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Correlation between sodium intake and obesity with related factors among Koreans: a cross-sectional study on dietary intake and eating habits

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ABSTRACT

Purpose: Sodium is essentially required for homeostasis and physiological functions, but excessive sodium consumption increases the risk of obesity and other chronic disorders. Korean studies on the sodium-obesity relationship are limited, and thus, this study was undertaken to determine the nature of the relationship between sodium intake and obesity in Korean adults.
Methods: Forty-two participants were divided into 2 groups according to body mass index (BMI, non-obese BMI < 25 kg/m^2, obese BMI ≥ 25 kg/m^2). Dietary intakes and eating habits were analyzed using 3-day food records and a food frequency questionnaire. Anthropometric data were obtained from bioimpedance results, and fasting glucose and lipid levels were measured.
Results: Mean weight, BMI, waist and hip circumferences, and body fat mass were greater in the obese group than in the non-obese group for men and women. Skeletal muscle mass and body fat mass were higher in obese women than in non-obese women. Biochemical data were no different in these two subgroups except triglycerides (TGs), which were higher in obese women. Nutrient intakes were not significantly different in obese and non-obese groups. However, obese men consumed excessive sodium, while obese women consumed slightly more than non-obese women. Obese men preferred salty foods and tended to overeat. Positive correlations were found between sodium intake and weight in men and percent body fat mass (PBFM) in women. Correlation analysis (adjusted for energy intake) of the relation between sodium intake and obesity-related factors showed sodium intake was positively correlated with PBFM and TG in women.
Conclusion: This anthropometric and biochemical data analysis emphasizes the need for awareness and interventions to mitigate the health risks of elevated sodium consumption. Our findings should aid future studies on the relationship between sodium and obesity and contribute to preventing and managing this metabolic condition.

Keywords: sodium; obesity; dietary intake; eating habits; nutrient intake

INTRODUCTION

Obesity and overweight portray a promptly growing hazard to the health of populations in several countries, and their increasing prevalence has become a worldwide health issue [1,2]. In 2009, the prevalence of obesity with a BMI ≥ 25 kg/m^2 in South Korea was 29.7%.

Conflict of Interest
There are no financial or other issues that might lead to conflict of interest.

Author Contributions
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However, in 2019, it showed an increasing trend at 36.3% [3]. Recently, the rate of obesity increases with age; however, among adults aged < 40 years, a considerable and concerning increase was observed in the rate of severe obesity, highlighting a serious problem [4]. The increasing prevalence of obesity significantly affects the development of comorbidities, including hypertension, coronary heart disease, non-insulin-dependent diabetes mellitus, and dyslipidemia [5,6].

Numerous studies have shown that fatty, high-calorie foods, and a sedentary lifestyle are the primary causes of obesity [7]. An epidemiological model considers the pathophysiology of obesity and the interaction of environmental factors (availability and accessibility of energy-dense food, low requirements for physical activity) with genetic susceptibility, resulting in a positive energy balance and an increased body weight [4].

A study reported that sodium intake is associated with obesity and central obesity in adults [8]. Sodium is an essential element that is required for homeostasis and physiological functions and its insufficient intake is usually associated with unfavorable health outcomes. However, consuming large quantity of sodium can put one at risk for a number of chronic disorders [9,10]. Sodium intake trigger thirst and appetite, and eventually increases energy intake and extracellular volume [11,12]. In addition, increased consumption of processed foods may result in excessive sodium intake, and thus energy is crucial in understanding the association between salt intake and overweight/obesity [13,14].

In animal research, excessive salt intake increases insulin-induced glucose metabolism and adipocyte insulin sensitivity for glucose absorption, which in turn promotes adipocyte hypertrophy and increases the majority of numerous adipose depots [15]. In other study, rats on high sodium diets had obesity, elevated plasma leptin concentrations, and adipocyte hypertrophy [16]. Moreover, a high-salt diet increased fasting ghrelin, which regulates hunger, glucose homeostasis, and fat deposition and can be a potential factor of obesity [17]. Another study on children with obesity revealed that while obese girls had higher visfatin levels and Na/K consumption, obese boys consumed significantly more sodium [18].

