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Comparison of Waist-to-height Ratio (WHtR), Body Mass Index (BMI) and Waist Circumference (WC) as a Screening Tool for Prediction of Metabolic-related Diseases

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Abstract

The present study showed WHtR to be significantly better than BMI and WC for prediction of metabolic-related diseases in the middle-aged and older people in Korea, based on Bayesian ordered probit model analysis. The variations of WC, BMI and WHtR were compared according to the number of metabolic-related diseases such as hypertension, dyslipidemia, stroke, myocardial infarction, angina pectoris and diabetes. It was found that the three measures showed the similar variation except a very few extreme cases for age less than 40. For subjects over the age of 40, WC was not significant and WHtR gave more influence in greater variability than BMI on the number of metabolic diseases. Also, the rate of change for WHtR was higher than for BMI as the number of metabolic-related diseases increased. Specifically, the difference of the marginal effect of WHtR between no disease and only one disease was 1.81 times higher than that of BMI. Moreover, it was pointed out that the threshold value of WHtR for obesity should be considered differently by age.

Key words: BMI, WHtR, Bayesian Ordered Probit Model, Metabolic, Obesity

1. Introduction

BMI, WC and WHtR are typical measurement tools for obesity. Among these, BMI has been used most widely to predict obesity-related diseases such as metabolic syndrom and cardiovascular disease (CVD). However, there has been controversy which one is better to use, pointing out that BMI does not distinguish fat from muscle or between different types of fat distribution[1,2].

Especially, WC was proposed as an alternative proxy for central or abdominal fat[3] since abdominal obesity was observed to be more dangerous to CVD and diabetes[4]. However, WC has some limitations to use since WC may over- and under-evaluate risk for tall and short individuals with similar WC[4]. As another proxy for central obesity, WHtR was appeared by correcting WC with adjusting for variations in height[5].

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Comparison of these measurements has been studied to find the best measurement which is a simple and effective measure of obesity to help predict metabolic risk factors. However, it still remains contentious despite years of research.

Given the researches so far; WC has been proposed as the best measure with high correlation with abdominal fat and with high association with cardiovascular risk factors when targeting mainly Caucasians[6-8]. On the other hand, recent systematic reviews and meta analyses showed that WHtR was a better screening tool than WC and BMI for adult cardiometabolic risk factors when targeting mainly Asians[4,9,10]. So it was suggested in the study for an adult population in Singapore[11] that combination of BMI and WHtR could have the best clinical utility in identifying patients with CVD risk factors.

Thus WHtR must be considered importantly as a screening tool for obesity-related diseases in Asia. However, BMI is still being used primarily in Korea while WHtR is rarely used for the prediction of metabolic-related diseases. The purpose of the present paper is to show that WHtR is better than BMI and WC

by using the big data from Korean National Health and Nutrition Examination Survey (KNHANES) conducted in 2013 based on a model-based statistical analysis. The KNHANES has been conducted periodically since 1998 to assess the health and nutritional status of the civilian noninstitutionalized population of the Korea[2].

We study the changes of BMI, WC and WHtR in accordance with the increase in the number of metabolic-related diseases in order to find out the most influential measure. Metabolic-related diseases considered were hypertension, dyslipidemia, stroke, myocardial infarction, angina pectoris and diabetes. In addition to BMI, WC and WHtR, we also consider age, gender and metabolic risk factors such as systolic blood pressure (SBP), diastolic blood pressure (DBP), triglyceride (TG), high density lipoproteins (HDL), fasting plasma glucose (GLU) as a highly correlated variables with the number of metabolic-related diseases. Bayesian ordered probit model was used for the analysis.

2. Methods

2.1. Study Subjects

This study is based on data for adults (age 19 older) from the First Korean National Health and Nutrition Examination Survey (KNHANES) in 2013. There were total of 6113 respondents in the survey. Excluding data with one or more missing values, we used the remaining 4894 subjects for our analysis.

2.2. Variables

2.2.1. Number of Diagnosed Metabolic-related Diseases

The data contains information on whether each subject received a diagnosis from a doctor for metabolic-related diseases such as hypertension, dyslipidemia, stroke, myocardial infarction, angina pectoris, diabetes. Score one or zero was given depending on whether one has received a diagnosis or not from a doctor for each disease.

Among the 6 diseases, myocardial infarction and angina pectoris were combined as one variable since they both concern the heart and its functions. So score of 1 was given when either myocardial infarction or angina pectoris have been diagnosed and score of 0 when neither of them was diagnosed.

