The findings from a meta-analysis of 7 cross-sectional studies (12 effect sizes) indicated that body weight was significantly greater among adults in the highest group of dietary sodium intake (body weight mean difference = 8.28 kg; 95% CI, 6.69–9.86; $P < 0.001$; $I^2 = 66\%$), presenting substantial heterogeneity (**Fig. 4**) [15,16,18,19,21,34,41]. The results of a

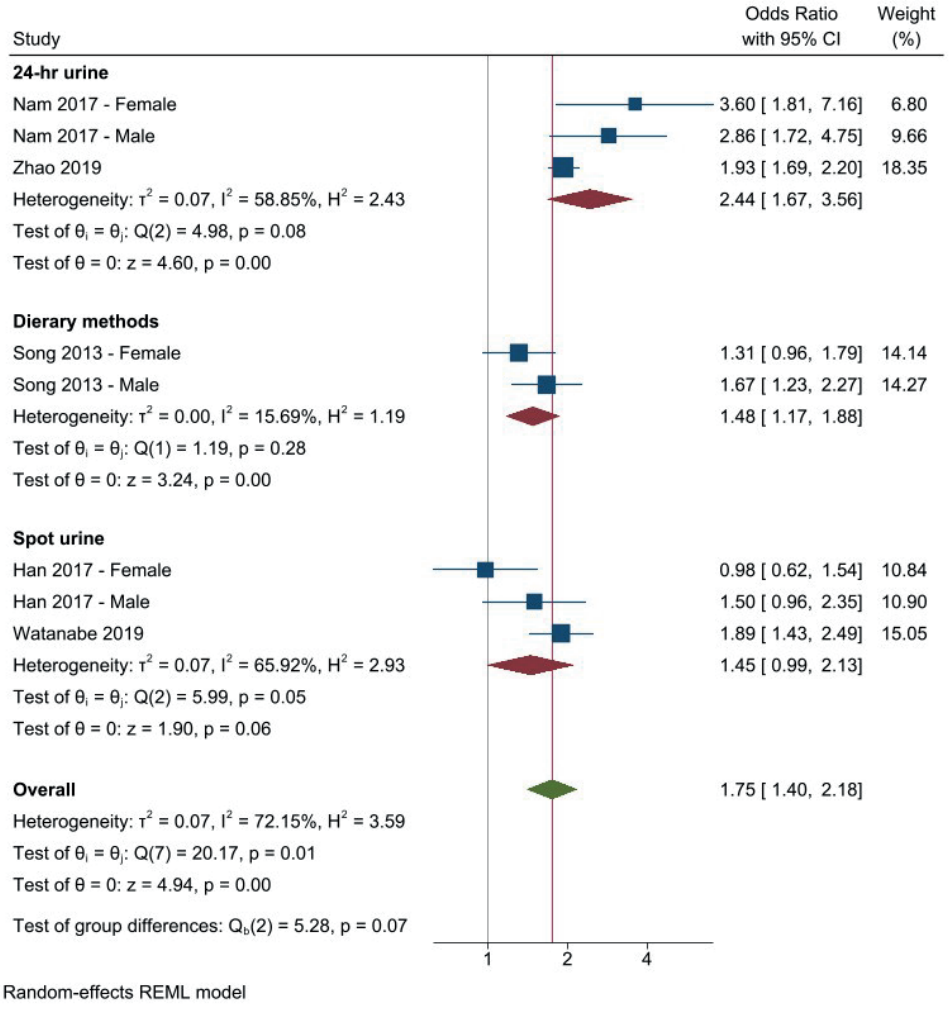


**Fig. 3.** Pooled risk of overweight or obesity by sodium intake assessment.
OR, odds ratio; CI, confidence interval; REML, Restricted Maximum Likelihood.


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subgroup analysis showed that body weight was greatest in studies that used 24-h urine (body weight mean difference = 9.00 kg; 95% CI, 7.53–10.48; $P < 0.001$; $I^2 = 46\%$) [15,16,18,19,21], followed by those that used overnight urine (body weight mean difference = 5.00 kg; 95% CI, 3.46–6.54; $P < 0.001$) [41]. Studies that used dietary methods showed that there was an insignificant relationship between dietary salt intake and body weight [34].

*Waist circumference: cross-sectional studies*

We performed a meta-analysis of 10 cross-sectional studies (13 effect sizes) (**Fig. 5**) [15,17,19,23,25,27-30,37]. The results of this meta-analysis showed that higher sodium intake was significantly associated with an increase in waist circumference (waist circumference mean difference = 4.99 cm; 95% CI, 4.00–5.99; $P < 0.001$; $I^2 = 89\%$), presenting considerable heterogeneity. In a subgroup analysis by sodium intake assessment, waist circumference was greater in studies that used 24-h urine (waist circumference mean difference = 6.34 cm; 95% CI, 5.27–7.42; $P < 0.001$; $I^2 = 0\%$) [15,17,19,23] compared to those that utilized spot urine