Therefore, this study aimed to determine the correlation between sodium intake and obesity by analyzing the dietary intake and eating habits of Korean adults. This study is envisioned to contribute to the development of strategies that lower the prevalence of obesity and its associated risk factors.

METHODS

Participants

This research was carried out in Changwon, South Korea, between July 2017 and July 2018. Total 42 participants in the cross-sectional study were selected from Changwon National University. The age range of the 42 self-enrolled participants in this study was 24 to 48 years old. Adults with a history of cancer, heart disease, liver infections, endocrine disorders, long-term medication use, cancer, or pregnancy or lactation were not included in the study. Online and offline media (posters, blogs, and social network services) were used to achieve recruitment. Eligibility was determined at a screening visit after potential participants conducted phone screening. This study was approved by the Changwon National University's Institutional Review Boards (Approval No.104027-201706-HR-008).

Anthropometric data

Of the 42 participants, 19 male and 23 female were subcategorized into lean and obese according to body mass index (BMI). The height, weight, percent body fat mass (PBFM), body fat mass (BFM), and skeletal muscle mass were measured using the bioelectrical impedance analysis (InBody 720 Body composition Analyzer; Bio Space Co., Seoul, Korea) while participants were lightly dressed and not wearing shoes. BMI was calculated by dividing the weight (in kg) by height squared (in m). Obesity was defined as having a BMI of 25 kg/m^2 or higher. The participants' written informed consent was obtained.

Biochemical data

Blood samples were drawn from the veins following a 12-hour fast. An absorptiometry kit (Bayers, Tarrytown, NY, USA) was used to assess the levels of glucose, triglycerides (TGs), total cholesterol (TC), and high-density lipoprotein cholesterol (HDL-C). Using enzyme analysis kits (Asan Pharmaceuticals Co., Ltd., Hwasung, Korea), the colorimetric method was used to assess the plasma levels of glutamic oxaloacetic transaminase (GOT) and glutamic pyruvic transaminase (GPT).

Dietary Intake and eating habits

The dietary intake and eating habits of all participants were analyzed through a 3-day food record and food frequency questionnaire. All participants were requested to record their habitual eating frequency in accordance with the following food groups: bread; whole grain pasta; dairy products; meat; fruits and fruit juices; vegetables and vegetable juices; carbonated drinks; meals or snacks such as pizza, fries, burgers, sweets, chicken, and cakes; crisps; and other salty snacks. The food intake frequency survey assessed the food intake frequency to investigate the major sources of energy and nutrients. In this study, the frequency of consuming salty foods was analyzed. The Computer Aided Nutrient Analysis Program version 5.0 (CAN-Pro; The Korean Nutrition Association, Seoul, Korea) was used to analyze the dietary intake. Sodium intake ratio (%) was calculated by dividing sodium intake by adequate intake and multiplying by 100. Sodium-chronic disease risk reduction intake (CDRR) ratio (%) was calculated by dividing sodium intake by CDRR and multiplying by 100.

Statistical analysis

The collected data were analyzed using SPSS (version 27.0; IBM Corp., Armonk, NY, USA). The differences between the lean and obese groups were analyzed using the Mann-Whitney U test. Spearman correlation coefficients were used to assess the associations between sodium intake and obesity-related indicators. Qualitative variables were reported in terms of percentage distribution and evaluated using the χ^2 test. The p-values between the groups within the same sex were considered statistically different. Results with $p < 0.05$ and $p < 0.01$ were considered statistically significant.

RESULTS

Anthropometric data of the participants

The characteristics of the study participants are shown in **Table 1**. Obese male and female groups had BMI ≥ 25 kg/m^2. The distribution of age in obese and lean participants was not significantly different. The average weight, BMI, waist circumference, hip circumference, and waist hip ratio in the obese groups were significantly higher than that in the lean groups in both sexes ($p < 0.05$).

