ORIGINAL RESEARCH

Association Between Obesity and Blood Pressure in Common Korean People

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Purpose: The aim of this study was to investigate the associations of high blood pressure (BP) and wide pulse pressure (PP) with obesity among common Korean people.

Materials and Methods: This study analyzed data from the Seventh Korean National Health and Nutrition Examination Survey (2017). The associations of BP with body mass index (BMI) and waist-to-height ratio (WHT2R) were investigated using their lump mean values.

Results: The BPs of males and females increased with BMI, the PP of females increased with BMI and then decreased, and the PP of males is nearly independent of BMI. The BPs of males and females increased to their maximum values with WHT2R and then decreased. The PPs of males and females increased with WHT2R.

Conclusion: BMI can be used as a useful predictor for high BP, and WHT2R can be used as a useful predictor for wide PP.

Keywords: hypertension, pulse pressure, waist-to-height ratio, body mass index, lump mean value

Introduction

Obesity has been attracting much attention because it is known to be associated with high blood pressure (BP) and pulse pressure (PP).[1–7] PP is the difference between systolic blood pressure (SBP) and diastolic blood pressure (DBP). Hypertension and PP are major predictors of myocardial infarction, stroke, and other cardiovascular diseases. The body mass index (BMI) has been considered as a useful index for assessing obesity[8–10] and is known to be causally associated with hypertension, which can be reduced by weight loss.[11–15] However, BMI alone is not appropriate for distinguishing between body fat and muscle. As an alternative, waist circumference (WC) has been used to evaluate abdominal obesity[16–22] because it is known to be highly correlated with visceral fat and is easy to measure.[23,24] Therefore, BMI and WC are commonly recommended as measures of obesity.

It is known that normal-weight individuals with abdominal obesity can have metabolic risks.[25,26] Higher risks of cardiovascular diseases were found in individuals with normal BMI and abdominal obesity compared to individuals with high BMI but no abdominal obesity.[27–29] Some studies have shown that BMI and WC are associated with incident hypertension,[30,31] and a combination of them may be a better predictor of obesity-related disease than BMI or WC alone.[32] Individuals with abdominal obesity were more likely to have metabolic syndrome than those without abdominal obesity.[33] Therefore, WC should also be measured in conjunction with BMI to define obesity and predict obesity-related hypertension.

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This paper considers BMI and the waist-to-height ratio (WHT2R) as obesity indices. WHT2R is a new waist-to-height ratio introduced in this paper, which is defined as WC divided by the square of the height and considers the facts that WC is more associated with cardio-metabolic mortality than BMI, and height has an inverse association with mortality.[34–36] On the other hand, it is nearly impossible to investigate the association of BP with obesity individually because the distribution of BP with obesity is quite complicated. Thus, this paper investigates it using the lump mean value (LMV). For that purpose, male and female subjects were divided into groups with successive BMI or WHT2R except near the two endpoints.

This paper examined the association of BP with BMI and WHT2R using their LMVs and regression methods, which fit the LMVs of BP with respect to the BMI and WHT2R to a straight line or Gaussian curve. The cutoff values for BMI and WHT2R for high BP and wide PP were determined from the straight lines or Gaussian curves. This paper discussed whether BMI and WHT2R could be used as useful predictors for high BP and wide PP.

Materials and Methods
Study Design and Participants

This study analyzed the public-use releases of the Seventh Korean National Health and Nutrition Examination Survey in 2017 (KNHANES VII-2, approval number 117002), which was performed by the Korea Centers for Disease Control and Prevention (KCDCP). KNHANES is a nationwide, population-based, cross-sectional survey conducted by the Division of Chronic Disease Surveillance of the KCDCP to examine the health and nutritional status of the population. The survey was conducted after approval by the institutional review board (IRB) in the KCDCP, and written informed consent was obtained from each participant at the time of enrollment. The final study cohort comprised 2550 males and 2938 females from a total of 6235 subjects aged 10 to 80 years. Subjects were excluded if they had extreme values of BMI, WHT2R, or BP in order to investigate the association between abdominal obesity and blood pressure in common Korean people (Table 1).