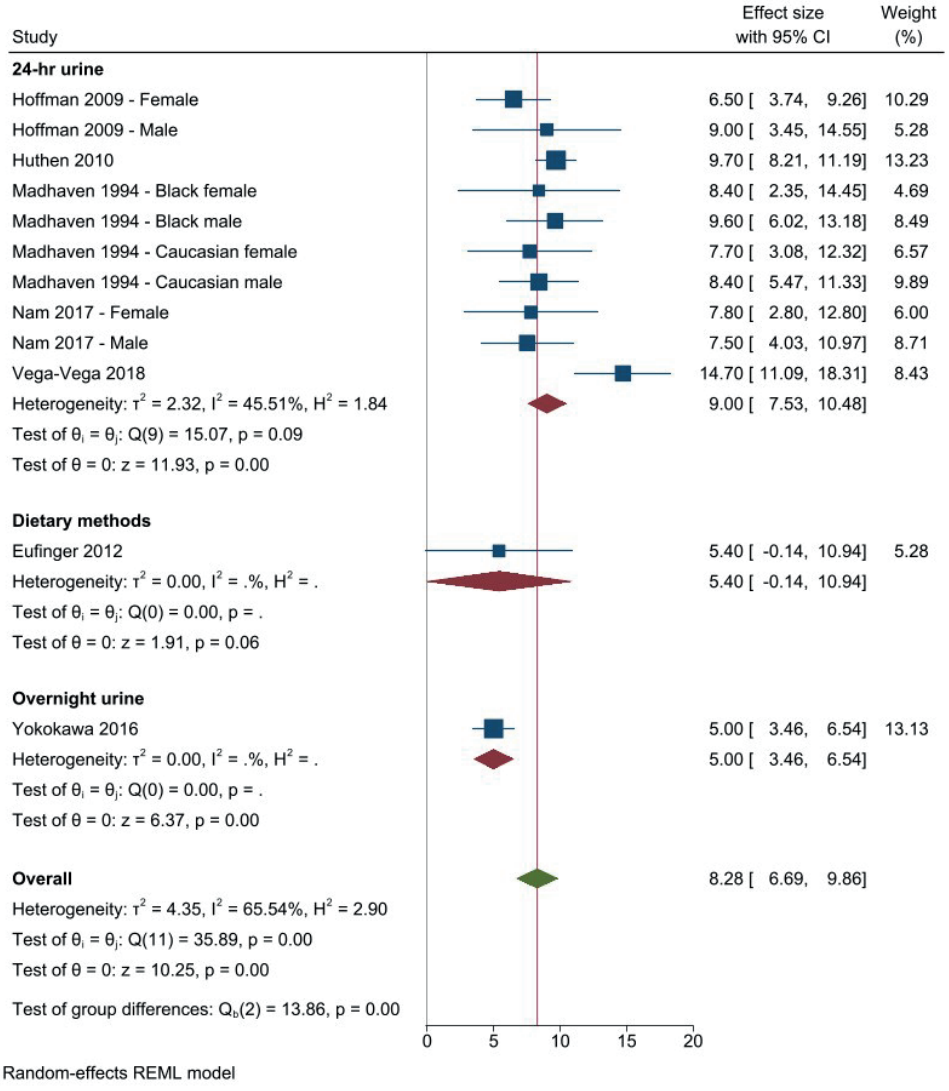


**Fig. 4.** Pooled mean difference in body weight by sodium intake assessment.
CI, confidence interval; REML, Restricted Maximum Likelihood.


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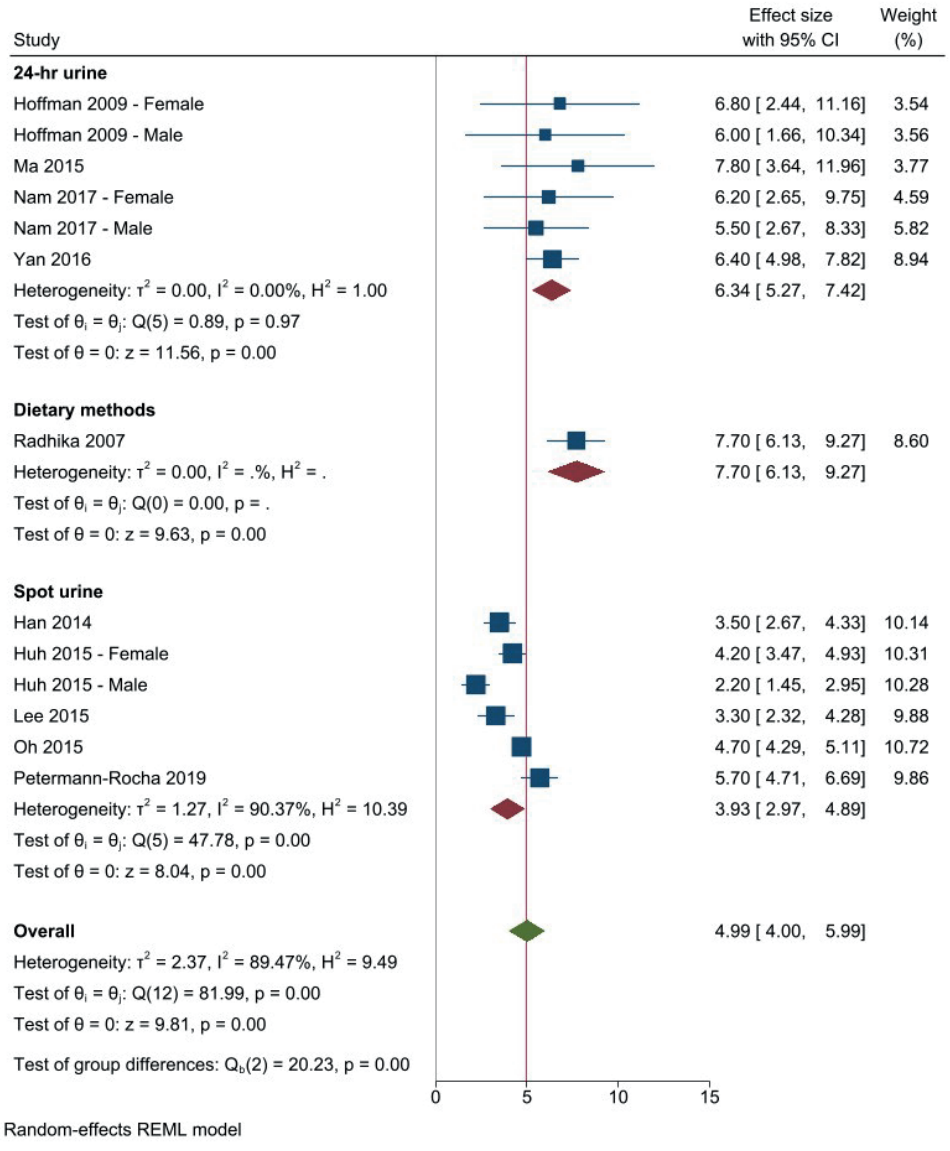


**Fig. 5.** Pooled mean difference in waist circumference by sodium intake assessment.
CI, confidence interval; REML, Restricted Maximum Likelihood.

