**RESEARCH ARTICLE**

**Obesity-related hypertension: Findings from The Korea National Health and Nutrition Examination Survey 2008–2010**

Hong Seok Lee, Yong-Moon Park, Kyungdo Han, Jin-Hong Yang, Seungwon Lee, Seong-Su Lee, Soonjib Yoo, Sung Rae Kim

1 Division of Cardiology, Department of Medicine, Mayo Clinic, Scottsdale, AZ, United States of America, 2 Division of Cardiology, Department of Medicine, University of California Riverside, Riverside, CA, United States of America, 3 Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, United States of America, 4 Epidemiology Branch, National Institute of Environmental Health Sciences, National Institutes of Health, Research Triangle Park, NC, United States of America, 5 Department of Statistics and Actuarial Science, Soongsil University, Seoul, Korea, 6 Department of Emergency Medicine, College of Medicine, The Catholic University of Korea, Seoul, Korea, 7 Department of Anesthesiology and Pain Medicine, Samsung Medical Center, Sungkyunkwan University School of Medicine, Seoul, Korea, 8 Division of Endocrinology and Metabolism, Department of Internal Medicine, Bucheon St. Mary’s Hospital, College of Medicine, The Catholic University of Korea, Seoul, Korea

These authors contributed equally to this work.

* kimsungrae@catholic.ac.kr

**Abstract**

We aimed to investigate the association of various obesity parameters and phenotypes with hypertension in nationally representative Korean adults. Among adults aged 19 years and older who participated in the Korea National Health and Nutrition Examination Survey in 2008–2010, a total of 16,363 subjects (8,184 men and 8,179 women) were analyzed. Hypertension was defined as blood pressure of 140/90 mm Hg or higher or taking antihypertensive medication. Multiple logistic regression analysis was used to estimate multivariable-adjusted odds ratios (ORs) and 95% confidence intervals (CIs). Higher obesity parameters (body mass index (BMI) representing general obesity, waist circumference (WC) representing central obesity, and percentage body fat (PBF) representing elevated body fat) were consistently associated with increased odds of prevalent hypertension (OR, 7.54; 95% CI, 5.89–9.65 for BMI ≥30 vs. 18.5–23; OR, 3.97; 95% CI, 3.41–4.63 for WC ≥95 cm in males and ≥90 cm in females vs. <85 cm in males and <80 cm in females; OR, 3.56; 95% CI, 3.05–4.15 for PBF, highest vs. lowest quartile; all \( p \) trends <0.0001). These associations were stronger in the younger age group (<40 years), and were observed in both sexes. Furthermore, even in individuals with normal BMI (18.5–23), the odds of prevalent hypertension were consistently increased in those with central obesity (WC≥90 cm in males, WC≥80 cm in females; normal weight central obesity phenotype) (OR, 1.89; 95% CI, 1.63–2.19) and those with high PBF (highest quartile of PBF; normal weight obesity phenotype) (OR, 1.49; 95% CI, 1.25–1.77). These associations were consistent with updated hypertension guidelines in 2017. Obesity may be positively associated with hypertension, regardless of obesity parameters. Even within normal BMI range, high WC and high PBF may be associated with hypertension.
Introduction

The increasing prevalence of obesity worldwide represents a major public health problem. Obesity reduces healthy life years, increases mortality, and poses an increasing health economic burden [1,2]. Obesity increases the risk of metabolic diseases, such as hypertension, diabetes, and dyslipidemia, which lead to increases in cardiovascular morbidity and mortality [3,4]. Obesity can be represented by various measurements, such as body mass index (BMI) [5] waist circumference (WC) [6], and percentage body fat (PBF) [7].

Hypertension prevalence in obese people with high BMI was reported to be 40.5% in the US [8]. The prevalence of hypertension has been reported to increase progressively with increasing BMI [9]. There is evidence to indicate that weight gain may increase blood pressure (BP) [10], and that weight reduction can prevent or delay obesity-related risk factors for cardiovascular diseases, including hypertension. It has been shown that increased BF composition is associated with hypertension [11]. Abnormalities in body fat distribution also might play an important role in the development of hypertension [12,13]. Central body fat has been associated with insulin resistance and dyslipidemia, suggesting that it is a more potent determinant of BP elevation than peripheral body fat. Visceral obesity appears to be especially important in the activation of the sympathetic nervous system and the renin-angiotensin-aldosterone system, thereby increasing the risk for the development of hypertension and its associated comorbidities. [14,15]

Several epidemiologic studies have explored hypertension prevalence in obese patients defined by BMI [3,16–20]. However, it is not known whether the association between various obesity parameters and hypertension differs by specific obesity phenotypes, such as normal weight obesity (represented by normal BMI with high PBF) and normal weight central obesity phenotypes (represented by normal BMI with high WC). Therefore, we aimed to investigate the relationship of various obesity parameters and phenotypes with hypertension using a nationally representative sample in Korea.