Data Analysis

This study investigated the association between obesity and BP using the LMVs of BMI, WHT2R, and BP given in Tables S1–S4. The WHT2R is defined as follows:

Table 1 Ranges of Systolic and Diastolic Pressures, BMI, and WHT2R considered

Quantity [Unit]	Men		Women	
	Min.	Max.	Min.	Max.
SYS [mmHg]	96	159	87	156
DIA [mmHg]	56	101	55	99
BMI [kg/m^2]	16.01	32.93	15.98	31.96
WHT2R x 10^{-4} [cm^{-1}]	20.11	37.97	24.03	41.01

Abbreviations: SYS, systolic pressure; DIA, diastolic pressure; BMI, body mass index; WHT2R, waist circumference divided by the square of the height.

$$\text{WHT2R} \equiv \frac{\text{waist circumference}}{(\text{height})^2} \tag{1}$$

Each lump was composed of different numbers of subjects with successive BMI or WHT2R except near the two endpoints. The number of subjects contained in each lump was slightly different according to obesity because the number of subjects with the same BMI or WHT2R is not uniform and decreases toward the two endpoints due to a lack of subjects. The associations of BMI and WHT2R with BP were investigated using Microsoft Excel 2014, SPSS (version 25), and regressions in Sigmaplot 14. This paper examines the association between obesity and BP by considering linearity and Gaussianity. Linearity is defined as:

$$y(x) = mx + c \tag{2}$$

where x is the LMV of BMI or WHT2R, c is a constant, m is the slope, and $y(x)$ is the LMV of SBP, DBP, or PP. In this study, the Gaussianity is defined as:

$$y(x) = y_0 + a \exp\left[-\frac{(x - x_0)^2}{2b} \right] \tag{3}$$

where y_0 is the minimum value of $y(x)$ when the constant a is positive, $\sqrt{b}$ is the standard deviation, which determines the width of the distribution, and x_0 is the x value corresponding to the maximum value of $y(x)$.

Results
Association Between BMI and Blood Pressure

Figure 1 shows BP with respect to BMI (Tables S1 and S2). It was fitted to straight lines given by Eq. (2). The parameters m and c are shown in the figure. r^2 is the coefficient of determination. The males' (Figure 1A) and females' (Figure 1B) SBP and DBP increase as BMI increases, and the goodness of fit for linear regression is

sufficient according to r^2. The males' SBP increases from 113.88mmHg to 126.40mmHg, and their DBP increases from 70.85mmHg to 83.47mmHg when BMI increases from 17.21kg/m^2 to 31.60kg/m^2. The females' SBP increases from 107.50mmHg to 124.10mmHg, and their DBP increases from 69.00mmHg to 77.80mmHg when BMI increases from 17.32kg/m^2 to 30.68kg/m^2.

The cutoff values of BMI for SBP and DBP can be obtained from Figure 1. The males' cutoff values are 24.3kg/m^2 for an SBP of 120mmHg and 27.6kg/m^2 for a DBP of 80mmHg. The females' cutoff values are 27.3kg/m^2 and 34.1kg/m^2 for the same SBP and DBP. The females' cutoff value for DBP was extrapolated from the blue line.

Figure 2 shows males' and females' PPs with respect to BMI. The association between the males' PP and BMI cannot be obtained by either Eq. (2) or Eq. (3) because PP fluctuates near 43mmHg, and r^2 for the linear regression is very small. But the association between females' PP and BMI can be obtained by Eq. (3), and the goodness of fit for Gaussian regression is sufficient according to r^2. Females' PP increases from 37.5mmHg to the maximum value (point A) of 44.9mmHg when BMI increases from 17.3kg/m^2 to 26.8kg/m^2 and then it decreases to 42.4mmHg until BMI increases to 30.7kg/m^2.

Association Between WHT2R and Blood Pressure

BP with respect to WHT2R is shown in Figure 3 and is fitted to Gaussian curves given by Eq. (3) (Tables S3 and S4). Males' (Figure 3A) and females' (Figure 3B) SBP and DBP increase to their maximum values as WHT2R increases, and then they decrease. The goodness of fit for Gaussian regression is sufficient according to r^2.

Males' SBP increases from 110.41mmHg to the maximum value (point A) of 124.33mmHg when WHT2R increases from 21.92×10^{-4}cm^{-1} to 34.60×10^{-4}cm^{-1} and then it decreases to 123.56mmHg until WHT2R increases to 36.87×10^{-4}cm^{-1}. Males' DBP increases from 71.45mmHg to the maximum value (point B) of 78.40mmHg when WHT2R increases from 21.92×10^{-4}cm^{-1} to 30.80×10^{-4}cm^{-1} and then it decreases to 74.34mmHg until WHT2R increases to 36.87×10^{-4}cm^{-1}. Therefore, DBP reaches the maximum value earlier than SBP.