(waist circumference mean difference = 3.93 cm; 95% CI, 2.97–4.89; $P < 0.001$; $I^2 = 90\%$) [25,27-29]. Additionally, one study utilizing the dietary method showed that higher sodium intake is significantly associated with greater waist circumference (waist circumference mean difference = 7.70 cm; 95% CI, 6.13–9.27; $P < 0.001$) [37].

*Abdominal obesity: cross-sectional studies*

We employed a meta-analysis of 5 cross-sectional studies (7 effect sizes) to investigate the association between dietary sodium intake and abdominal obesity (**Fig. 6**) [19,27,42,44,45]. The findings from this pooled analysis showed that higher sodium intake was significantly associated with an increased risk of abdominal obesity (OR, 2.05; 95% CI, 1.72–2.44; $P < 0.001$; $I^2 = 67\%$), presenting substantial heterogeneity. Subgroup analysis by sodium intake assessment showed that the association between dietary sodium intake and the risk of


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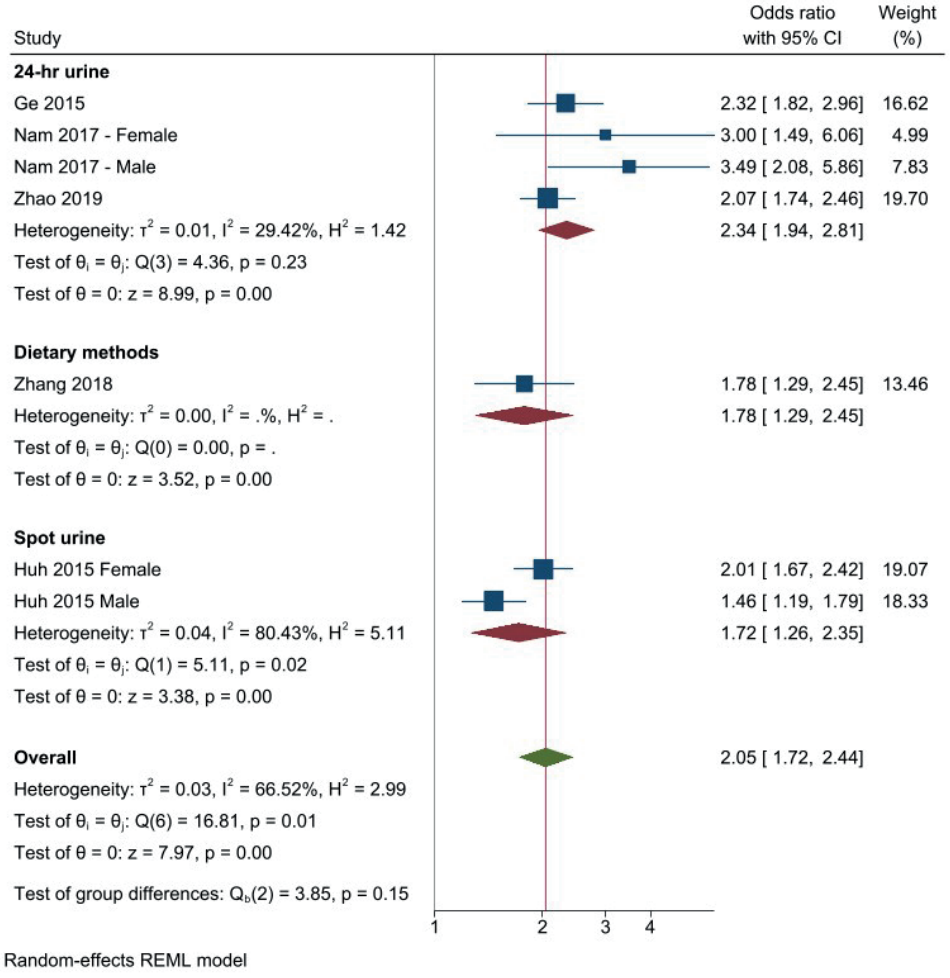


**Fig. 6.** Pooled risk of abdominal obesity by sodium intake assessment.
OR, odds ratio; CI, confidence interval; REML, Restricted Maximum Likelihood.

abdominal obesity was not significantly different among groups. There was a significant association between dietary sodium intake and the risk of abdominal obesity in all 3 groups: (1) 24-h urine (OR, 2.34; 95% CI, 1.94–2.81; $P < 0.001$; $I^2 = 29\%$) [19,42,44]; (2) dietary methods (OR, 1.78; 95% CI, 1.29–2.45; $P < 0.001$) [45]; and (3) spot urine (OR, 1.72; 95% CI, 1.26–2.35; $P < 0.001$) [27].

*Body weight: RCTs*

The prior systematic review included 15 RCTs with durations ranging from 3 mon to 4 yrs. Included RCTs were conducted in various countries: (1) 4 in the USA; (2) 3 in the UK; (3) 3 in Australia; and (4) 1 in the Netherlands, 1 in Italy, 1 in Belgium, 1 in Japan, and 1 in China. Ten RCTs employed nutrition education or nutrition counseling and behavioral strategies to reduce sodium intake. Grimes *et al.* [11] performed a pooled analysis of RCTs to examine the effects of a reduced sodium diet on body weight. The findings of 15 RCTs reported that reduced-sodium diets compared to a usual diet or control diet showed non-significant effects on body weight [46-60].