Materials and methods

Study population

This was a cross-sectional study using a nationally representative survey performed by the Korea Centers for Disease Control and Prevention. Data between 2008 and 2010 of the Korea National Health and Nutrition Examination Survey (KNHANES) was obtained for analysis. KNHANES adopted a rolling survey sampling design that applied a complex, stratified, multistage probability-cluster survey using a representative Korean population sample aged 1 year and above. In the present analysis, among the subjects aged 19 years and older who completed both a health interview survey and a health examination survey from 2008 to 2010, a total of 16,363 subjects (8,184 men and 8,179 women) were included in this study. The KNHANES was conducted by specially trained interviewers or examiners who were not provided with any prior information about the participants. The survey was composed of three parts: a health interview survey, a health examination survey, and a nutrition survey. Extra details regarding the study design and methods are provided elsewhere. All of the participants signed an informed consent in this survey. This study was approved by the Institutional Review Board of the Catholic University of Korea. We confirm that all research was performed in accordance with relevant guidelines/regulations, and informed consent was obtained from all participants and/or their legal guardians.

Measurements

All subject measurements were performed by trained examiners. Information regarding the demographic status and health-related characteristics was collected during the health interview.
survey and included the following: age, educational attainment, household income, living with a spouse or not, and use of antihypertensive medication. In addition, lifestyle characteristics including smoking, alcohol consumption, and exercise were investigated using self-administered questionnaires. The education level was split into three groups: 6 years or fewer (elementary school or less), 7 to 12 years (middle school to high school), and 13 years or more (college or higher). Household income was divided into quartiles, and the lowest quartile was the lowest income class. Smoking status was categorized into three groups: current smoker, never smoked, or past smoker. Alcohol consumption status was classified into three groups: non-drinker, mild-to-moderate drinker (< 30.0 g alcohol/day), and heavy drinker (≥ 30.0 g alcohol/day), after converting the average frequency and amount of alcoholic beverages into the amount of pure alcohol (in grams) consumed per day. Regular exercise was designated as ‘yes’ when the subject reported moderate exercise for more than 30 minutes at a time and more than five times per week or vigorous exercise for more than 20 minutes at a time and more than three times per week on a regular basis. Nutrient intakes, including total energy and sodium consumptions, were assessed with a 24-hour dietary recall questionnaire administered by a trained dietician. Height was measured to the nearest 0.1 cm by a portable stadiometer (SECA 225, SECA, Deutschland, Hamburg, Germany) while the subjects were standing barefoot. Body weight was measured to the nearest 0.1 kg on a balanced scale (GL-6000-20, CAS KOREA, Seoul, Korea) while the participants wore a lightweight gown. BMI was calculated from the measured height and weight using the following formula: BMI = weight (kg) / height squared (m$^2$). We used BMI classification for the Asian-Pacific region [21]. BMI was categorized as follows: normal weight (18.5 ≤ BMI < 23 kg/m$^2$), overweight (23 ≤ BMI < 25 kg/m$^2$), Obese I (25 ≤ BMI < 30 kg/m$^2$), and Obese II (BMI ≥ 30 kg/m$^2$). WC was measured to the nearest 0.1 cm using a measuring tape (SECA 200, SECA, Deutschland) in a horizontal plane at the level of the midpoint between the iliac crest and the costal margin at the end of a normal expiration. The PBF (fat mass/total mass) was measured using dual-energy X-ray absorptiometry (DXA; QDR 4500A, Hologic Inc., Waltham, MA, US) [22] and was divided into four even quartiles. BP was measured from the right arm using a standard mercury sphygmomanometer (Baumanometer, WA Baum Co., New York, USA) after 5 minutes of rest in the sitting position. Systolic and diastolic BPs were measured three times at 30-second intervals, and the second and third measurements were averaged to produce the final BP used for analysis.

**Definitions**

Hypertension was defined as an average BP of 140/90 mm Hg or higher, or if the participant was taking antihypertensive medication. Normotension was defined as BP less than 120/80 mm Hg. Prehypertension is the status of systolic BP of 120 to 139 mm Hg or diastolic BP 80 to 89 mm Hg based on the Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation and Treatment of High Blood Pressure (JNC 7) guideline [23]. A new guideline, proposed by the American College of Cardiology and the American Heart Association in 2017, set to lower the definition of hypertension to systolic BP of 130 mm Hg or higher or diastolic BP of 80 mm Hg or higher, [24] was used to conduct a sensitivity analysis. In addition, for abdominal obesity, we used sex-specific cutoff points individualized for men and women: 90 cm for men, and 80 cm for women [21]. The normal weight obesity phenotype was defined when participants had normal body weight by BMI, but had a high PBF (highest quartile of PBF) [25], whereas the normal-weight central obesity phenotype was defined when participants had normal body weight, but had high WC (≥90 cm for men and ≥80 cm for women) [26]. Participants were considered to have diabetes if fasting plasma glucose was 126 mg/dL or greater or they were receiving insulin or oral diabetes medications. Participants were
considered to have hypercholesterolemia if their total cholesterol was 240 mg/dL or greater or if they were taking cholesterol-lowering medication.

**Statistical analysis**

All statistical analyses were performed with SAS, version 9.3 (SAS Institute, Inc., Cary, North Carolina) for the complex KNHANES sampling design. Subjects’ characteristics were shown as mean with standard error (SE) for continuous variables and percentage with SE for categorical variables. Continuous variables were compared using linear regression analysis, and categorical data were compared using the Rao-Scott chi-square test, which is a design-adjusted Pearson chi-square test used for complex survey data. For subgroup analyses, the domain option was used to preserve appropriate subsamples in the complex sampling designs.