The number of diagnosed metabolic-related diseases was calculated as the sum of the scores for hypertension, dyslipidemia, stroke, myocardial infarction or angina pectoris and diabetes, so the possible values were 0, 1, 2, 3, 4 and 5.

2.2.2. Explanatory Variables

Besides BMI, WC and WHtR, variables used as a measure for determining the metabolic syndrome in general were considered. These variables were SBP, DBP, TG, HDL and GLU.

In addition, gender and age were included as demographic factors. Therefore a total of 10 variables, SBP, DBP, TG, HDL, GLU, WC, BMI, WHtR, gender and age were used as explanatory variables.

3. Statistical Analysis

For comparing the influence for WC, BMI and WHtR on metabolic-related diseases, Bayesian ordered probit model was applied. Bayesian ordered probit model is described as follows[12].

Suppose ordinal categorical variables $y_1,\cdots,y_n$ for n subjects are observed independently and assume each $y_i,\ i=1,\cdots,n$ has the discrete ordered values of $0,1,\cdots,J$. We assume the following model for a latent variable y_i^* and an explanatory variable vector $x_i=(x_{i1},\cdots,x_{iK})$,

$$y_i^* = x_i'\beta+\epsilon_i,\ \epsilon_i \sim N(0,1),\ i=1,\cdots,n,$$
$$y_i = \begin{cases} 0, & -\infty < y_i^* < \gamma_0 \\ 1, & \gamma_0 < y_i^* < \gamma_1 \\ \vdots & \\ J, & \gamma_{J-1} < y_i^* < \infty \end{cases} \quad (1)$$

From this

$$P(Y_i=j)=\Phi(\gamma_j-x_i'\beta)-\Phi(\gamma_{j-1}-x_i'\beta),\quad j=0,\cdots,J, \quad (2)$$

where $\gamma_{-1}=-\infty$, $\gamma_J=\infty$ and $\Phi(\cdot)$ denotes the cumulative distribution function for $N(0,1)$.

In the model (1), parameters are regression coefficients β and thresholds $\gamma=(\gamma_0,\cdots,\gamma_{J-1})$, $\gamma_0<\gamma_1$, $<\cdots<\gamma_{J-1}$ and $Y^*=(Y_1^*,\cdots,Y_n^*)$ is a latent variable which is not observed. Therefore the posterior

probability distribution for (β, γ, Y^*) for given priors $\pi(\beta)$ and $\pi(\gamma)$ is

$$\begin{aligned}&\pi(\beta,\gamma,y^*|y)\\&\propto \exp(-\frac{1}{2}(y^*-x\beta)'(y^*-x\beta))\\&\prod_{i=1}^{n}\sum_{j=0}^{J} I(\gamma_{j-1}<y_i^*<\gamma_j,\ y_i=j)\\&\times\pi(\beta)\pi(\gamma)I(-\infty<\gamma_0<\cdots<\gamma_{J-1}<\infty).\end{aligned} \quad (3)$$

Assume that noninformative priors, $\pi(\beta)\propto 1$, $\pi(\gamma)\propto 1$. Then we get the conditional posterior probability distribution for each parameter as follows.

$$\begin{aligned}&\beta|\gamma,y^*,y\sim N((X'X)^{-1}X'y^*,\ (X'X)^{-1}),\\&y_i^*|\beta,\gamma,y\sim N(x_i'\beta,1)\sum_{j=0}^{J} I(\gamma_{j-1}<y_i^*<\gamma_j,\ y_i=j)\\&\gamma_j|\beta,y^*,y,\gamma_{t,}t\neq j\sim I[\max\{\max(y_i^*|y_i=j),\gamma_{j-1}\}\\&<\gamma_j<\min\{\min(y_i^*|y_i=j+1),\gamma_{j+1}\}]\end{aligned} \quad (4)$$

Thus we can get the joint posterior random samples from $\pi(\beta,\gamma,y^*|y)$ in (3) by gibbs sampling or metropolis-hastings method from (4) and testing or estimation is performed based on the samples generated.

Now, the marginal effect of kth explanatory variable for $P(Y_i=j)$ can be derived by differentiating $P(Y_i=j)$ in (2) by kth explanatory variable,

$$\begin{aligned}M_{ki}&=\frac{\partial P(Y_i=j)}{\partial x_{ki}}\\&=\{\phi(\gamma_{j-1}-x_i'\beta)-\phi(\gamma_{j-1}-x_i'\beta)\}\beta_k,\\&k=1,\cdots K,\ i=1,\cdots,n\end{aligned} \quad (5)$$

where $\phi(\cdot)$ denotes the probability density function for $N(0,1)$.