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**Table 3.** Results of individual reviews that state a narrative synthesis for obesity-related outcomes

| Author/Year | Study types (sodium intake assessment) | Outcomes | Narrative synthesis |
|---|---|---|---|
| Grimes *et al*. (2021) [11] | Longitudinal studies<br>· Larsen *et al*. (2013) (24-h urine) [4]<br>· Ard *et al*. (2004) (24-h urine) [61]<br>· Sakaki *et al*. (2014) (diet history) [62]<br>· Takahashi *et al*. (2006) (24-h urine) [63] | Body weight | No change in body weight in 4 studies |
| | Longitudinal study<br>· Larsen *et al*. (2013) (24-h urine) [4] | Waist circumstance | No change in waist circumference in 1 study |
| | Longitudinal study<br>· Larsen *et al*. (2013) (24-h urine) [4] | Body fat | Per 100 mmol/d increase in sodium → Significant increase in body fat in 1 study |
| | Longitudinal study<br>· Larsen *et al*. (2013) (24-h urine) [4] | Fat free mass | Per 100 mmol/d increase in sodium → Significant decrease in fat free mass in 1 study |
| Kang *et al*. (2016) [13] | Cross-sectional study<br>· Song *et al*. (2013) (dietary method) [43] | Risk of being overweight | · Males: higher sodium intake → Significantly increased risk of being overweight<br>· Females: no association |
| | Cross-sectional study<br>· Kim *et al*. (2015) (dietary method) [64] | Risk of obesity | · Males: ≥ 4 g vs. < 2 g of sodium intake → Significantly increased risk of obesity<br>· Females: no association |
| | Cross-sectional study<br>· Lim and Yang (2014) (dietary method) [65] | Waist circumference | Higher sodium intake was significantly associated with greater waist circumference |
| | Cross-sectional study<br>· Oh *et al*. (2015) (24-h urine) [66] | Risk of abdominal obesity | Higher sodium intake was significantly associated with a higher risk of abdominal obesity |
| | Cross-sectional study<br>· Oh *et al*. (2015) (spot urine) [29] | Body fat | Higher sodium intake was significantly associated with higher body fat |

### Narrative synthesis

*Obesity-related outcomes: longitudinal studies*

Grimes *et al.* [11] included 4 longitudinal studies to examine the association between dietary sodium intake and obesity outcomes. Four studies showed that higher sodium intake did not change body weight [4,61-63] (**Table 3**). One study indicated that higher sodium intake did not increase waist circumference [4]. However, higher sodium intake significantly increased body fat [4] but decreased fat free mass per a 100 mmol/d sodium increase [4].

*Obesity-related outcomes: a systematic review including only Korean studies*

Kang *et al.* [13] included only Korean studies that examined the association between dietary sodium intake and obesity-related outcomes. Two studies suggested that higher sodium intake increased the risk of overweight/obesity in males but not in females [43,64]. Higher sodium intake was significantly associated with: (1) greater waist circumference in one study [65]; (2) increased risk of abdominal obesity in one study [66]; and (3) increased body fat in one study [29].

## DISCUSSION

The main findings from this review of systematic reviews and re-meta-analysis indicated consistently positive associations between dietary sodium intake and obesity-related outcomes in cross-sectional studies. Additionally, subgroup analyses showed that the associations between dietary sodium intake and obesity outcomes (i.e., BMI, body weight, and waist circumference) were significantly different across sodium intake assessments. Compared to studies utilizing 24-h urine collection, the other sodium intake assessments (spot or overnight urine and dietary methods) tend to underestimate the sodium-obesity association in cross-sectional studies. This review of the systematic reviews provides useful


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information to detect the difference in the association between sodium intake and obesity-related outcomes by sodium intake assessment.

The possible biological mechanisms could explain this positive association between dietary sodium intake and obesity. First, salt treatment increased adipogenesis/lipogenesis and pro-inflammatory adipocytokine secretion. However, it decreased lipolysis in a dose-dependent manner in adipocytes, suggesting inflammatory adipogenesis as a possible mechanism [67]. Second, endogenous fructose production was identified as the primary mechanism regarding salt-induced obesity in high-salt-fed mice [68]. High-salt-diet-fed rats were also associated with increased adipose tissue mass by enhancing insulin-stimulated glucose uptake and lipogenic capacity [69,70]. Third, a high-salt diet (18 g/day) increased significantly fasting ghrelin levels compared to a normal salt diet (3 g/day) in normotensive subjects, indicating that increased ghrelin induced obesity by stimulating appetite, fat accumulation, and glucose intolerance [71]. In addition, increased salt intake (6 g/day) decreased significantly diet-induced thermogenesis compared to the placebo group, which contributes to increased weight gain [72].

To identify the association between sodium intake and obesity, it is critical to use a valid, reliable tool for assessing sodium intake. Twenty-four urine collection is known to be the gold standard method for the assessment of dietary sodium intake [7], as about 90% of ingested sodium is excreted in urine within 24 h [73]. Because participants would carry a considerable burden with 24-h urine collection, some researchers tend to utilize more convenient or affordable alternatives such as spot or overnight urine and dietary assessments. However, this dietary assessment intake is limited to reflecting dietary sodium intake due to the variable of sodium content from food sources (e.g., home-cooked foods, restaurant foods, or processed foods), the omission of discretionary salt use, and the under-reporting of problems, especially for obese participants [7]. Spot or overnight urine samples are influenced by many non-dietary sources. Short-term urine samples would varied sodium content due to hydration status, body standing position, time of day, natriuretic or diuretic substance (e.g., caffeine), and disease status (e.g., renal disease and cardiac diseases) [74,75]. Consequently, short-term urine collection (i.e., spot urine or overnight urine) and dietary assessment methods could not replace 24-h urine.