We estimated odds ratios (ORs) and 95% confidence intervals (CIs) for the association between obesity parameters and prevalent hypertension using multiple logistic regression. Tests for linear trend across each category of obesity parameter were performed by modeling an ordinal variable for each obesity category. Potential confounders or effect modifiers were ascertained a priori based on a literature review. The following covariates were included in multivariable-adjusted models: age and sex in model 1; and age, sex, smoking (never smoked, current smoker, past smoker), alcohol consumption (non-drinker, mild-to-moderate drinker, heavy drinker), physical activity (regular exercise, non-regular exercise, no exercise), living with spouse or not, income (quartiles), educational attainment (≤ 6 years, 7–12 years, ≥ 13 years), energy intake from fat, and sodium consumption in model 2. We evaluated whether there is a synergistic interaction between BMI and WC as well as BMI and PBF in relation to prevalent hypertension. We also assessed potential effect modification by diabetes, education, income, smoking habit, alcohol consumption, and exercise through stratified analysis and interaction testing using a likelihood ratio test. Furthermore, we examined the associations by sex to explore sex-specific association between obesity parameters and hypertension. Statistical significance was determined with two-sided tests. Significance level \( \alpha \) was set at 0.05.

**Results**

Differences in general characteristics by BP classification are summarized in Table 1. Hypertensive participants were relatively older (\( p < 0.001 \)) compared with those without hypertension or pre-hypertension, were more likely to have past smoking history (\( P < 0.001 \)), and were less likely to be mild-moderate drinkers (\( P < 0.001 \)). They were also more likely to have lower educational level and household income (both \( P < 0.001 \)); to have higher levels of BMI, WC, and PBF (\( P < 0.001 \)); and to have diabetes, hypercholesterolemia, and lower income (\( P < 0.001 \)). They were less likely to consume dietary fats but were more likely to consume sodium.

The prevalence of hypertension and prehypertension with respect to increasing BMI, WC, and PBF is shown in Fig 1A, 1B and 1C, respectively. Overall, the prevalence of hypertension increased as BMI, WC, and PBF increased (each \( p \text{ trend} < 0.001 \)). This trend was also observed when stratified by age group (Fig 2A, 2B and 2C). Interestingly, the prevalence of prehypertension was also increased with increasing BMI, WC, and PBF in younger ages of less than 40 years (\( p \text{ trend} < 0.001 \)). The difference of prevalence between hypertension and prehypertension was increased with increasing BMI, WC, and PBF in those in middle and old age (\( p \text{ trend} < 0.001 \)).

The associations between various obesity parameters and prevalent hypertension are shown in Table 2. Hypertension was significantly associated with elevated BMI, WC, and PBF level after adjusting for potential confounders. Higher obesity parameters were associated with increased odds of hypertension (OR: 7.54; 95% CI, 5.89–9.65 for BMI \( \geq 30 \) vs. 18.5–23, \( p \text{ trend} < 0.001 \)).
When stratified by age group, the association between obesity parameters and hypertension was consistently stronger in the younger age group (<40 years) (p interaction = 0.07 for BMI, p interaction = 0.004 for WC, p interaction = 0.10 for PBF level) (Table 3).

Evidence related to the role of central obesity and body fat in the association between BMI and prevalent hypertension is shown in Table 4. Compared with those with normal BMI and
WC, those with high BMI and high WC had the highest OR for prevalent hypertension (OR: 3.46; 95% CI, 3.07–3.90, \( p \) interaction = 0.06). Similar associations were found in the combination of BMI and PBF. Among individuals with normal BMI, the odds of hypertension was consistently elevated in individuals with the normal weight central obesity phenotype [normal BMI and high WC (WC \( \geq \) 90 in male, WC \( \geq \) 80 in female); OR: 1.89; 95% CI, 1.63–2.19] and with normal weight obesity phenotype (normal BMI and highest quartile of BF; OR: 1.49; 95% CI, 1.25–1.77). Associations appear to be stronger in the younger age group (< 40 years), although there was no significant interaction.

In the sensitivity analyses, these associations were consistent with using a new guideline (S1 and S2 Tables). No differential association was observed by diabetes, education, income, smoking habit, alcohol consumption, and exercise (S3, S4, and S5 Tables).

Sex-specific associations between obesity parameters and hypertension are shown in S6 to S8 Tables. Overall, there was no difference between sexes in the association of BMI, WC, and PBF with hypertension (S6 Table). However, associations differed by sex and age group (\( p \) interaction = 0.03 for BMI, \( p \) interaction = 0.06 for WC, \( p \) interaction = 0.003 for PBF level).
and a stronger association between BMI and hypertension was clearly seen in women at younger ages of less than 40 years and older ages of 65 or more (S7 Table). The role of central obesity and body fat in the association between BMI and prevalent hypertension appeared to be stronger in women at younger ages of less than 40 years compared with men in the same age group (S8 Table).

**Discussion**

In this nationally representative population-based study in South Korea, increasing BMI, WC, and PBF were significantly associated with an increased prevalence of hypertension, especially in young adults (< 40 years). Furthermore, we observed a positive association of high WC and PBF with hypertension in individuals within the normal range of BMI.