The marginal effect M_{ki} is the change in $P(Y_i=j)$ when kth explanatory variable for subject i increases by one unit for the other variables fixed. For continuous variable x_k, this represents instantaneous change.

3. Results and Discussion

3.1. Descriptive Statistics for Changes of BMI, WC and WHtR

For hypertension, dyslipidemia, stroke, myocardial infarction or angina pectoris and diabetes there were 3,466 respondents for having none of them, 816 for one disease, 417 for two diseases, 166 for three diseases, 25 for four diseases and 4 for all the five diseases. Note that the frequency of more than 3 diseases is small and it is very serious if one has at least three or more diseases.

Therefore let us define the dependent variable Y; $Y=0$ if no disease, $Y=1$ if just one disease, $Y=2$ if exactly two diseases and $Y=3$ if at least three diseases. The frequency table for the dependent variable Y is given in Table 1.

First, we study the changes of BMI, WC and WHtR in accordance with a level change of Y. Fig. 1 shows conditional probability density plots based on the kernel functions for BMI, WC and WHtR given $Y=j$ $(j=0,1,2,3)$. Difference between no disease ($Y=0$) and at least one disease ($Y\geq 1$) was evident for WHtR in comparison with those of BMI and WC.

Next, means and standard deviations of BMI, WC and WHtR for $Y=j$ $(j=0,1,2,3)$ are given in Table 2. For the direct comparison each variable was standardized with mean 0 and variance 1. Among the three variables WHtR showed the biggest mean difference (=0.664), the next was WC (=0.506) and BMI showed the least mean difference (=0.335) between $Y=0$ and $Y=1$. Also, the mean change of WHtR (=0.274) between $Y=1$ and $Y=2$ was bigger than the other two (WC:0.196, BMI:0.177). For $Y=2$ and $Y=3$ the mean change of WHtR and BMI were similar (WHtR: 0.202, BMI: 0.224) and WC changed least (WC: 0.145). On the average WHtR changed most as Y increased. In addition, the mean at $Y=0$ was smaller than the overall mean zero and the means at $Y=j$,$j=1,2,3$ were greater than zero for all the three variables. Fig. 2 provides graphical change of means for the three variables according to $Y=j$,$j=0,1,2,3$.

On the other hand, obesity is closely related with age and abdominal obesity is mostly appearing since the Middle Ages. Fig. 3 and Table 3 shows the changes of the average of the three variables based on 40 years old.

For age less than 40 (1,544 subjects) the rate of mean change of the three variables were substantially the same

Table 1. Frequency table for Y

y	0	1	2	3
Frequency (%)	3466(70.8)	816(16.6)	417(8.5)	195(4.0)

Table 2. Means and standard deviations

y	BMI		WC		WHtR	
	Mean (sd)	Standardized mean (sd)	Mean (sd)	Standardized mean (sd)	Mean (sd)	Standardized mean (sd)
0	23.352 (3.386)	-0.129 (0.986)	78.750 (9.635)	-0.178 (0.976)	0.481 (0.057)	-0.236 (0.927)
1	24.502 (3.140)	0.206 (0.915)	83.757 (9.041)	0.329 (0.916)	0.522 (0.056)	0.428 (0.897)
2	25.112 (3.339)	0.383 (0.972)	85.696 (8.659)	0.525 (0.877)	0.539 (0.055)	0.702 (0.895)
3	25.881 (3.667)	0.607 (1.068)	87.124 (9.722)	0.670 (0.985)	0.551 (0.065)	0.904 (1.053)
Total	23.794 (3.433)	0 (1)	80.510 (9.871)	0 (1)	0.495 (0.062)	0 (1)

