Article

Tracking Obesity Phenotypes in Korean Adults Based on KNHANES (2015-2019)

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Abstract: The prevalence of obesity in Korean adults was 56.1% in 2019. This study aimed to find obesity phenotypes from the KNHANES(2015–2019) and determine the risk factors associated with each type. In 15,179 participants, three obesity phenotypes, high BMI (short heavy obesity, n=1,685), high waist circumference (WC) (tall abdominal obesity, n=549), and BMI/WC combination (heavy abdominal obesity, n=3,538), were compared to non-OB (n=9,425). Marital status, lower income and education levels were highly associated with abdominal obesity. Insufficient exercise or skipping breakfast were associated with the WC or BMI/WC obesity type. The BMI/WC risk was 3.25 times higher in males with high TG and 4.6–4.8 times higher in females with high FAS or TG, and the risk increased to 7-8 times higher in three combinations (HYP+HDLc+FBS) compared to the control. The K-Score to test balanced diets was lower in BMI/WC than in others. Low intakes of FI-4(fruits) in men and FI-2(meat), FI-3 (vegetables), and FI-5 (milk/milk products) in women with BMI/WC and WC types, but BMI type was not associated with diets. Compared to BMI, the BMI/WC or WC obesity type was an indicator of metabolically unhealthy obesity associated with obesogenic environments including food/diets pattern and unhealthy behaviors.

Keywords: obesity phenotypes; obesogenic environments; metabolic syndrome; K-score; food pattern

1. Introduction

The Korea National Health and Nutrition Examination Surveys (KNHANES; 2010–2019) indicated that the prevalence of obesity (+overweight) and metabolic syndrome (MetSyn) in Korean adults (aged 19–64) was approximately 56.1% (males;68.5%, females; 43%) and 21.5% (males;27.9%, females;15%), respectively, in 2019 [1]. The patterns of obesity and MetSyn prevalence in both genders were similar [1,2]. NECP ATP-III based MetSyn, the cluster of obesity, hypertension (HYP), diabetes (DM), and dyslipidemia (DYS) are associated with the risk of cardiovascular diseases (CVD) and a 1.5-fold increase in the risk of all-cause mortality [3]. Obesity and MetSyn are mutual health risk factors; however, their degree of severity is different according to the interacted criteria or various obesogenic environments (OB-En), such as dietary habits and behaviors, lifestyles, activities, genetics, family history, etc [4].

Despite the availability of several advanced methods to evaluate fat accumulation in the body, body mass index (BMI) is globally used as an obesity indicator because of its convenience [5]. However, the BMI may be a misleading indicator because it can be altered by race, sex, age, and other OB-En factors. Additionally, the risk of obesity or MetSyn might depend on various metabolically healthy/unhealthy conditions under the same BMI [6,7]. Abdominal obesity (high WC) clustered with MetSyn or CVD risk factors may better predict the risk of metabolic abnormalities [8-10] . Recent studies discussed classifying obesity phenotypes with metabolic abnormalities in healthy/unhealthy populations and finding useful tools for obesity [11-14]. A study reported that approximately 30% of individuals with obesity were metabolically healthy, and visceral fats or the thickness of the carotid artery were lower in individuals with "metabolically healthy" obesity than in those with "metabolically unhealthy" obesity [11]. Heavy and central obesity increases the risk of metabolic abnormalities by 2.6 folds. Moreover, fatty liver condition was observed in normal-weight populations with central obesity [12]. In the US population, a high risk of obesity was observed in non-OB individuals along with CVD risk factors rather than in OB without CVD [13]. The BMI-based definition of obesity should be revised to include the new mechanical approaches in obesities, the pro-inflammation or acceleration of CVD, and MetSyn [14]. However, the results of obesity phenotypes were inconsistent because it was difficult to define the category of metabolically healthy/ unhealthy obesity, and the clustering of risk factors depended on the researcher's purpose.