Major scientific organizations have raised concerns about research methods for sodium intake assessments. Spot and short-duration timed urine collection methods show systematic errors in estimating an individual's sodium intake [76,77]. The International Consortium for Quality Research on Dietary Sodium/Salt (TRUE) recommends that single spot or short-duration timed urine collections not be used for assessments of dietary sodium intake of individuals especially related to health outcomes [74]. Consequently, it is critical to identify the association between sodium intake and obesity outcomes by utilizing a valid sodium assessment tool such as 24-h urine collection.

We concluded that there is a cross-sectional association between sodium intake and adiposity outcomes. These cross-sectional associations between dietary sodium and obesity were significantly different across sodium intake assessments. Studies that used spot or overnight urine tended to underestimate the sodium-obesity association compared to those utilizing 24-h urine collection. The limitation of this review is that we used only the PubMed database to search for relevant studies. It is recommended that more databases be used to conduct comprehensive searches. Another limitation is that some observational studies did not control


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for confounding factors for obesity-related outcomes. To identify the causal effects of sodium intake on obesity, we need more high-quality RCTs with the provision of a sodium-reduced diet or foods and a large number of prospective cohort studies that use 24-h urine collection.

## SUPPLEMENTARY MATERIAL

### Supplementary Table 1

Search strategy: PubMed (search date: 10/24/2022)

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## REFERENCES

1. NCD Risk Factor Collaboration (NCD-RisC). Trends in adult body-mass index in 200 countries from 1975 to 2014: a pooled analysis of 1698 population-based measurement studies with 19·2 million participants. Lancet 2016;387:1377-96.
PUBMED | CROSSREF
2. Ansari S, Haboubi H, Haboubi N. Adult obesity complications: challenges and clinical impact. Ther Adv Endocrinol Metab 2020;11:2042018820934955.
PUBMED | CROSSREF
3. Hruby A, Hu FB. The epidemiology of obesity: a big picture. Pharmacoeconomics 2015;33:673-89.
PUBMED | CROSSREF
4. 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:e69689.
PUBMED | CROSSREF
5. Yi SS, Firestone MJ, Beasley JM. Independent associations of sodium intake with measures of body size and predictive body fatness. Obesity (Silver Spring) 2015;23:20-3.
PUBMED | CROSSREF
6. Yoon YS, Oh SW. Sodium density and obesity; the Korea National Health and Nutrition Examination Survey 2007-2010. Eur J Clin Nutr 2013;67:141-6.
PUBMED | CROSSREF
7. McLean RM. Measuring population sodium intake: a review of methods. Nutrients 2014;6:4651-62.
PUBMED | CROSSREF
8. Grimes CA, Bolhuis DP, He FJ, Nowson CA. Dietary sodium intake and overweight and obesity in children and adults: a protocol for a systematic review and meta-analysis. Syst Rev 2016;5:7.
PUBMED | CROSSREF
9. Whiting P, Savović J, Higgins JP, Caldwell DM, Reeves BC, Shea B, Davies P, Kleijnen J, Churchill R; ROBIS group. ROBIS: a new tool to assess risk of bias in systematic reviews was developed. J Clin Epidemiol 2016;69:225-34.
PUBMED | CROSSREF
10. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. BMJ 2003;327:557-60.
PUBMED | CROSSREF
11. Grimes CA, Bolton KA, Booth AB, Khokhar D, Service C, He FH, Nowson CA. The association between dietary sodium intake, adiposity and sugar-sweetened beverages in children and adults: a systematic review and meta-analysis. Br J Nutr 2021;126:409-27.
PUBMED | CROSSREF
12. Moosavian SP, Haghighatdoost F, Surkan PJ, Azadbakht L. Salt and obesity: a systematic review and meta-analysis of observational studies. Int J Food Sci Nutr 2017;68:265-77.
PUBMED | CROSSREF
13. Kang YJ, Wang HW, Cheon SY, Lee HJ, Hwang KM, Yoon HS. Associations of obesity and dyslipidemia with intake of sodium, fat, and sugar among Koreans: a qualitative systematic review. Clin Nutr Res 2016;5:290-304.
PUBMED | CROSSREF

14. Baudrand R, Campino C, Carvajal CA, Olivieri O, Guidi G, Faccini G, Vöhringer PA, Cerda J, Owen G, Kalergis AM, et al. High sodium intake is associated with increased glucocorticoid production, insulin resistance and metabolic syndrome. Clin Endocrinol (Oxf) 2014;80:677-84.
PUBMED | CROSSREF

15. Hoffmann IS, Cubeddu LX. Salt and the metabolic syndrome. Nutr Metab Cardiovasc Dis 2009;19:123-8.
PUBMED | CROSSREF

16. Hulthén L, Aurell M, Klingberg S, Hallenberg E, Lorentzon M, Ohlsson C. Salt intake in young Swedish men. Public Health Nutr 2010;13:601-5.
PUBMED | CROSSREF

17. Ma Y, He FJ, MacGregor GA. High salt intake: independent risk factor for obesity? Hypertension 2015;66:843-9.
PUBMED | CROSSREF

18. Madhavan S, Alderman MH. Ethnicity and the relationship of sodium intake to blood pressure. J Hypertens 1994;12:97-103.
PUBMED | CROSSREF

19. Nam GE, Kim SM, Choi MK, Heo YR, Hyun TS, Lyu ES, Oh SY, Park HR, Ro HK, Han K, et al. Association between 24-h urinary sodium excretion and obesity in Korean adults: a multicenter study. Nutrition 2017;41:113-9.
PUBMED | CROSSREF