For females (Figure 3B), SBP increases from 104.37mmHg to the maximum value (point C) of 125.66mmHg when WHT2R increases from 24.22×10^{-4}cm^{-1} to 39.60×10^{-4}cm^{-1} and then it decreases to 125.50mmHg until WHT2R increases to 40.44×10^{-4}cm^{-1}. DBP increases from 69.66mmHg to
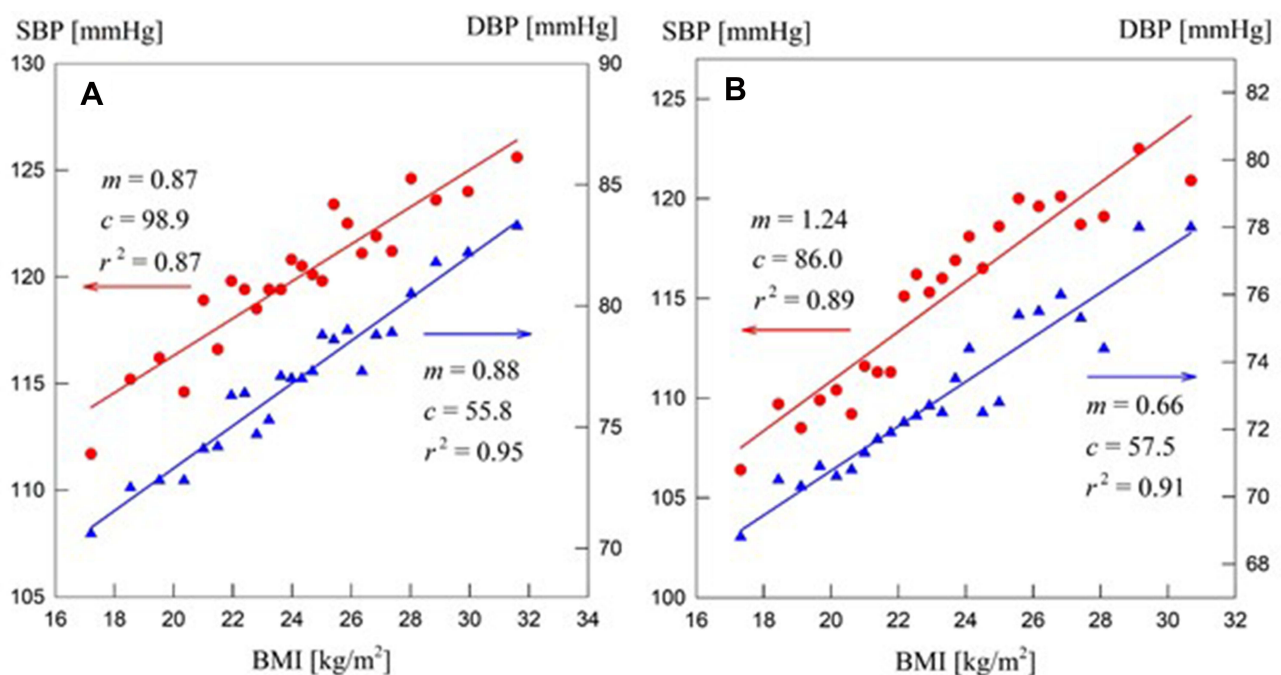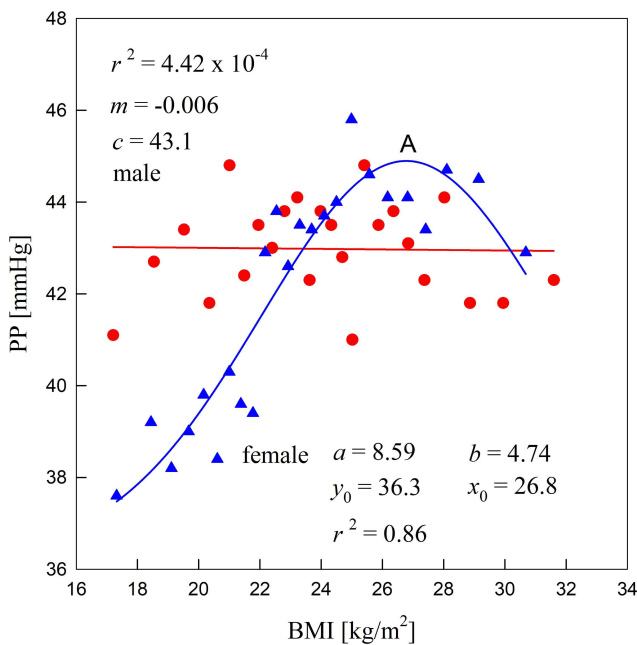

Figure 1 The LMVs of SBP (red) and DBP (blue) with respect to the LMV of BMI for males (**A**) and females (**B**).