Additionally, dietary factors, one of important OB-En factors, mauy influence obesity phenotypes [15]. The BMI/WC obesity type was strongly associated with a high intake of energy and fat despite gender differences; however, some of the studies reported that dietary intake of total energy, carbohydrate, fat, dietary fibers, and sodium was not affected by obesity types such as high BMI or WC [16,17]. Since habitual consumers of high-fat diets had high resting metabolic rates, the BMI and body fat% might not change compared to that in the obesity type with low-fat diet intake [18]. The risk of obesity was reportedly increased by 46.0 times for children with the mutants of salt-sensitive genes; hence, studies on gene-diet interaction related to obesity are required [19,20]. Since the lack of dietary diversity has become a problem for increasing chronic diseases, a method for evaluating the dietary diversity score (DDS) or dietary patterns as a good marker for obesities should be developed [21,22].

This study aimed to track obesity phenotypes such as BMI/WC, WC, and BMI, which indicators may have an implication for metabolically health or not, and investigate the association of OB-En factors, including lifestyles, education, environment, and nutrition, with Korean obesity phenotypes.

2. Materials and Methods

2.1. Study design and data collection

Raw data from the five-year KNHANES (6th: 2015, 7th: 2016–2018, and 8th: 2019) were used for this descriptive research. Among adults aged 19–64 (n= 39,759), we excluded those with incomplete or missing data (BMI, WC or MetSyn criteria), pregnant/lactating females, individuals who are unable to do basic physical activities, individuals whose total energy intake per day was <500 Kcal or >5000 Kcal, and individuals on medication for obesity, diabetes, hypertension, and cancer (Fig. 1). Consequently, the total number of study participants was 15,179 (males;6,678, females;8,519). Using obesity criteria for adults (BMI >25, WC >90 cm for males or >85 cm for females), we classified non-OB (normal BMI with normal WC, n = 9,425) and three obesity phenotypes as BMI/WC (high BMI with high WC, n = 3,538), BMI (high BMI with normal WC, n =1,685) and WC (high WC with normal BMI, n = 549). The MetSyn criteria were followed by NCEP ATP-III, such as obesity (WC criteria), diabetes (FBS > 100 mg/dL), dyslipidemia (TG >150 mg/dL or HDLc <40 mg/dL for male; <50 mg/dL for females) and hypertension (SBP >135 mmHg, DBP >85 mmHg). MetSyn disease was indicated if >3 of the above-listed five criteria existed. Since we collected secondary data from the KNHANES, fast-track IRB was approved by the Konyang University (KYU 2022-09-005).

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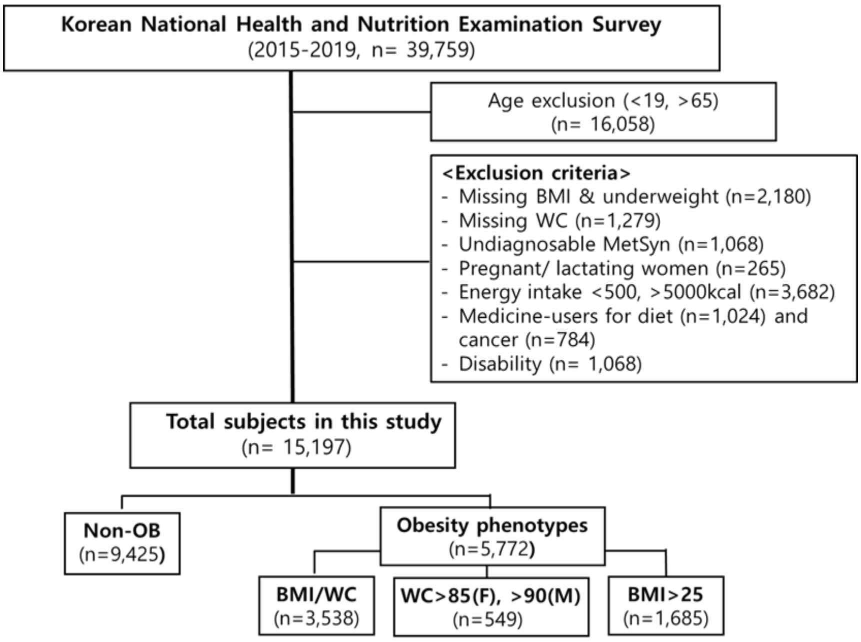

Figure 1. Flowchart showing the inclusion and exclusion criteria for the study participants