Table 1. Anthropometric data of the participants

Characteristics	Male			Female		
	Lean (n = 6)	Obese (n = 13)	p-value	Lean (n = 15)	Obese (n = 8)	p-value
Age (yrs)	38.31 ± 14.03	32.36 ± 10.47	0.521	36.03 ± 11.38	32.65 ± 10.77	0.547
Height (cm)	172.63 ± 5.46	173.02 ± 6.86	0.906	161.92 ± 4.43	160.37 ± 6.28	0.151
Weight (kg)	68.67 ± 6.74	83.59 ± 12.84	0.017	55.70 ± 6.99	72.55 ± 15.36	0.001
BMI (kg/m^2)	23.18 ± 1.75	27.97 ± 2.71	0.002	21.01 ± 2.47	29.93 ± 3.24	0.000
WC (cm)	79.25 ± 7.21	95.04 ± 8.97	0.001	69.67 ± 7.52	86.63 ± 12.66	0.001
HC (cm)	95.92 ± 3.94	103.38 ± 6.45	0.017	92.60 ± 5.62	103.19 ± 8.62	0.002
WHR	0.83 ± 0.05	0.92 ± 0.08	0.007	0.75 ± 0.07	0.84 ± 0.08	0.013
BFM (kg)	14.67 ± 5.07	22.92 ± 6.79	0.012	15.98 ± 4.58	28.29 ± 10.17	0.001
SMM (kg)	30.37 ± 4.95	34.45 ± 4.77	0.152	21.31 ± 2.84	25.39 ± 2.57	0.005
PBFM (%)	21.40 ± 7.80	27.00 ± 5.10	0.087	28.10 ± 2.90	39.50 ± 5.80	0.002
PSMM (%)	44.20 ± 5.10	41.40 ± 3.00	0.106	38.80 ± 2.90	33.40 ± 3.20	0.004

Values are mean ± standard deviation.
BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist hip ratio; BFM, body fat mass; SMM, skeletal muscle mass; PBFM, percent body fat mass; PSMM, percent skeletal muscle mass.
These p-values between the groups within same gender were statistically different evaluated by Mann-Whitney U test

Table 2. Biochemical data of the participants

Characteristics	Male			Female		
	Lean (n = 6)	Obese (n = 13)	p-value	Lean (n = 15)	Obese (n = 8)	p-value
Glucose (mg/dL)	81.11 ± 12.40	87.23 ± 9.07	0.179	78.31 ± 11.56	78.05 ± 15.04	0.963
Triglyceride (mg/dL)	111.18 ± 51.08	106.13 ± 49.46	0.701	70.85 ± 31.47	135.04 ± 49.87	0.001
TC (mg/dL)	149.04 ± 23.38	165.88 ± 32.06	0.210	155.08 ± 19.12	159.13 ± 21.38	0.661
HDL-C (mg/dL)	30.70 ± 6.85	29.16 ± 6.63	0.639	40.15 ± 13.97	31.04 ± 11.21	0.128
GOT (IU/U)	13.93 ± 6.60	14.50 ± 10.15	0.903	10.71 ± 6.61	30.53 ± 44.92	0.102
GPT (IU/U)	8.74 ± 4.74	11.74 ± 9.06	0.416	5.79 ± 3.44	11.98 ± 10.47	0.144

Values are mean ± standard deviation.
TC, total cholesterol; HDL-C, high-density lipoprotein cholesterol; GOT, glutamic oxaloacetic transaminase; GPT, glutamic pyruvic transaminase.
These p-values between the groups within same gender were statistically different evaluated by Mann-Whitney U test.

Biochemical data of the participants

The biochemical data of the study participants are shown in **Table 2**. No significant differences were observed in the mean glucose, TGs, TC, HDL-C, GOT, and GPT levels between the obese and lean groups in both sexes. However, the female obese groups had significantly higher TGs levels than that of their lean counterparts ($p < 0.05$).