In addition to overall positive association of increased BMI, WC, and PBF with prevalent hypertension, we observed that higher abdominal obesity or body fat composition with normal
BMI was associated with increased odds of hypertension. Moreover, the highest odds of hypertension were observed when the obese individuals also had abdominal obesity (Table 4). One epidemiologic study also found that young women had more prevalent hypertension if they had high WC [27]. The study also measured abdominal obesity using computed tomography (CT) scans to assess visceral fat, and it showed that central obesity-related visceral fat is a risk for hypertension [28]. These findings suggest that BMI alone has a limitation as a parameter to explain obesity-related hypertension. Recent studies have shown that WC, waist-to-hip ratio, and visceral fat measurement may be better discriminators of obesity-related complications than BMI [29,30,31]. It has been emphasized that central obesity has a stronger association with hypertension than general obesity. Increased abdominal fat representing central obesity is also known to be a more important factor in hypertension management [19,32].

Normal weight obesity represented by normal BMI with elevated PBF was suggested as another type of obesity that is related to increased cardiovascular risk in many studies. While individuals with higher body fat composition may be susceptible to metabolic disease, including hypertension [33], higher body fat in normal range of BMI was regarded to be a controversial risk factor for hypertension [34]. However, our study results showed that higher body fat was associated with increased odds of hypertension, suggesting that lowering body fat composition may increase the chance to control BP in normal-weight individuals [35]. Furthermore, the association between normal weight obesity and hypertension may differ by sex and age.

### Table 2. Association of body mass index, waist circumference, and percentage body fat with prevalent hypertension.

|                | Hypertension | OR (95% CI) |
|----------------|--------------|-------------|
|                | No           | Yes         | p         | Model1 | Model2 |
| **BMI (kg/m²)**|              |             |           |        |        |
| <18.5          | 6.2(0.3)     | 1.6(0.2)    | <.0001    | 0.46(0.32–0.67) | 0.43(0.30–0.63) |
| 18.5–23        | 46.5(0.6)    | 25.7(0.8)   |           | 1      | 1      |
| 23–25          | 22.3(0.5)    | 25(0.7)     | 1.77(1.56–2.00) | 1.78(1.55–2.03) |
| 25–30          | 22.2(0.5)    | 40.6(0.9)   | 3.06(2.71–3.47) | 3.09(2.71–3.51) |
| ≥30            | 2.8(0.2)     | 7(0.5)      | 6.17(4.87–7.83) | 7.54(5.89–9.65) |
| **p for trend**|              |             | <.0001    | <.0001 |        |
| **WC (cm)**    |              |             | <.0001    |        |        |
| <85 in male and <80 in female | 66.1(0.6) | 36.9(1.0) | 1 | 1 |
| 85–90 in male and 80–<85 in female | 16.9(0.4) | 22.2(0.7) | 1.71(1.51–1.93) | 1.75(1.54–1.99) |
| 90–95 in male and 85–<90 in female | 9.7(0.3) | 20.6(0.7) | 2.66(2.31–3.07) | 2.76(2.38–3.19) |
| 95 in male and 90 in female | 7.4(0.3) | 20.3(0.8) | 3.55(3.05–4.12) | 3.97(3.41–4.63) |
| **p for trend**|              |             | <.0001    | <.0001 |        |
| **Percentage body fat** | | | <.0001 | | |
| Q1             | 30(0.8)      | 13.9(0.7)   | 1         | 1      |
| Q2             | 25.9(0.5)    | 22.5(0.7)   | 1.86(1.59–2.16) | 1.87(1.59–2.19) |
| Q3             | 23.3(0.5)    | 28.1(0.8)   | 2.37(2.04–2.76) | 2.45(2.09–2.88) |
| Q4             | 20.7(0.8)    | 35.6(1.1)   | 3.44(2.95–4.01) | 3.56(3.05–4.15) |
| **p for trend**|              |             | <.0001    | <.0001 |        |

Data are presented as percentages (SE) or odds ratio (95% confidence interval).

Abbreviations: BMI, Body Mass Index; WC, Waist Circumference; Q, Quartile.

Model 1: Adjusted for age and sex.

Model 2: Adjusted for age, sex, smoking (never smoker, current smoker, past smoker), alcohol consumption (non-drinker, mild to moderate drinker, heavy drinker), physical activity (regular exercise, non-regular exercise, no exercise), living with spouse or not, income (quartiles), educational attainment (≤ 6 years, 7–12 years, ≥13 years), energy intake from fat, and sodium consumption.

https://doi.org/10.1371/journal.pone.0230616.t002
our stratified analysis by sex and age groups, the association was stronger in women than in men among young individuals (<40 years old), which is consistent with a prior study [36].

BMI was reported to lack the power to differentiate between body fat and lean body mass [37]. We also consider that body composition, such as muscle mass, could affect BP. Usually, muscle mass had an inverse relationship with the PBF [38]; therefore, individuals with a high PBF could have lower muscle mass, which may be related to high prevalence of hypertension.