General characteristics, such as marital status, with/without a spouse, income levels, economic activities, and education levels, were compared to obesity types. For health behaviors, we modified "Alameda seven health behaviors" (non-smoking, moderate drinking, adequate sleep, maintaining a desirable weight, exercising, eating breakfast, and avoiding snacks) [23]. Non-smoking was defined as not smoking in one's lifetime or having smoked in the past but not currently. Moderate drinking was defined as not drinking throughout one's lifetime or drinking less than twice a week within the past year. Adequate sleep was defined as sleeping 7 to 8 hrs per night. Exercising was defined as a healthy behavior if a person reported exercising for ≥150 min per week [24]. Having breakfast was defined as a healthy behavior if a person had breakfast five to seven times a week. Eating out rarely was defined as a healthy behavior if a person reported eating out less than five times a week.

2.2. K-scoring to test balanced diets, foods patterns, and nutrients

To evaluate balanced diets, we used the K-scoring method, which used a score from 0–10 depending on the weighted degree of correspondence with the recommendation of serving numbers for six primary food intake (FI) groups based on calorie intake, and the total sum was calculated. The six-FI groups based on the Korean Food Balance Wheels provided by the 2020 Korean Dietary Reference Intakes (KDRIs) included FI-1 (grains; 300 kcal), FI-2 (meats, fish, eggs, and beans; 100 kcal), FI-3 (vegetables; 15 Kcal), FI-4 (Fruits; 50 kcal), FI-5 (Milk and Dairy products; 125 kcal), and FI-6 (Oils/Fats and Sugar; 45 kcal) per one serving. Within each component, if the number of servings consumed exceeded the recommended intake, the score was deducted proportionally: the lowest possible score due to deduction was zero [Supplementary table 1] [25]. After collecting the 24 hrs dietary recall data from the KNHANES (2015–2019), we calculated the total intake of 23 subdivided foods belonging to FI-1 and FI-6, classified by the International Foods Code System. The average intake of 22 nutrients, including energy (Kcal), vitamins (g), and minerals (g) based on 2020 KDRIs, was compared among different obesity types.

2.3. Statistics

Statistical analyses were performed using SAS ver. 9.4 (SAS Institute Inc, Cary, NC, USA). Complex sample data analysis was performed using weights following the Korea Disease Control and Prevention Agency's guidelines for using raw data from the

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KNHANES [26]. The Rao-Scott chi-square test or general linear model (GLM) test was performed to find the differences in general characteristics, diet habits, and the balance of diets and nutrients among individuals with different obesity phenotypes. The GLM test, followed by the Bonferroni method, was performed for post-hoc analysis. Logistic regression analysis was used for the risk strength of MetSyn criteria (odds ratio (OR) and marginal probabilities) according to obesity phenotypes. All data were separately analyzed by gender because of differences in gender distribution. To determine the dietary pattern according to obesity types, principal component analysis was performed in the first step of extracting factors (eigenvalue > 1.0); non-correlated factors were derived using orthogonal rotation (varimax option) [27].

3. Results

3.1. First General characteristics of obesity phenotypes

Obesity phenotypes in Koreans OB population (39.5% of total) were defined by high BMI(11.6% of total, short heavy obesity), high WC(3.3% of total, tall abdominal obesity), and a combination type of high BMI/WC (23.5% of total, heavy abdominal obesity) (Table 1). The WC portion did not differ between gender; however, the proportion of BMI/WC and BMI phenotypes was 13% and 6% higher in males than in females, respectively. the WC seems to grow as people get older, but the non-OB group was the youngest. Compared to the non-OB group, the BMI group was defined as “short/heavy obesity” and the WC group as "tall/abdominal obesity" (normal wt). Both males and females with heavy/abdominal obesity" (normal height; Ht) belonged to the BMI/WC group, which was metabolically considered the worst of all obesity phenotypes.