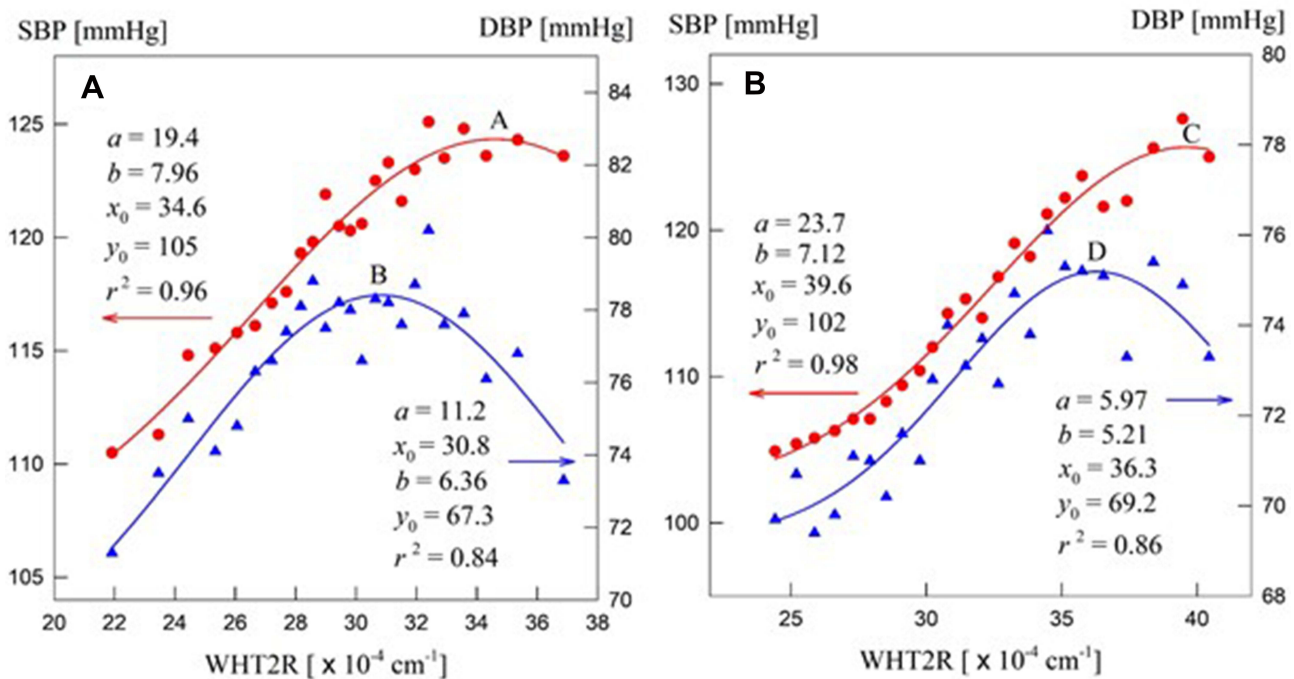**Figure 2** The LMVs of PP with respect to the LMV of BMI for males (red) and females (blue).

the maximum value (point D) of 75.19mmHg when WHT2R increases from 24.42×10^{-4}cm^{-1} to 36.30×10^{-4}cm^{-1} and then it decreases to 73.56mmHg until WHT2R increases to 40.44×10^{-4}cm^{-1}. Therefore, DBP reaches the maximum value earlier than SBP, as in males.

Figure 4 shows that males' and females' PPs increase with WHT2R. The association of males' and females' PPs with WHT2R can be obtained by Eq. (2), and the goodness of fit for Gaussian regression is sufficient according to r^2. The cutoff values of WHT2R for PP can be recommended from Figure 4. Males' and females' cutoff values are 31.9×10^{-4}cm^{-1} and 34.2×10^{-4}cm^{-1}for PP of 45mmHg, respectively.

Discussion

The associations of BP with BMI and WHT2R were investigated using their LMVs. SBPs and DBPs increased with BMI for both males and females. PP increased with BMI for females and was nearly independent of BMI for males. Therefore, BMI can be used as a predictor of high BP for both males and females and for wide PP for females. Males' and females' SBPs and DBPs increased to their maximum values with WHT2R and then decreased. The PPs of males and females increased with WHT2R. Therefore, WHT2R can be used as a predictor of high BP for both males and females until they increase to their maximum values, as well as for wide PP for both males and females.