In our study, people less than 40 years of age tended to have more prehypertension as BMI, WC, and PBF increased. Our findings suggest that younger age might require earlier control and management of obesity to prevent development of hypertension or delay hypertension once age increases. Young persons were found to have a stronger association between adiposity and hypertension [39]. Therefore, younger-aged subjects' prehypertension with obesity may need to be screened and managed properly for preventing hypertension [40]. In addition, hypertension could be masked among prehypertensive obese young persons, and it might require regular BP checks for screening [41]. This population might have elevated BP at a certain time; therefore, elevated BP can be detected [42].

The limitations of our study include its cross-sectional design, and thus, no causal relationships could be obtained. To confirm the relationship between obesity status and hypertension management, long-term intervention studies are necessary. However, this study was based on a nationally representative sample of the Korean adult population, which is a major strength. In addition, data were collected based on standardized protocols to minimize the influence of measurement errors. Finally, we were able to assess potential effect modification by sex and

| Table 3. Odds ratios and 95% confidence intervals for the association between obesity parameters and prevalent hypertension by age group. |
|-----------------|-----------------|-----------------|-----------------|
| BMI (kg/m^2)    | 19–39 (n = 5301)| 40–64 (n = 7491)| ≥65 (n = 3571)  |
| <18.5           | 1.00(0.42–2.40) | 0.41(0.21–0.76) | 0.40(0.24–0.66) |
| 18.5–23         | 1               | 1               | 1               |
| 23–25           | 2.20(1.48–3.26) | 1.57(1.32–1.88) | 1.50(1.16–1.93) |
| 25–30           | 3.77(2.52–5.64) | 2.91(2.45–3.46) | 2.01(1.59–2.53) |
| ≥30             | 7.63(4.59–12.68)| 7.27(5.16–10.25)| 4.99(2.39–10.42)|
| P for trend     | <.0001          | <.0001          | <.0001          |

| WC (cm)         | 19–39 (n = 5301)| 40–64 (n = 7491)| ≥65 (n = 3571)  |
| <85 in male and <80 in female | 1       | 1       | 1               |
| 85–90 in male and 80–<85 in female | 2.04(1.43–2.93)| 1.56(1.32–1.84)| 1.41(1.12–1.78) |
| 90–95 in male and 85<90 in female | 2.60(1.75–3.87)| 2.80(2.31–3.41)| 1.84(1.43–2.36) |
| ≥95 in male and ≥90 in female | 4.80(3.30–6.98)| 3.32(2.73–4.07)| 2.54(1.92–3.35) |
| P for trend     | <.0001          | <.0001          | <.0001          |

| Percentage body fat | 19–39 (n = 5301)| 40–64 (n = 7491)| ≥65 (n = 3571)  |
| Q1                | 1               | 1               | 1               |
| Q2                | 1.88(1.22–2.89) | 1.86(1.48–2.33) | 1.68(1.28–2.19) |
| Q3                | 2.47(1.58–3.85) | 2.37(1.91–2.93) | 2.07(1.59–2.68) |
| Q4                | 4.28(2.93–6.26) | 3.50(2.79–4.37) | 2.21(1.69–2.91) |
| P for trend       | <.0001          | <.0001          | <.0001          |

Abbreviations: BMI, body mass index; WC, waist circumference; Q, quartile
Adjusted for age, sex, smoking (never smoker, current smoker, past smoker), alcohol consumption (non-drinker, mild to moderate drinker, heavy drinker), physical activity (regular exercise, non-regular exercise, no exercise), living with spouse or not, income (quartiles), educational attainment (≤6 years, 7–12 years, ≥13 years), energy intake from fat, and sodium consumption.

https://doi.org/10.1371/journal.pone.0230616.t003
In conclusion, there was a positive association between various obesity parameters and hypertension in representative Korean adults. Even within the normal range of BMI, high WC and high PBF were associated with hypertension. Thus, measurement of BMI may not be sufficient to establish the association between obesity and hypertension. Our findings suggest that it is important to recognize and manage high-risk patients with proper obesity risk assessment because hypertension in normal weight obesity could be easily neglected. Our study results also suggest that obese young people with prehypertension may require more attention and early appropriate management to control.

### Supporting information

**S1 Table.** Association of body mass index, waist circumference, and percentage body fat with prevalent hypertension based on a new guideline.

(OCX)

**S2 Table.** Combined associations of body mass index and other obesity parameters with prevalent hypertension based on new guideline.

(OCX)

**S3 Table.** Subgroup analysis for the association between body mass index and prevalent hypertension.

(OCX)
S4 Table. Subgroup analysis for the association between waist circumference and prevalent hypertension.
(DOCX)

S5 Table. Subgroup analysis for the association between percentage body fat and prevalent hypertension.
(DOCX)

S6 Table. Association of body mass index, waist circumference, and percentage body fat with prevalent hypertension by sex.
(DOCX)

S7 Table. Odds ratio and 95% confidence intervals for the association between obesity parameters and prevalent hypertension by sex and age group.
(DOCX)

S8 Table. Combined associations of body mass index and other obesity parameters with prevalent hypertension by sex and age group.
(DOCX)

Acknowledgments

Hong Seok Lee, Yong-Moon Park, and Sung Rae Kim conceived the project and developed the overall research plan; Kyungdo Han performed statistical analyses; Hong Seok Lee and Yong-Moon Park wrote the manuscript; all authors interpreted the data and critically revised the manuscript for important intellectual content. Hong Seok Lee, Yong-Moon Park, and Sung Rae Kim had primary responsibility for final contents. All authors read and approved the final manuscript. This research was supported in part by the Intramural Research Program of the NIH, National Institute of Environmental Health Sciences.