The high WC proportion was higher in the married than in unmarried individuals; however, the BMI/WC proportion was higher in those married with a spouse (32.2%) than in those married without a spouse (23.55%) or in single males (25.4%) ($p < 0.001$). In females, those married with a spouse had higher WC or BMI than the single with or without marriage (p <. 0.001). Interestingly, there was a high OB possibility in the males with economic activities but females without economic activities, therefore, lower income levels were associated with females obesity ($p < 0.001$). In females, lower grade of education, elementary (39%) or middle (25%) school, were associated with increasing BMI/WC type. However, the risk of BMI type was not significantly associated with general characteristics compared to that of abdominal obesity.

Table 1. Gender differences in the general characteristics associated with obesity phenotypes

		Male				Female			
		Non-OB	**BMI/WC**	**WC**	**BMI**	**Non-OB**	**BMI/WC**	**WC**	**BMI**
Subjects	n (%)	3494(52.9)	1999(29.6)	251(3.3)	934(14.2)	5931(71.4)	1539(16.7)	298(3.2)	751(8.7)
	p-value		<.001				<.001		
Age	(M±SE)*	40.1±0.24^{a}	41.55±0.28^{b}	49.77±0.68^{c}	40.64±0.46^{ab}	40.85±0.2^{a}	46.32±0.36^{c}	49.33±0.85^{d}	42.18±0.56^{b}
	p-value		<.001				<.001		
Anthropometrics	Ht (M±SE)*	172.55±0.12^{b}	173.66±0.16^{c}	175.44±0.39^{d}	170.57±0.23^{a}	159.78±0.09^{c}	158.95±0.19^{b}	161.25±0.4^{d}	157.36±0.26^{a}
	p-value		<.001				<.001		
	Wt (M±SE)*	66.97±0.13^{a}	86.56±0.27^{d}	74.64±0.36^{b}	75.89±0.21^{c}	55.09±0.08^{a}	73.36±0.32^{d}	62.25±0.32^{b}	65.05±0.23^{c}
	p-value		<.001				<.001		
	BMI (M±SE)*	22.47±0.03^{a}	28.66±0.07^{d}	24.23±0.04^{b}	26.06±0.03^{c}	21.58±0.02^{a}	28.99±0.1^{d}	23.92±0.06^{b}	26.24±0.04^{c}
	p-value		<.001				<.001		
	WC (M±SE)*	80.48±0.1^{a}	97.05±0.15^{d}	92.12±0.13^{c}	86.42±0.1^{b}	73.4±0.09^{a}	92.67±0.21^{d}	87.31±0.14^{c}	81.33±0.12^{b}
	p-value		<.001				<.001		
Marital Status	Non-married	1098(59.4)	457(25.4)	21(1.1)	263(14.2)	1153(79.8)	145(9.4)	17(1.2)	141(9.6)
	Married with spouse	2243(49.1)	1477(32.2)	216(4.4)	640(14.3)	4294(69.6)	1208(18.4)	241(3.7)	537(8.3)
	Married without spouse	153(59.4)	65(23.5)	14(4.9)	31(12.2)	481(63.2)	185(22.1)	40(4.7)	73(10)

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	p-value	94.23(<.001)				105.42(<.001)			
Income 1)	Q1	289(58.1)	131(26)	17(2.9)	61(13.1)	416(62.2)	196(24.2)	35(5)	64(8.6)
	Q2	758(51.7)	454(30.1)	63(3.8)	206(14.5)	1328(65.3)	451(20.8)	88(3.8)	208(10.2)
	Q3	1094(52)	676(31.4)	66(2.8)	293(13.7)	1865(70.4)	502(17.3)	82(3)	240(9.3)
	Q4	1341(53.4)	733(28.5)	103(3.6)	371(14.5)	2311(78.3)	388(11.8)	91(2.6)	237(7.3)
	p-value	10.71(.296)				128.05(<.001)			
Economic activity 2)	Yes	2712(51.8)	1633(30.7)	201(3.5)	734(14)	3585(72.5)	871(15.7)	151(2.7)	473(9)
	No	585(59.5)	249(25.4)	29(2)	128(13.2)	2091(69.8)	603(18.3)	136(4)	237(8)
	p-value	19.9(<.001)				16.59(.001)			
Education level 2)	elementary S.	186(57.9)	85(25.7)	14(3.5)	42(12.9)	286(43.3)	262(38.8)	47(7.1)	68(10.8)
	Middle S.	225(52.2)	116(28.8)	18(3)	62(16.1)	428(60.9)	182(24.6)	39(5)	71(9.5)
	High S.	1292(55.5)	675(27.7)	85(3)	324(13.8)	2074(69.2)	567(17.5)	122(4)	294(9.3)
	College	1607(51)	1013(31.7)	115(3.4)	443(13.9)	2894(79)	462(11.6)	78(1.7)	277(7.6)
	p-value	16.61(.055)				9(<.001)			

*The mean difference of statistics was described by the Bonferroni method with superscript$^{(a,b,c,d)}$ (α=.05/6=.0083).