20. Polonia JJ, Magalhaes MT, Senra D, Barbosa L, Silva JA, Ribeiro SM. Association of 24-h urinary salt excretion with central haemodynamics and assessment of food categories contributing to salt consumption in Portuguese patients with hypertension. Blood Press Monit 2013;18:303-10.
PUBMED | CROSSREF

21. Vega-Vega O, Fonseca-Correa JI, Mendoza-De la Garza A, Rincón-Pedrero R, Espinosa-Cuevas A, Baeza-Arias Y, Dary O, Herrero-Bervera B, Nieves-Anaya I, Correa-Rotter R. Contemporary dietary intake: too much sodium, not enough potassium, yet sufficient iodine: the SALMEX Cohort results. Nutrients 2018;10:816.
PUBMED | CROSSREF

22. Verhave JC, Hillege HL, Burgerhof JG, Janssen WM, Gansevoort RT, Navis GJ, de Zeeuw D, de Jong PE; PREVEND Study Group. Sodium intake affects urinary albumin excretion especially in overweight subjects. J Intern Med 2004;256:324-30.
PUBMED | CROSSREF

23. Yan L, Guo X, Wang H, Zhang J, Tang J, Lu Z, Cai X, Liu L, Gracely EJ, Ma J. Population-based association between urinary excretion of sodium, potassium and its ratio with albuminuria in Chinese. Asia Pac J Clin Nutr 2016;25:785-97.
PUBMED

24. Rhee MY, Kim JH, Kim YS, Chung JW, Bae JH, Nah DY, Kim YK, Lee MM, Lim CY, Byun JE, et al. High sodium intake in women with metabolic syndrome. Korean Circ J 2014;44:30-6.
PUBMED | CROSSREF

25. Han SY, Hong JW, Noh JH, Kim DJ. Association of the estimated 24-h urinary sodium excretion with albuminuria in adult Koreans: the 2011 Korea National Health and Nutrition Examination Survey. PLoS One 2014;9:e109073.
PUBMED | CROSSREF

26. Han W, Hu Y, Tang Y, Xue F, Hou L, Liang S, Zhang B, Wang W, Asaiti K, Pang H, et al. Relationship between urinary sodium with blood pressure and hypertension among a Kazakh community population in Xinjiang, China. J Hum Hypertens 2017;31:333-40.
PUBMED | CROSSREF

27. Huh JH, Lim JS, Lee MY, Chung CH, Shin JY. Gender-specific association between urinary sodium excretion and body composition: analysis of the 2008-2010 Korean National Health and Nutrition Examination Surveys. Metabolism 2015;64:837-44.
PUBMED | CROSSREF

28. Lee SK, Kim JS, Kim SH, Kim YH, Lim HE, Kim EJ, Park CG, Cho GY, Kim J, Baik I, et al. Sodium excretion and cardiovascular structure and function in the nonhypertensive population: the Korean Genome and Epidemiology Study. Am J Hypertens 2015;28:1010-6.
PUBMED | CROSSREF

29. Oh SW, Han KH, Han SY, Koo HS, Kim S, Chin HJ. Association of sodium excretion with metabolic syndrome, insulin resistance, and body fat. Medicine (Baltimore) 2015;94:e1650.
PUBMED | CROSSREF

30. Petermann-Rocha F, Sillars A, Brown R, Sweeney L, Troncoso C, García-Hermoso A, Leiva AM, Martínez MA, Diaz-Martínez X, Poblete-Valderrama F, et al. Sociodemographic patterns of urine sodium

excretion and its association with hypertension in Chile: a cross-sectional analysis. Public Health Nutr 2019;22:2012-21.
PUBMED | CROSSREF

31. Watanabe S, Konta T, Ichikawa K, Watanabe M, Ishizawa K, Ueno Y, Yamashita H, Kayama T, Kubota I. The association between urinary sodium excretion and blood pressure in a community-based population: the Yamagata (Takahata) study. Clin Exp Nephrol 2019;23:380-6.
PUBMED | CROSSREF

32. Pfister R, Michels G, Sharp SJ, Luben R, Wareham NJ, Khaw KT. Estimated urinary sodium excretion and risk of heart failure in men and women in the EPIC-Norfolk study. Eur J Heart Fail 2014;16:394-402.
PUBMED | CROSSREF

33. Welsh CE, Welsh P, Jhund P, Delles C, Celis-Morales C, Lewsey JD, Gray S, Lyall D, Iliodromiti S, Gill JM, et al. Urinary sodium excretion, blood pressure, and risk of future cardiovascular disease and mortality in subjects without prior cardiovascular disease. Hypertension 2019;73:1202-9.
PUBMED | CROSSREF

34. Eufinger SC, Votaw J, Faber T, Ziegler TR, Goldberg J, Bremner JD, Vaccarino V. Habitual dietary sodium intake is inversely associated with coronary flow reserve in middle-aged male twins. Am J Clin Nutr 2012;95:572-9.
PUBMED | CROSSREF

35. Jablonski KL, Gates PE, Pierce GL, Seals DR. Low dietary sodium intake is associated with enhanced vascular endothelial function in middle-aged and older adults with elevated systolic blood pressure. Ther Adv Cardiovasc Dis 2009;3:347-56.
PUBMED | CROSSREF

36. Murata A, Fujino Y, Pham TM, Kubo T, Mizoue T, Tokui N, Matsuda S, Yoshimura T. Prospective cohort study evaluating the relationship between salted food intake and gastrointestinal tract cancer mortality in Japan. Asia Pac J Clin Nutr 2010;19:564-71.
PUBMED

37. Radhika G, Sathya RM, Sudha V, Ganesan A, Mohan V. Dietary salt intake and hypertension in an urban south Indian population--[CURES - 53]. J Assoc Physicians India 2007;55:405-11.
PUBMED