Author Contributions

**Conceptualization:** Hong Seok Lee, Yong-Moon Park, Kyungdo Han, Soonjib Yoo.

**Data curation:** Hong Seok Lee, Yong-Moon Park, Kyungdo Han, Seungwon Lee, Sung Rae Kim.

**Formal analysis:** Hong Seok Lee, Yong-Moon Park, Kyungdo Han, Jin-Hong Yang, Seung-won Lee.

**Funding acquisition:** Yong-Moon Park, Kyungdo Han.

**Investigation:** Hong Seok Lee, Yong-Moon Park, Kyungdo Han.

**Methodology:** Hong Seok Lee, Yong-Moon Park, Kyungdo Han.

**Project administration:** Jin-Hong Yang.

**Resources:** Hong Seok Lee, Yong-Moon Park, Kyungdo Han, Jin-Hong Yang, Seungwon Lee, Seong-Su Lee, Soonjib Yoo.

**Software:** Hong Seok Lee, Kyungdo Han, Jin-Hong Yang, Sung Rae Kim.

**Supervision:** Hong Seok Lee, Kyungdo Han, Jin-Hong Yang, Seong-Su Lee, Sung Rae Kim.

**Validation:** Hong Seok Lee, Yong-Moon Park, Kyungdo Han, Seong-Su Lee, Soonjib Yoo, Sung Rae Kim.
Visualization: Hong Seok Lee, Yong-Moon Park, Kyungdo Han, Soonjib Yoo, Sung Rae Kim.

Writing – original draft: Hong Seok Lee, Yong-Moon Park, Kyungdo Han, Seong-Su Lee, Soonjib Yoo, Sung Rae Kim.

Writing – review & editing: Hong Seok Lee, Yong-Moon Park, Kyungdo Han, Jin-Hong Yang, Seungwon Lee, Seong-Su Lee, Soonjib Yoo.

References

1. Shrivastava UA, Mohan V, Unnikrishnan R, Bachani D. Obesity, Diabetes and Cardiovascular Diseases in India: Public Health Challenges. *Current diabetes reviews*. 2016; 23(1):33–54. https://doi.org/10.1002/cdr.2900 PMID: 23364850

2. Humphreys B, McLeod L, Ruseski J. Physical activity and health outcomes: evidence from Canada. *Health economics*. 2014; 23(1):33–54. https://doi.org/10.1002/hec.2900 PMID: 23364850

3. Lee HS, Hwang IY, Park YJ, Yoon SH, Han K, Son JW, et al. Prevalence, awareness, treatment and control of hypertension in adults with diagnosed diabetes: the Fourth Korea National Health and Nutrition Examination Survey (KNHANES IV). *Journal of human hypertension*. 2013; 27(6):381–387. https://doi.org/10.1038/jhh.2012.56 PMID: 23223084

4. Landecho M, Moncada R, Valentı ´ V, Fruhbeck G. Cardiovascular Prevention in Obese Patients. *Current pharmaceutical design*. 2016; 22(37):5687–5697. https://doi.org/10.2174/1381612822666160822125834 PMID: 27545979

5. Aekplakorn W. Prevalence, treatment, and control of metabolic risk factors by BMI status in Thai adults: National Health Examination Survey III. *Asia-Pacific Journal of public health*. 2011; 23(3):298–306. https://doi.org/10.1177/1010539509340690 PMID: 20460284

6. Ostchega Y, Hughes JP, Terry A, Fakhouri THI, Miller I. Abdominal Obesity, Body Mass Index, and Hypertension in US Adults: NHANES 2007–2010. *American Journal of Hypertension*. 2012; 25(12):1271–1278. https://doi.org/10.1038/ajh.2012.120 PMID: 22895451

7. Delvecchio L, Reaburn P, Trapp G, Korhonen M. Effect of concurrent resistance and sprint training on body composition and cardiometabolic health indicators in masters cyclists. *Journal of Exercise Rehabilitation*. 2016; 12(5):442–450. https://doi.org/10.12965/jer.1632672.336 PMID: 27807523

8. Cathleen D. Gillespie KAH. Prevalence of Hypertension and Controlled Hypertension—United States, 2007–2010. CDC. 2013; 62(3):144–148.

9. Song H, Park S-J, Jang D, Kwon D, Lee H-J. High consumption of salt-fermented vegetables and hypertension risk in adults: a 12-year follow-up study. *Asia Pacific Journal of Clinical Nutrition*. 2017; 26(4):696–707. https://doi.org/10.6133/apcn.042016.13 PMID: 28582822

10. Simonds S, Pryor J, Ravussin E, Greenway F, Dileone R, Allen A, et al. Leptin mediates the increase in blood pressure associated with obesity. *Cell*. 2014; 159(6):1404–1416. https://doi.org/10.1016/j.cell.2014.10.058 PMID: 25480301