The temporal behavior of BP depends on the peripheral vascular resistance, arterial compliance, and blood inertance.[37–39] The peripheral resistance represents the

Figure 3 The LMVs of SBP (red) and DBP (blue) with respect to the LMV of WHT2R for males (**A**) and females (**B**).
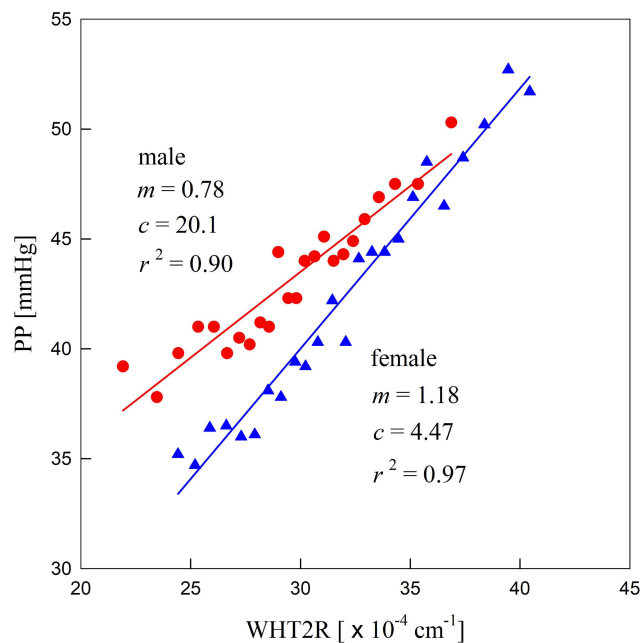
Figure 4 The LMVs of PP with respect to the LMV of WHT2R for males (red) and females (blue).

resistance to blood flow in the arterial system, which is mainly in the resistance vessels (ie, small arterials and arterioles). The arterial compliance of the arterial wall is the ratio of a volume change to the resulting change in pressure of blood vessels that consist of large elastic arteries and small distal arteries. The compliance depends on the radius and wall thickness of the vessel and decreases with age due to progressive changes in the elastin and collagen content of the arterial wall.

Blood inertance represents the inertia of blood mass in the artery. It is known that the peripheral resistance is the main factor for the risk of hypertension, but arterial compliance is also important for old-age systolic hypertension.[40,41] Blood inertance is predominant in large arteries. It is also known that increased stiffness within the thoracic aorta increases PP because of an increase in SBP and a decrease in DBP.[42,43] Therefore, the increase in BP may be explained by increased stroke volume and contractility of the heart, combined with increased systemic vascular resistance caused by increased sympathetic activity.

This paper showed that BMI and WHT2R can be used as useful predictors for high BP and wide PP, respectively. The cutoff values for males' BMI were 24.3kg/m^2 for an SBP of 120mmHg and 27.6kg/m^2 for a DBP of 80mmHg, and females' cutoff values were 27.3kg/m^2 and

34.1kg/m^2 for the same SBP and DBP. Males' and females' cutoff values for WHT2R were $31.9 \times 10^{-4} \text{cm}^{-1}$ and $34.2 \times 10^{-4} \text{cm}^{-1}$ for a PP of 45mmHg, respectively.

The results were applicable to investigate the cause-effect relationships between BP and BMI or WHT2R by linear and Gaussian regressions. Linear regression and Gaussian regression mean that the relationship between the two variables is represented as a straight line and a Gaussian curve, respectively. The effect is determined by only one cause when a straight line represents the relationship and two or more causes when a Gaussian curve represents the relationship. This means that fat or muscle included in the BMI can be the dominant variable affecting the SBP and DBP (Figure 1), and both visceral fat and subcutaneous fat included in the WHT2R can be the dominant variables affecting the SBP and DBP (Figure 3).

Conclusion

The associations of BP with BMI and WHT2R among common Korean people cannot be interpreted individually, but their characteristics can be analyzed by their LMVs. Although the cutoff values for the BMI and WHT2R for high BP and wide PP recommended in this paper can be used as guidelines for Korean people with a similar physique, it is expected that the cutoff values for other ethnicities can be obtained using the present method. On the other hand, the aging process decreases arterial compliance and increases peripheral resistance because with age, the stiffness of the artery wall increases, the viscosity increases, and the radius of the artery wall decreases.[44] This will be investigated using the present method in the near future.

Acknowledgments

Disclosure

The author reports no conflicts of interest in this work.

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