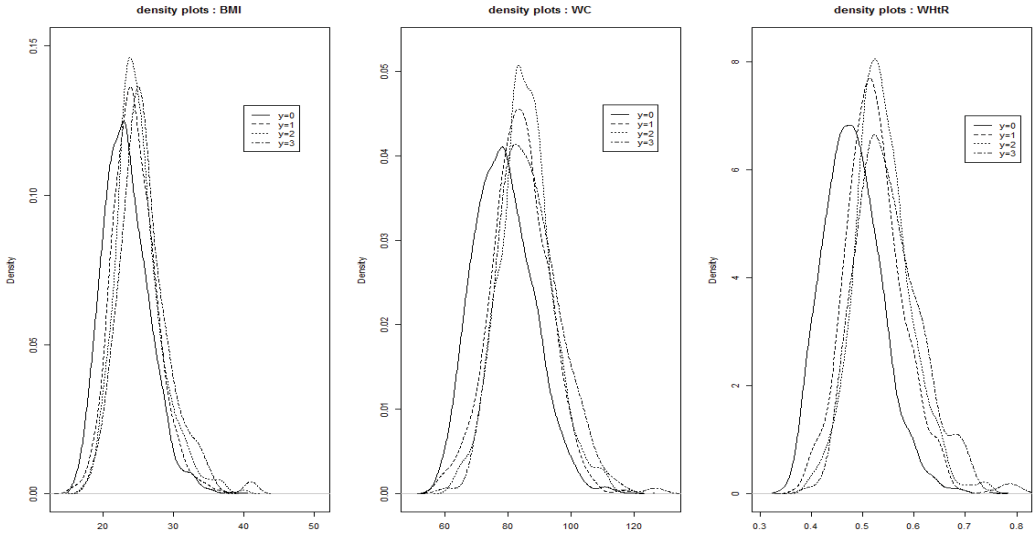

Fig. 1. Density plots conditioned on the levels of *Y*

in the interval between $Y=0$ and $Y=2$ and all the three showed a sudden change in the mean value between $Y=2$ and $Y=3$ with most noticeable change for BMI. However, only 2 subjects were diagnosed with more than 2 diseases (that is, $Y=3$) among 1,544 respondents with age < 40. Moreover, their observed quantities for the three variables at $Y=3$ were the extreme values (BMI: 40.761, 33.537, WC: 126.8, 101.0, WHtR: 0.689, 0.568) corresponding to extreme obesity.

For more than 40 years of age(3,350 subjects) the three variables had different rate of change in the mean.

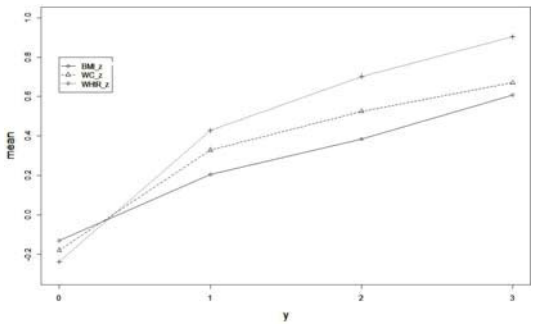

Fig. 2. Standardized means for BMI, WC, WHtR by levels of Y

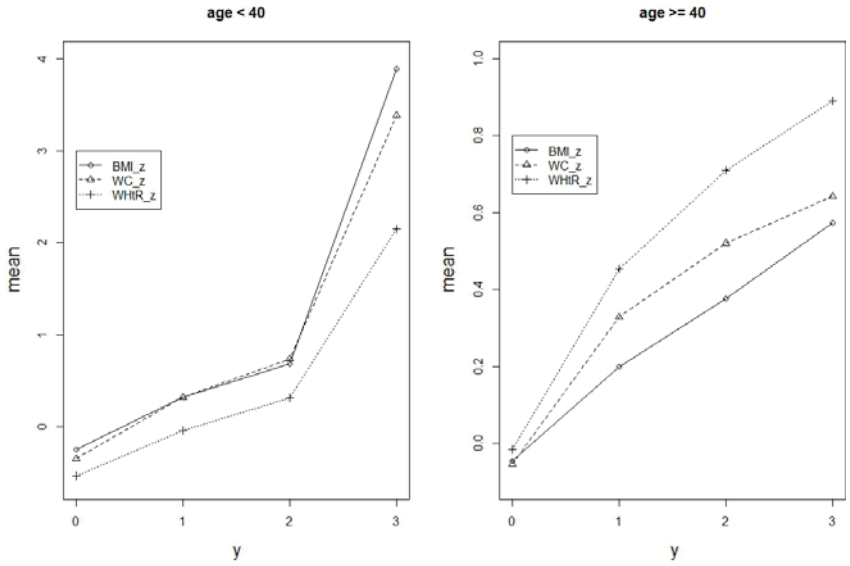

Fig. 3. Standardized means for BMI, WC, WHtR by levels of Y with age <40 and age ≥40