Dietary intake of the participants

The dietary intake of the study participants is shown in **Table 3**. No significant difference was observed in the nutrient intake between the male and female groups. The sodium intake in the obese male group surpassed the recommended daily allowance by more than 2 times and significantly higher compared to that in the normal male group ($p < 0.05$). Increase in sodium intake was observed in obese female group compared to that in their lean group; however, the difference was not significant. The obese male group exceed the recommended amount of sodium intake for CDRR by approximately 1.8 times.

Eating habits of participants

The eating habits of the study participants are shown in **Table 4**. The obese male group exhibited a higher frequency of "eating until a full stomach" and a greater preference for salty food than those of the lean male group. Additionally, the obese male group tended to overeat 2–3 or 4 times per week, with a habit of snacking 2–3 or 4 times per week. A noticeable preference for salty food was observed in the obese male group compared to that in the lean male group ($p < 0.05$).

Table 3. Dietary intake of the participants

Characteristics	Male			Female		
	Lean (n = 6)	Obese (n = 13)	p-value	Lean (n = 15)	Obese (n = 8)	p-value
Energy (kcal)	2,178.47 ± 572.85	2,264.88 ± 611.82	0.639	1,847.70 ± 452.60	1,670.01 ± 314.13	0.335
Carbohydrate (g)	299.34 ± 84.45	288.51 ± 74.66	0.765	221.05 ± 55.99	212.20 ± 52.24	0.716
Protein (g)	75.52 ± 21.65	88.88 ± 33.30	0.579	76.43 ± 29.15	66.33 ± 16.36	0.378
Fat (g)	56.63 ± 22.65	75.79 ± 31.87	0.282	69.39 ± 32.16	58.04 ± 15.97	0.362
C:P:F (%)	55.6:14.1:23.2	52.0:15.7:29.0		49.1:16.3:33.1	50.4:16.1:31.3	
Fiber (g)	19.61 ± 3.67	17.58 ± 5.82	0.411	18.65 ± 9.46	15.90 ± 3.38	0.438
Vitamin A (μgRAE)	271.27 ± 127.34	326.50 ± 142.59	0.521	322.39 ± 146.97	496.32 ± 371.19	0.673
Vitamin D (μg)	2.45 ± 0.74	1.78 ± 1.23	0.152	2.49 ± 2.23	5.11 ± 8.81	0.658
Vitamin B_1 (mg)	1.59 ± 0.74	2.04 ± 0.49	0.179	1.94 ± 0.51	1.60 ± 0.49	0.450
Vitamin B_2 (mg)	1.23 ± 0.49	1.64 ± 0.65	0.210	1.36 ± 0.88	1.40 ± 0.51	0.880
Vitamin C (mg)	100.73 ± 137.73	73.95 ± 76.88	0.579	61.37 ± 28.27	61.99 ± 36.12	0.967
Calcium (mg)	468.78 ± 118.65	518.89 ± 254.46	0.831	511.44 ± 321.97	465.65 ± 209.44	0.685
Sodium (mg)	2,797.14 ± 845.23	4,129.46 ± 1,831.50	0.045	2,633.33 ± 800.59	2,971.14 ± 1,142.86	0.415
Sodium (%)[1)]	186.48 ± 56.35*	275.30 ± 122.10	0.045	175.56 ± 53.37	198.08 ± 76.19	0.308
Sodium-CDRR (%)	121.61 ± 36.75*	179.54 ± 79.63	0.045	114.49 ± 34.81	129.18 ± 49.69	0.308
Iron (mg)	16.63 ± 5.40	21.66 ± 11.26	0.579	14.92 ± 6.83	16.96 ± 6.66	0.499

Values are mean ± standard deviation.
C, carbohydrate; P, protein; F, fat; CDRR, chronic disease risk reduction intake.
[1)]Ratio of Dietary Reference Intakes for Koreans.
These p-values between the groups within same gender were statistically different evaluated by Mann-Whitney U test.