38. Sharma S, McFann K, Chonchol M, Kendrick J. Dietary sodium and potassium intake is not associated with elevated blood pressure in US adults with no prior history of hypertension. J Clin Hypertens (Greenwich) 2014;16:418-23.
PUBMED | CROSSREF

39. Shikata K, Kiyohara Y, Kubo M, Yonemoto K, Ninomiya T, Shirota T, Tanizaki Y, Doi Y, Tanaka K, Oishi Y, et al. A prospective study of dietary salt intake and gastric cancer incidence in a defined Japanese population: the Hisayama study. Int J Cancer 2006;119:196-201.
PUBMED | CROSSREF

40. Zhao X, Yin X, Li X, Yan LL, Lam CT, Li S, He F, Xie W, Sang B, Luobu G, et al. Using a low-sodium, high-potassium salt substitute to reduce blood pressure among Tibetans with high blood pressure: a patient-blinded randomized controlled trial. PLoS One 2014;9:e110131.
PUBMED | CROSSREF

41. Yokokawa H, Yuasa M, Nedsuwan S, Moolphate S, Fukuda H, Kitajima T, Minematsu K, Tanimura S, Marui E. Daily salt intake estimated by overnight urine collections indicates a high cardiovascular disease risk in Thailand. Asia Pac J Clin Nutr 2016;25:39-45.
PUBMED | CROSSREF

42. Zhao L, Cogswell ME, Yang Q, Zhang Z, Onufrak S, Jackson SL, Chen TC, Loria CM, Wang CY, Wright JD, et al. Association of usual 24-h sodium excretion with measures of adiposity among adults in the United States: NHANES, 2014. Am J Clin Nutr 2019;109:139-47.
PUBMED | CROSSREF

43. Song HJ, Cho YG, Lee HJ. Dietary sodium intake and prevalence of overweight in adults. Metabolism 2013;62:703-8.
PUBMED | CROSSREF

44. Ge Z, Guo X, Chen X, Tang J, Yan L, Ren J, Zhang J, Lu Z, Dong J, Xu J, et al. Association between 24 h urinary sodium and potassium excretion and the metabolic syndrome in Chinese adults: the Shandong and Ministry of Health Action on Salt and Hypertension (SMASH) study. Br J Nutr 2015;113:996-1002.
PUBMED | CROSSREF

45. Zhang X, Wang J, Li J, Yu Y, Song Y. A positive association between dietary sodium intake and obesity and central obesity: results from the National Health and Nutrition Examination Survey 1999-2006. Nutr Res 2018;55:33-44.
PUBMED | CROSSREF

46. Appel LJ, Espeland MA, Easter L, Wilson AC, Folmar S, Lacy CR. Effects of reduced sodium intake on hypertension control in older individuals: results from the Trial of Nonpharmacologic Interventions in the Elderly (TONE). Arch Intern Med 2001;161:685-93.
PUBMED | CROSSREF

47. Bulpitt CJ, Daymond M, Bulpitt PF, Ferrier G, Harrison R, Lewis PJ, Dollery CT. Is low salt dietary advice a useful therapy in hypertensive patients with poorly controlled blood pressure? Ann Clin Res 1984;16 Suppl 43:143-9.
PUBMED

48. Geleijnse JM, Witteman JC, Bak AA, den Breeijen JH, Grobbee DE. Reduction in blood pressure with a low sodium, high potassium, high magnesium salt in older subjects with mild to moderate hypertension. BMJ 1994;309:436-40.
PUBMED | CROSSREF

49. Kumanyika SK, Hebert PR, Cutler JA, Lasser VI, Sugars CP, Steffen-Batey L, Brewer AA, Cameron M, Shepek LD, Cook NR, et al. Feasibility and efficacy of sodium reduction in the Trials of Hypertension Prevention, phase I. Hypertension 1993;22:502-12.
PUBMED | CROSSREF

50. Nowson CA, Wattanapenpaiboon N, Pachett A. Low-sodium dietary approaches to stop hypertension-type diet including lean red meat lowers blood pressure in postmenopausal women. Nutr Res 2009;29:8-18.
PUBMED | CROSSREF

51. Petersen KS, Torpy DJ, Chapman IM, Guha S, Clifton PM, Turner K, Keogh JB. Food label education does not reduce sodium intake in people with type 2 diabetes mellitus. A randomised controlled trial. Appetite 2013;68:147-51.
PUBMED | CROSSREF

52. Beard TC, Cooke HM, Gray WR, Barge R. Randomised controlled trial of a no-added-sodium diet for mild hypertension. Lancet 1982;2:455-8.
PUBMED | CROSSREF

53. Dodson PM, Beevers M, Hallworth R, Webberley MJ, Fletcher RF, Taylor KG. Sodium restriction and blood pressure in hypertensive type II diabetics: randomised blind controlled and crossover studies of moderate sodium restriction and sodium supplementation. BMJ 1989;298:227-30.
PUBMED | CROSSREF

54. Gilleran G, O'Leary M, Bartlett WA, Vinall H, Jones AF, Dodson PM. Effects of dietary sodium substitution with potassium and magnesium in hypertensive type II diabetics: a randomised blind controlled parallel study. J Hum Hypertens 1996;10:517-21.
PUBMED

55. He FJ, Wu Y, Feng XX, Ma J, Ma Y, Wang H, Zhang J, Yuan J, Lin CP, Nowson C, et al. School based education programme to reduce salt intake in children and their families (School-EduSalt): cluster randomised controlled trial. BMJ 2015;350:h770.
PUBMED | CROSSREF