Table 3. Means and standard deviations based on age 40

(a) age < 40 (n=1544)

y	Unstandardized				Standardized		
	n	BMI	WC	WHtR	BMI_z	WC_z	WHtR_z
0	1491	22.97 (3.79)	77.10 (10.37)	0.463 (0.057)	-0.241 (1.103)	-0.346 (1.050)	-0.528 (0.915)
1	43	24.92 (4.49)	83.69 (11.37)	0.493 (0.057)	0.327 (1.307)	0.322 (1.151)	-0.037 (0.913)
2	8	26.14 (2.68)	87.81 (9.09)	0.515 (0.044)	0.683 (0.780)	0.740 (0.920)	0.318 (0.716)
3	2	37.15 (5.11)	113.9 (18.24)	0.629 (0.086)	3.890 (1.488)	3.382 (1.848)	2.155 (1.380)

standard deviations were given in parentheses

(b) age≥40 (n=3350)

y	Unstandardized				Standardized		
	n	BMI	WC	WHtR	BMI_z	WC_z	WHtR_z
0	1975	23.64 (3.02)	80.00 (8.84)	0.494 (0.054)	-0.044 (0.879)	-0.052 (0.875)	-0.015 (0.875)
1	773	24.48 (3.05)	83.76 (8.90)	0.523 (0.055)	0.199 (0.889)	0.329 (0.902)	0.454 (0.890)
2	409	25.09 (3.35)	85.65 (8.66)	0.540 (0.056)	0.378 (0.976)	0.521 (0.877)	0.710 (0.897)
3	193	25.76 (3.48)	86.85 (9.29)	0.551 (0.065)	0.574 (1.014)	0.642 (0.941)	0.891 (1.046)

standard deviations were given in parentheses

WHtR not only had the largest mean value overall but also had the highest rate of change between $Y=0$ and $Y=2$. For $Y=3$, there were 193 subjects and their values of the three variables were not extreme.

Therefore it is reasonable to focus on age ≥40 only for comparing the influence of the three variables because of the same rate of the mean change between $Y=0$ and $Y=2$ and too small number of samples with extreme values at $Y=3$ in age <40.

3.2. Bayesian Ordered Probit Model Analysis

Bayesian ordered probit model was applied to the data for age≥40 for the comparison of the influence on metabolic disease of the three variables BMI, WC and WHtR. Each of the 10 explanatory variables was standardized for ease of comparison.

The statistical package "Zelig" installed in R was used to get posterior samples from (3) by using a Gibbs sampler with data augmentation from (4). 105,000 random samples were generated then first 5,000 samples were discarded as burn-in. From the remaining 100,000 samples, average of random samples for each parameter, β and γ, was taken as an estimate of the parameter. The convergence of the coefficients was confirmed through the path plots but was omitted here.

The results were summarized in Table 4 with estimates of coefficients (β) and marginal effects for each explanatory variable. Significant variables for the response variable Y were age, SBP, BMI, WHtR, GLU and TG. Age ($\beta=0.456$) gave the greatest impact on Y and the next was GLU ($\beta=0.284$), SBP ($\beta=0.155$), WHtR ($\beta=0.151$), BMI ($\beta=0.084$) and TG ($\beta=0.028$) in order. Hence WHtR gave more influence in greater variability than BMI. That is, the number of metabolic-related diseases is more closely related with WHtR than BMI. Note that the mean change of WC seemed apparent in Fig. 3, but it was not significant.

The marginal effect for each variable given in Table 4 was calculated by using the formula (5) fixing the other variables to their average values. All marginal effects for age, SBP, BMI, WHtR, GLU and TG were significant for each probability $P(Y=j),\ j=0,1,2,3$ and HDL showed significant marginal effect for $P(Y=3)$ only.

The marginal effect of age was negative for $P(Y=0)$ and $P(Y=1)$ and was positive for $P(Y=2)$ and $P(Y=3)$. Thus the more the age, the probability of $P(Y=0)$ and $P(Y=1)$ became smaller and the probability of $P(Y=2)$ and $P(Y=3)$ became larger. Similarly, the marginal effects of SBP, BMI, WHtR, GLU and TG were negative for $P(Y=0)$ and were positive for $P(Y=1)$, $P(Y=2)$ and $P(Y=3)$. So the greater the value of each SBP, BMI, WHtR, GLU and TG, $P(Y=0)$ became smaller and each probability of $P(Y=1)$, $P(Y=2)$ and $P(Y=3)$ became larger.