Table 4. Eating habits of the participants

Survey questions	Male			Female		
	Lean (n = 6)	Obese (n = 13)	p-value	Lean (n = 15)	Obese (n = 8)	p-value
Meal quantity			0.045			0.160
Till a full stomach	1 (16.7)	8 (61.5)		2 (12.5)	3 (42.9)	
Occasionally	3 (50.0)	5 (38.5)		11 (68.8)	2 (28.6)	
Always a little	2 (33.3)	0 (0.0)		3 (18.8)	2 (28.6)	
Overeating (a week)			0.342			0.813
Rarely (≤ 1 times)	2 (33.3)	1 (7.7)		7 (43.8)	3 (42.9)	
Sometimes (2–3 times)	3 (50.0)	10 (76.9)		8 (50.0)	3 (42.9)	
Often (≥ 4 times)	1 (16.7)	2 (15.4)		1 (6.3)	1 (14.3)	
Snacks intake (a week)			0.784			0.143
Rarely (≤ 1 times)	1 (16.7)	1 (7.7)		3 (18.8)	3 (42.9)	
Sometimes (2–3 times)	3 (50.0)	6 (46.2)		7 (43.8)	4 (57.1)	
Often (≥ 4 times)	2 (33.3)	6 (46.2)		6 (37.5)	0 (0.0)	
Salty food			0.016			0.198
Like	1 (16.7)	2 (15.4)		4 (26.7)	1 (14.3)	
A little like	0 (0.0)	6 (46.2)		1 (6.7)	2 (28.6)	
Usual	1 (16.7)	4 (30.8)		4 (26.7)	0 (0.0)	
Hate	4 (66.7)	0 (0.0)		4 (26.7)	4 (57.1)	
Very hate	0 (0.0)	1 (7.7)		2 (13.3)	0 (0.0)	

Values are presented as number (%).
These p-values between the groups within same gender were statistically different evaluated by χ^2 test

Correlations coefficients between sodium intake and variables

The correlations between sodium intake and obesity-related factors in male and female are shown in **Fig. 1**. Sodium intake was positively associated with weight (r = 0.484 and p-value = 0.036) in male. Sodium intake was positively associated with PBFM (r = 0.489 and p-value = 0.018) in female. As a result of correlation analysis between obesity and obesity-related factors adjusting for energy intake in female, PBFM (r = 0.525 and p-value = 0.012) and TGs (r = 0.444 and p-value = 0.038) increased as sodium intake increased (**Fig. 2**). However, there was no correlation between obesity and obesity-related factors in males after adjusting for energy intake; the data is not shown.

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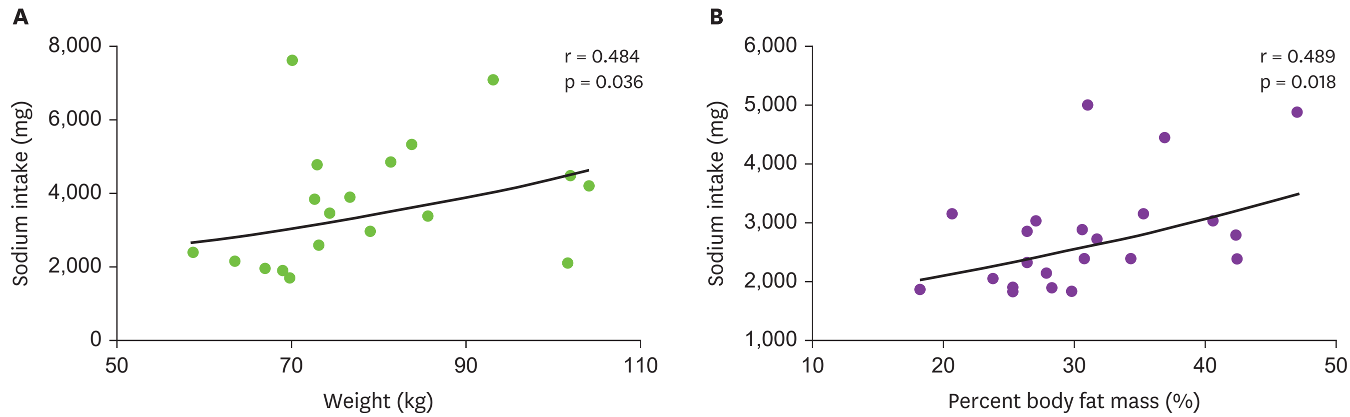

Fig. 1. Correlation coefficients between sodium intake and body weight in male (A) and body fat in female (B).