11. Yano Y, Vongpatanasin W, Ayers C, Turer A, Chandra A, Carnethon M, et al. Regional Fat Distribution and Blood Pressure Level and Variability: The Dallas Heart Study. *Hypertension*. 2016; 68(3):576–583. https://doi.org/10.1161/HYPERTENSIONAHA.116.078765 PMID: 27432862

12. Jean N, Somers V, Sochor O, Medina Inojosa J, Llano E, Lopez Jimenez F. Normal-weight obesity: implications for cardiovascular health. *Current Atherosclerosis Reports*. 2014; 16(12):464–464. https://doi.org/10.1007/s11883-014-0464-7 PMID: 25342492

13. Shea JL, King MTC, Yi Y, Guillaume W, Sun G. Body fat percentage is associated with cardiometabolic dysregulation in BMI-defined normal weight subjects. *NMCD Nutrition Metabolism and Cardiovascular Diseases*. 2012; 22(9):741–747.

14. Poirier P, Després JP. Exercise in weight management of obesity. *Cardiology clinics*. 2001; 19(3):459–470. https://doi.org/10.1016/s0733-8651(05)70229-0 PMID: 11570117

15. Ruiz Hurtado G, Ruliope L. Hypertension and obesity: correlates with renin-angiotensin-aldosterone system and uric acid. *The journal of clinical hypertension*. 2014; 16(8):559–560. https://doi.org/10.1111/jch.12355 PMID: 24953647

16. Masters R, Reither E, Powers D, Yang YC, Burger A, Link B. The impact of obesity on US mortality levels: the importance of age and cohort factors in population estimates. *American Journal of Public Health*. 2013; 103(10):1895–1901. https://doi.org/10.2105/AJPH.2013.301379 PMID: 23948004

17. Sahakyan K, Somers V, Rodriguez Escudero J, Hodge D, Carter R, Sochor O, et al. Normal-Weight Central Obesity: Implications for Total and Cardiovascular Mortality. *Annals of Internal Medicine*. 2015; 163(11):827–835. https://doi.org/10.7326/M14-2525 PMID: 26551006
18. Lee H-S, Kwon H-S, Lee J-H, Park Y, Lim S, Lee S-H, et al. Prevalence, awareness, treatment, and control of hypertension among people over 40 years old in a rural area of South Korea: The Chungju Metabolic Disease Cohort (CMC) Study. *Clinical and experimental hypertension*. 2010; 32(3):166–178. https://doi.org/10.3109/10641960903254497 PMID: 20504124

19. Park Y-M, Kwon H-S, Lim S, Lee J-H, Yoon K-H, Song H-Y, et al. Optimal waist circumference cutoff value reflecting insulin resistance as a diagnostic criterion of metabolic syndrome in a non-diabetic Korean population aged 40 years and over: the Chungju Metabolic Disease Cohort (CMC) study. *Yonsei Medical Journal*. 2010; 51(4):511–518. https://doi.org/10.3349/ymj.2010.51.4.511 PMID: 20499415

20. Gregg E, Cheng Y, Cadwell B, Imperatore G, Williams D, Flegal K, et al. Secular trends in cardiovascular disease risk factors according to body mass index in US adults. *JAMA: the Journal of the American Medical Association*. 2005; 293(19):1868–1874. https://doi.org/10.1001/jama.293.15.1868 PMID: 15840861

21. Anuurad E, Shiwaku K, Nogi A, Kitajima K, Enkhmaa B, Shimono K, et al. The new BMI criteria for Asians by the regional office for the western pacific region of WHO are suitable for screening of overweight to prevent metabolic syndrome in elderly Japanese workers. *Journal of Occupational Health*. 2003; 45(6):335–343. https://doi.org/10.1539/joh.45.335 PMID: 14676412

22. Imboden M, Swartz A, Finch H, Harber M, Kaminsky L. Reference standards for lean mass measures using GE dual energy x-ray absorptiometry in Caucasian adults. *PLoS One*. 2017; 12(4):e0176161–e0176161. https://doi.org/10.1371/journal.pone.0176161 PMID: 28426779

23. Feldman H, Zuber K, Davis J. Staying up to date with the JNC 8 hypertension guideline. *JAAPA*. 2014; 27(8):44–49. https://doi.org/10.1007/01.JAA.0000451865.17954.9b PMID: 25054794

24. Whelton P, Carey R, Aronow W, Casey D, Collins K, Dennison Himmel farb C, et al. 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCN A Guideline for the Prevention, Detection, Evaluation, and Management of High Blood Pressure in Adults: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *Journal of the American College of Cardiology*. 2018; 71(19):e127–e248. https://doi.org/10.1016/j.jacc.2017.11.006 PMID: 29146535

25. Kim M, Han K, Kwon H-S, Song K-H, Yim H, Lee W-C, et al. Normal weight obesity in Korean adults. *Clinical endocrinology*. 2014; 80(2):214–220. https://doi.org/10.1111/cen.12162 PMID: 23362933

26. Park Y-M, Fung T, Stock S, Zhang J, Hazlett L, Han K, et al. Diet Quality and Mortality Risk in Metabolically Obese Normal-Weight Adults. *Mayo Clinic proceedings*. 2016; 91(10):1372–1383. https://doi.org/10.1016/j.mayocp.2016.06.022 PMID: 27712636

27. Zhang M ZY, Wang G, Zhang H, Ren Y, Wang B, Zhang L, et al. Body mass index and waist circumference combined predicts obesity-related hypertension better than either alone in a rural Chinese population. *Scientific Reports*. 2016; 6:31935–31935. https://doi.org/10.1038/srep31935 PMID: 27545898

28. Roka R, Michimi A, Macy G. Associations Between Hypertension and Body Mass Index and Waist Circumference in U.S. Adults: A Comparative Analysis by Gender. *High Blood Pressure & Cardiovascular Prevention*. 2015; 22(3):265–273.