Comparing the marginal effect of BMI and WHtR the

Table 4. The regression coefficients and the marginal effects

Explanatory variable	Coefficient (SE)	Marginal effects (SE)			
		y=0	y=1	y=2	y=3
intercepts	-0.281(0.024)***				
gender_z	0.017(0.033)	-.007(.013)	.006(.012)	.003(.005)	.001(.002)
age_z	0.456(0.031)***	-.175(.012)***	-.082(.007)***	.067(.005)***	.025(.003)***
SBP_z	0.155(0.030)***	-.059(.011)***	.028(.005)***	.023(.004)***	.009(.002)***
DBP_z	-0.037(0.029)	.014(.011)	-.007(.005)	-.005(.004)	-.002(.002)
WC_z	-0.008(0.070)	.003(.027)	-.001(.013)	-.001(.010)	-.000(.004)
BMI_z	**0.084(0.042)***	**-.032(.016)***	**.015(.008)**	**.012(.006)***	**.005(.002)****
WHtR_z	**0.151(0.073)***	**-.058(.029)***	**.027(.013)***	**.022(.011)***	**.008(.004)***
GLU_z	0.284(0.021)***	-.109(.008)***	.051(.004)***	.042(.003)***	.016(.002)***
HDL_z	-0.034(0.024)	.015(.009)	-.007(.004)	-.006(.004)	-.002(.001)*
TG	0.058(0.022)**	-.022(.009)**	.010(.004)**	.008(.004)*	.003(.001)**

*p<.05, **p<.01, ***p<.001

Table 5. Estimates for thresholds; Observed and predicted probabilities

j	γ_j	$P(Y=j)$; observed	$P(Y=j)$; predicted
0	0	0.590	0.593
1	0.882	0.231	0.230
2	1.703	0.122	0.119
3	∞	0.058	0.059

absolute value of the marginal effect of WHtR is larger than BMI for all of the probability $P(Y=j), j=0,1,2,3$. Hence the rate of change for WHtR was bigger than for BMI for each probability. Moreover, the difference of the marginal effect of WHtR between $P(Y=0)$ and $P(Y=1)$ was much larger (about 1.81 times) than that of BMI (BMI;0.047, WHtR;0.085). That is, WHtR was more sensitively changed to metabolic disease than BMI.

Finally, the estimates for thresholds were $\gamma_0=0$ since the model included the intercept and $\gamma_1=0.882(se=0.028)$, $\gamma_2=1.703(se=0.043)$ from the generated random samples. The observed values and the predicted values for $P(Y=j), j=0,1,2,3$ were given in Table 5.

4. Conclusion

For the comparison of influence for WC, BMI and WHtR on metabolic-related diseases, the variations of these three measures were compared according to the number of metabolic-related diseases. The number was counted for hypertension, dyslipidemia, stroke, myocardial infarction or angina pectoris and diabetes for each individual and classified as 4 categories; none, one, two and more than two diseases.

Now, age is an important factor for metabolic disorders and abdominal obesity is mostly appearing since the Middle Ages. So the changes of the three measures were investigated on the basis of 40 years of age. It was found that the three measures showed the similar variation except a very few extreme cases for age less than 40. So the analysis was focused on subjects with older than 40 years old by applying Bayesian ordered probit model.

As a result, WC was not significant and WHtR gave more influence in greater variability than BMI on the number of metabolic diseases for subjects over the age of 40. Marginally, the rate of change for WHtR was bigger than for BMI as the number of metabolic-related diseases increased. Specifically, the difference of the marginal effect of WHtR between no disease and only one disease was 1.81 times bigger than that of BMI. That is, WHtR was more sensitively changed to metabolic disease than BMI.

In the previous researches it has been showed that WHtR had a strong association with metabolic risks and suggested to use WHtR together with BMI[11,13]. Moreover, recent systemetic reviews and meta analyses showed that WHtR was a better screening tool than WC and BMI for adult cardiometabolic risk factors[4,9]. Here one step further, the present study showed that WHtR was better predictor than BMI based on the model-based statistical analysis in the middle-aged and older people in Korea. Hence WHtR should be used primarily to predict metabolic-related diseases in Korea or in Asia for middle-aged and older people.

Also, there were several discussions about the cut-off values of WHtR for a specific disease suggesting to use 0.5 as a threshold for obesity[1,4]. However, it was 0.493 and 0.523 on the average which is lower and higher than 0.5 with age younger and older than 40, respectively, for at least one metabolic-related disease in this study. This suggests that the threshold value of WHtR for obesity should be different by age. The threshold values of WHtR will be considered in the future study.

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