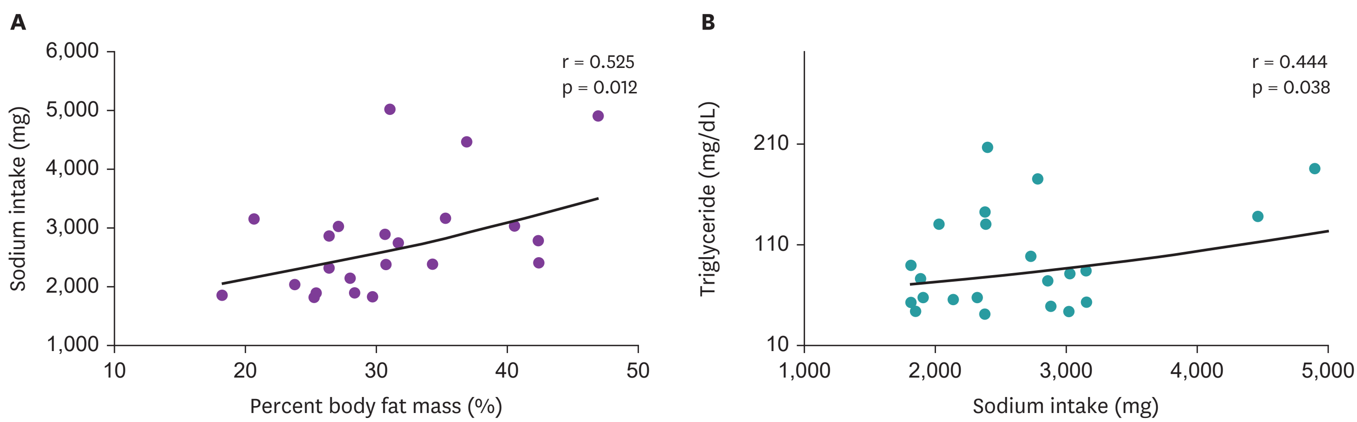

Fig. 2. Energy intake-adjusted correlation coefficients between sodium intake and percent body fat mass (A) or triglyceride (B) in female.

DISCUSSION

This study aimed to analyze dietary intake, particularly sodium, and obesity-related indicators in the groups of obese and normal weight adults. The results of the study showed a higher ratio of salt intake in obese men; significant differences in eating habits related to salt intake; and an association between sodium intake and weight, PBFM and TGs.

The analyzed sodium intake amounted to 2,797 mg and 4,192 mg in the male with and without obesity, respectively. The World Health Organization suggests consuming 5 g or 2,000 mg of salt per day [19], which is less than what was observed in the current study. Koreans typically consume foods with high sodium content, such as seasoned soups, stews, and pickled vegetables. Consequently, the average sodium intake for Korean adults exceeds 200% of the recommended daily sodium intake [20].

Our study indicates that the obese male group had a greater preference for salty food than that for the lean male group. A Korean review study assessed the association between dietary sodium intake and obesity-related outcomes [21]. Two studies reported that compared to females, high sodium intake increased the risk of overweight and obesity in males [22,23]. Increased dietary sodium directly correlates with increased calorie consumption, while decreased sodium consumption habits lower calorie intake [24,25]. Several studies on adults found a correlation between sodium intake and a number of adiposity outcomes, such as BMI or weight category, percent body fat, and obesity [26].