1) Chi-square analysis for tertile percentiles of income according to 2019 statistics; Lowest Q1; Minimum-1,000,000, 2nd tertile Q2; ₩1,000,001 - 2,000,000, 3rd tertile Q3; ₩2,000,001-3,150,300, Highest Q4; ₩3,150,301–Maxmuim. .

2) Chi-square analysis for "economic activities"; Yes: economic activities with employed status, No: unemployed status including house-wife, student, etc

3.2. Metabolic abnormalities and unhealthy behaviors in individuals with different obesity phenotypes

All criteria of MetSyn, such as high plasma levels of FBS, TG, HDLc, and HYP (SBP and DBP), were worst in the BMI/WC group compared to those in the other groups regardless of gender. We excluded WC criteria in this analysis because it was used for group classification. BMI/WC was the worst obesity type in individuals with metabolic abnormalities such as higher FBS, TG, and HYP with lower HDLc. The abnormal metabolic pattern in BMI/WC was similar to that in WC compared to that in BMI in males; however, no difference was observed between WC and BMI in females (Table 2).

WC obesity was found to be associated with unhealthy behaviores of insufficient exercise; however, the risk of developing BMI/WC type in males was associated with skipping breakfast. Regarding female obesity, insufficient exercise and eating homecooked meals increased the risk of WC; furthermore, smoking, insufficient sleep, and skipping breakfast were highly associated with the BMI/WC type. We found that the association between insufficient exercise and WC type or between skipping breakfast and BMI/WC type had substantial implications in Korean adults' obesity in both males and females (Table 2). Lastly, drinking and non-exercise hehaviores were associated with metabolic abnormalities in males, increasing BMI/WC obesity type. The risk of developing BMI obesity type was not associated with unhealthy behaviors compared to that of BMI/WC and WC, and their metabolic data.

Table 2. Effects of metabolic syndrome criteria and unhealthy behaviors on different obesity phenotypes.

		Male(n=6,443)				Female(n=8,270)			
		Non-OB	BMI/WC	WC	BMI	Non-OB	BMI/WC	WC	BMI
Subjects	n (%)	3494(52.9)	1999(29.6)	251(3.3)	934(14.2)	5931(71.4)	1539(16.7)	298(3.2)	751(8.7)
MetSyn Criteria1)	FBS	97.01±0.4^{a}	104.97±0.66^{b}	105.16±1.65^{b}	99.21±0.64^{a}	91.97±0.18^{a}	105.09±0.84^{c}	99.84±1.08^{b}	95.77±0.64^{a}
	TG	141.5±2.5^{a}	206.53±4.24^{c}	194.92±9.5^{bc}	173.24±4.96^{b}	92.82±0.96^{a}	149.69±2.95^{c}	130.22±5.49^{b}	121.98±3.19^{b}
	HDLc	50.34±0.2^{c}	43.86±0.24^{a}	45.56±0.77^{bc}	46.86±0.37^{b}	58.49±0.20^{d}	50.49±0.32^{a}	52.83±0.92^{abc}	51.92±0.45^{ab}
	HYP (SBP)	115.6±0.3^{a}	122.92±0.33^{c}	120.02±1.1^{abc}	119.93±0.48^{ab}	109.34±0.2^{a}	120.15±0.46^{c}	116.91±1.06^{b}	114.04±0.63^{b}
	HYP (DBP)	77.0±0.2^{a}	83.07±0.26^{c}	81.14±0.66^{b}	79.81±0.38^{b}	72.30±0.14^{a}	78.81±0.27c	75.42±0.73^{ab}	75.25±0.4^{b}
Healthy behavior 2)	Non-Smoking	2154(62.3)	1200(61.4)	138(54.1)	596(63.4)	5587(94.1)	1408(91.6)	276(93.9)	706(94.7)
	p-value	5.533(.137)				10.538(.015)			
	Non-Drinking	2262(67.3)	1244(64.6)	142(56.1)	590(64.2)	5063(85.3)	1297(84.6)	244(83.1)	647(87.6)
	p-value	12.403(.006)				3.55(.314)			