29. Sato F, Maeda N, Yamada T, Namazui H, Fukuda S, Natsukawa T, et al. Association of Epicardial, Visceral, and Subcutaneous Fat With Cardiometabolic Diseases. *Circulation Journal*. 2018; 82(2):502–508. https://doi.org/10.1253/circj.CJ-17-0820 PMID: 28954947

30. Uretsky S, Messerli F, Bangalore S, Champion A, Cooper Dehoff R, Zhou Q, et al. Obesity paradox in patients with hypertension and coronary artery disease. *The American journal of medicine*. 2007; 120(10):863–870. https://doi.org/10.1016/j.amjmed.2007.05.011 PMID: 17904457

31. Lee CMY, Huxley R, Wildman R, Woodward M. Indices of abdominal obesity are better discriminators of cardiovascular risk factors than BMI: a meta-analysis. *Journal of clinical epidemiology*. 2008; 61(7):646–653. https://doi.org/10.1016/j.jclinepi.2007.08.012 PMID: 18359190

32. Matsuzawa Y, Funahashi T, Nakamura T. The concept of metabolic syndrome: contribution of visceral fat accumulation and its molecular mechanism. *Journal of Atherosclerosis and Thrombosis*. 2011; 18(8):629–639. https://doi.org/10.5551/jat.7922 PMID: 21737960

33. Shah AD, Kandula NR, Lin F, Allison MA, Carr J, Herrington D, et al. Less favorable body composition and adipokines in South Asians compared with other US ethnic groups: results from the MASALA and MESA studies. *International Journal of Obesity*. 2016; 40(4):639–645. https://doi.org/10.1038/ijo.2015.219 PMID: 26499444

34. George C, Goedcke J, Crowther N, Jaff N, Kengne A, Norris S, et al. The Role of Body Fat and Fat Distribution in Hypertension Risk in Urban Black South African Women. *PLoS One*. 2016; 11(5): e0154894–e0154894. https://doi.org/10.1371/journal.pone.0154894 PMID: 27171011

35. Fazliana M, Liyana A, Omar A, Ambak R, Mohamad Nor N, Shamsudin U, et al. Effects of weight loss intervention on body composition and blood pressure among overweight and obese women: findings
36. WS A. Association of obesity with hypertension. *Annals of translational medicine*. 2017; 5(17).

37. Lavie C, Milani R, Ventura H. Obesity and cardiovascular disease: risk factor, paradox, and impact of weight loss. *Journal of the American College of Cardiology*. 2009; 53(21):1925–1932. https://doi.org/10.1016/j.jacc.2008.12.068 PMID: 19460605

38. Litwin S. Normal weight obesity: is bigger really badder? *Circulation: Cardiovascular Imaging*. 2012; 5(3):286–288. https://doi.org/10.1161/CIRCIMAGING.112.974840 PMID: 22592008

39. Jiang J DS, Chen Y, Liang S, Ma N, Xu Y, Chen X, et al. Comparison of visceral and body fat indices and anthropometric measures in relation to untreated hypertension by age and gender among Chinese. *International journal of cardiology*. 2016; 219:204–211. https://doi.org/10.1016/j.ijcard.2016.06.032 PMID: 27327508

40. Senthil S, Krishnadas S. Prehypertension and Its Determinants in Apparently Healthy Young Adults. *Journal of clinical and diagnostic research*. 2016; 10(9):CC05–CC08. https://doi.org/10.7860/JCDR/2016/20626 PMID: 27790426

41. Shen Y, Chang C, Zhang J, Jiang Y, Ni B, Wang Y. Prevalence and risk factors associated with hypertension and prehypertension in a working population at high altitude in China: a cross-sectional study. *Environmental Health and Preventive Medicine*. 2017; 22(1):19–19. https://doi.org/10.1186/s12199-017-0634-7 PMID: 29165123

42. Unsal S, Ozkara A, Albayrak T, Ozturk Y, Beyssel S, Kucukler FK. Evaluation of prehypertension and masked hypertension rate among clinically normotensive patients. *Clinical and experimental hypertension*. 2016; 38(2):218–224. https://doi.org/10.3109/10641963.2015.1047951 PMID: 26818410

43. Cohen JB, Townsend RR. The ACC/AHA 2017 Hypertension Guidelines: Both Too Much and Not Enough of a Good Thing? *Ann Intern Med*. 2018; 168(4):287–288. https://doi.org/10.7326/M17-3103 PMID: 29204627

44. Oliveros E, Somers V, Sochor O, Goel K, Lopez Jimenez F. The concept of normal weight obesity. *Progress in cardiovascular diseases*. 2014; 56(4):426–433. https://doi.org/10.1016/j.pcad.2013.10.003 PMID: 24438734