Emerging evidence suggests that high-salt diets directly and indirectly contribute to weight gain. Several possible hypothesized processes have been postulated to account for this relationship [27]. Foods high in sodium, especially fatty foods, have a generally high energy content [28]. Additionally, eating excessive quantity of these food triggers overeating, which results to weight gain [29]. Another hypothesis is that higher sodium intake leads to an increase in soft drink consumption.

Several factors account for the increase in food and salt intake associated with obesity, including: abnormalities in the gastrointestinal system that upregulate the consumption of water or salt solutions [30] decreased gastric and post-gastric satiety signals as a result of increased gastric capacity from long-term overeating [31] increase in all renin-angiotensin system components, including those found in the adipose tissue and in obesity that results in cravings for salt and water [32].

The salted food addiction hypothesis posits that salted food acts as an opiate agonist in the brain, producing a hedonic reward that is perceived as 'tasty' or 'delicious.' The urge or craving for salted food is perceived as a manifestation of opiate receptor withdrawal. Increased consumption of salted food can lead to salted food addiction, subsequently leading to an elevation in opioid 'tolerance,' overeating, increased calorie consumption, obesity, and other related illnesses [33]. Our study is consistent with this hypothesis as it shows that a group of obese men who prefer salty foods tends to overeat. Considering these potential reasons, energy metabolism may function as a mediator on the relationship between obesity and sodium intake.

The mechanisms underlying such a relationship are not completely understood. However, several studies on animals suggest that a high sodium diet may have an impact on how insulin and glucose are metabolized. This may increase leptin secretion or synthesis while also enhancing leptin resistance, which promotes energy dysregulation, accumulation of adipose tissue mass, and eventually leads to obesity [16]. Although our study does not analyze leptin, results showed that sodium intake was associated with TGs in female.

A high-salt diet may increase insulin resistance in rats [34]. A higher salt intake in humans was independently and significantly associated with insulin resistance [35,36]. Insulin resistance or impaired insulin sensitivity is one of the primary components of metabolic disorder, which includes hypertension, obesity, and dyslipidemia. This indicates that high salt intake could lead to a worse insulin resistance in people with salt sensitivity. A higher blood pressure response to sodium intake appears to be a consequence of insulin resistance. It remains unknown whether insulin resistance is caused by the impact of aldosterone, which is frequently incorrectly produced in salt sensitivity patients, via hybridization of the insulin and insulin growth factor receptors [37]. The result of this study corroborates with the hypothesis that a higher sodium intake, possibly via an effect on insulin resistance, promotes the development of metabolic disorder such as dyslipidemia.

Our study had few limitations. First, the data collection was not typical of the general community, and as only Koreans were included in the study sample, racial disparities were not examined. Second, the number of participants was relatively small, and the study is cross-sectional. Despite these limitations, our study showed an independent association between high sodium intake and obesity and metabolic disease particularly among females. Thus, the 2 approaches regarded as practical and cost-effective methods to accurately analyze the dietary habits are dietary recall and food-frequency questionnaire. In this study, nutrient intake and eating habits were analyzed using both methods and compared by sex.

SUMMARY

In this study, 42 participants aged 24–48 years were categorized into lean and obese groups based on their BMI. Anthropometric data were collected, revealing significant differences in weight, BMI, waist circumference, and other parameters between the 2 groups. Biochemical data showed elevated TGs levels in female obese groups. Dietary intake and eating habits were analyzed, with obese males showing higher sodium intake and preference for salty foods. Correlation analyses demonstrated a positive association between sodium intake and weight in male and PBFM in female. In addition, in a correlation analysis adjusted for energy intake, salt intake and TGs, and PBFM showed a positive correlation. Our study suggests that following the recommended sodium intake could have significant effects public health. In addition, the difference in sodium intake according to sex and obesity demonstrates that salt sensitivity may play a role not only in the association between sodium and obesity but also in the association between sodium and metabolic diseases. Further large-scale studies are required to evaluate the association between sodium intake and long-term outcomes in lean and obese individuals in the Korean population.

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