56. Nouvenne A, Meschi T, Prati B, Guerra A, Allegri F, Vezzoli G, Soldati L, Gambaro G, Maggiore U, Borghi L. Effects of a low-salt diet on idiopathic hypercalciuria in calcium-oxalate stone formers: a 3-mo randomized controlled trial. Am J Clin Nutr 2010;91:565-70.
PUBMED | CROSSREF

57. Hypertension Prevention Trial Research Group. The Hypertension Prevention Trial: three-year effects of dietary changes on blood pressure. Arch Intern Med 1990;150:153-62.
PUBMED | CROSSREF

58. Staessen J, Bulpitt CJ, Fagard R, Joossens JV, Lijnen P, Amery A. Salt intake and blood pressure in the general population: a controlled intervention trial in two towns. J Hypertens 1988;6:965-73.
PUBMED | CROSSREF

59. Takahashi Y, Sasaki S, Okubo S, Hayashi M, Tsugane S. Blood pressure change in a free-living population-based dietary modification study in Japan. J Hypertens 2006;24:451-8.
PUBMED | CROSSREF

60. The Trials of Hypertension Prevention Collaborative Research Group. Effects of weight loss and sodium reduction intervention on blood pressure and hypertension incidence in overweight people with high-normal blood pressure. The Trials of Hypertension Prevention, phase II. Arch Intern Med 1997;157:657-67.
PUBMED | CROSSREF

61. Ard JD, Coffman CJ, Lin PH, Svetkey LP. One-year follow-up study of blood pressure and dietary patterns in dietary approaches to stop hypertension (DASH)-sodium participants. Am J Hypertens 2004;17:1156-62.
PUBMED | CROSSREF

62. Sakaki M, Tsuchihashi T, Arakawa K. Characteristics of the hypertensive patients with good and poor compliance to long-term salt restriction. Clin Exp Hypertens 2014;36:92-6.
PUBMED | CROSSREF

63. Takahashi Y, Sasaki S, Okubo S, Hayashi M, Tsugane S. Maintenance of a low-sodium, high-carotene and -vitamin C diet after a 1-year dietary intervention: the Hiraka dietary intervention follow-up study. Prev Med 2006;43:14-9.
PUBMED | CROSSREF

64. Kim J, Lim G, Kang S, Lee K, Park T, Kim J. The relationship between daily sodium intake and obesity in Korean adults. Korean J Health Promot 2015;15:175-84.
CROSSREF

65. Lim S, Yang S. Association between dietary sodium intake and abdominal obesity in pre-diabetes Korean adults. J Korean Soc Food Sci Nutr 2014;43:763-71.
CROSSREF

66. Oh H, Kim H, Jun D, Lee S. Associations between 24-hour urine sodium excretion level and obesity-related metabolic risk factors. Korean J Community Nutr 2015;20:460-7.
CROSSREF

67. Lee M, Sorn SR, Lee Y, Kang I. Salt induces adipogenesis/lipogenesis and inflammatory adipocytokines secretion in adipocytes. Int J Mol Sci 2019;20:160.
PUBMED | CROSSREF

68. Lanaspa MA, Kuwabara M, Andres-Hernando A, Li N, Cicerchi C, Jensen T, Orlicky DJ, Roncal-Jimenez CA, Ishimoto T, Nakagawa T, et al. High salt intake causes leptin resistance and obesity in mice by stimulating endogenous fructose production and metabolism. Proc Natl Acad Sci U S A 2018;115:3138-43.
PUBMED | CROSSREF

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

70. 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;15:2200-8.
PUBMED | CROSSREF

71. Zhang Y, Li F, Liu FQ, Chu C, Wang Y, Wang D, Guo TS, Wang JK, Guan GC, Ren KY, et al. Elevation of fasting ghrelin in healthy human subjects consuming a high-salt diet: a novel mechanism of obesity? Nutrients 2016;8:323.
PUBMED | CROSSREF

72. Mähler A, Klamer S, Maifeld A, Bartolomaeus H, Markó L, Chen CY, Forslund SK, Boschmann M, Müller DN, Wilck N. Increased salt intake decreases diet-induced thermogenesis in healthy volunteers: a randomized placebo-controlled study. Nutrients 2022;14:253.
PUBMED | CROSSREF

73. Cogswell ME, Maalouf J, Elliott P, Loria CM, Patel S, Bowman BA. Use of urine biomarkers to assess sodium intake: challenges and opportunities. Annu Rev Nutr 2015;35:349-87.
PUBMED | CROSSREF

74. Campbell NR, He FJ, Tan M, Cappuccio FP, Neal B, Woodward M, Cogswell ME, McLean R, Arcand J, MacGregor G, et al. The International Consortium for Quality Research on Dietary Sodium/Salt (TRUE) position statement on the use of 24-hour, spot, and short duration (<24 hours) timed urine collections to assess dietary sodium intake. J Clin Hypertens (Greenwich) 2019;21:700-9.
PUBMED | CROSSREF

75. Bie P. Mechanisms of sodium balance: total body sodium, surrogate variables, and renal sodium excretion. Am J Physiol Regul Integr Comp Physiol 2018;315:R945-62.
PUBMED | CROSSREF

76. Huang L, Crino M, Wu JH, Woodward M, Barzi F, Land MA, McLean R, Webster J, Enkhtungalag B, Neal B. Mean population salt intake estimated from 24-h urine samples and spot urine samples: a systematic review and meta-analysis. Int J Epidemiol 2016;45:239-50.
PUBMED | CROSSREF

77. Ji C, Sykes L, Paul C, Dary O, Legetic B, Campbell NR, Cappuccio FP; Sub-Group for Research and Surveillance of the PAHO–WHO Regional Expert Group for Cardiovascular Disease Prevention Through Population-wide Dietary Salt Reduction. Systematic review of studies comparing 24-hour and spot urine collections for estimating population salt intake. Rev Panam Salud Publica 2012;32:307-15.
PUBMED | CROSSREF