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Exercise	1728(55.1)	910(50.1)	96(41.6)	510(60.6)	2705(50)	628(44.7)	103(38)	329(51.1)
p-value		35.515(<.001)				19.618(<.001)		
Adequate Sleep	985(49.1)	539(47.9)	60(45.8)	287(48.9)	1718(47.2)	375(41.5)	70(48.6)	215(43.6)
p-value		0.642(.887)				7.96(.047)		
With-Breakfast	1912(51)	1045(48.2)	165(59.3)	497(49.1)	3292(52.3)	917(55.8)	209(69.6)	412(50.4)
p-value		9.417(.024)				30.659(<.001)		
Non-Eating out	1124(29.7)	635(30.4)	99(35.8)	298(30.2)	3601(58.9)	1071(68.1)	229(74.4)	473(61.9)
p-value		3.268(.352)				50.654(<.001)		

1) Statistical significances are described by a superscript(a,b,c,d) with the Bonferroni method with P<0.01 (α=.01/6=.0083)
BMI or WC criteria were excluded among the five criteria of MetSyn because they were used to be classified groups. The criteria for FBS(FBS≥100mg/dL or hypoglycemic agent, insulin medication), TG(≥ 150 mg/dL), HDLc(< 40mg/dL for male and 50 mg/dL for female) and SBP/DBP(SBP≥ 130mmHg or DBP≥ 85mmHg or hypotensive agent medication) were applied. We excluded medicine-users for WC because of using in group classification.

2) Chi-square analysis for the modified "Alameda 7-health-behaviors", Non-Smoking defined as never smoked or smoking in the past; Non-Drinking defined as non-drink or drinking less than twice a week within the past year; With-Breakfast defined as having breakfast 5–7 times a week; Adequate sleep was defined as sleeping 7 to 8 h per night; Exercising was defined as a health behavior if a person reported exercising for 150 min or longer per week Eating out rarely was defined as a health behavior if a person reported eating out less than 5 times a week.

3.3. Risk of metabolic abnormalities according to obesity phenotypes

Using the OR analysis to show the relative risk of obesity phenotypes compared to the non-OB group, we found that all four MetSyn criteria were associated with the risk of BMI/WC or WC obesity type. Regarding the risk of BMI/WC obesity type, the high-risk factor in single criteria was TG (3.25 times) in males and, FAS (4.76 s), and TG (4.58) in females; however, the high-risk factor in two combinations was HYP + HDLc for males (5.45) and TG+FBS (6.95) or HYP+FBS (6.79) for females. The highest risk factor in the three combinations was HYP+HDLc+FBS in males (7.15) and females (7.99) compared to the non-OB group (Fig 2).

Furthermore, in females, the TG+FBS combination increased the risk of developing WC obesity type by 4.59 times compared to the risk of single criteria, TG (3.5) or FBS (3.21). When HYP criteria were added to TG+FBS in females, OR for WC increased to 5.95 times. Compared to that in females, the risk of obesity was not different in WC and BMI obesity type in two combinations for males. The highest risk of WC in three combinations for males was HYP+HDL+FBS (OR = 4.0). Additionally, unlike in the case of BMI/WC, the risk of obesity for WC in the single or two/three combination was decreased upon adjusted the age (Fig 2).

The three combinations of high HYP and FBS with low HDLc were high-risk factors for BMI/WC or WC types in both males and females. However, the OR in BMI obesity type did not change in two or three combinations of MetSyn criteria compared to single criteria. Therefore, the criteria for MetSyn cannot explain the prevalence of obesity if BMI was the only obesity indicator. Moreover, high or low levels of BMI were not associated with MetSyn prevalence and vice versa.

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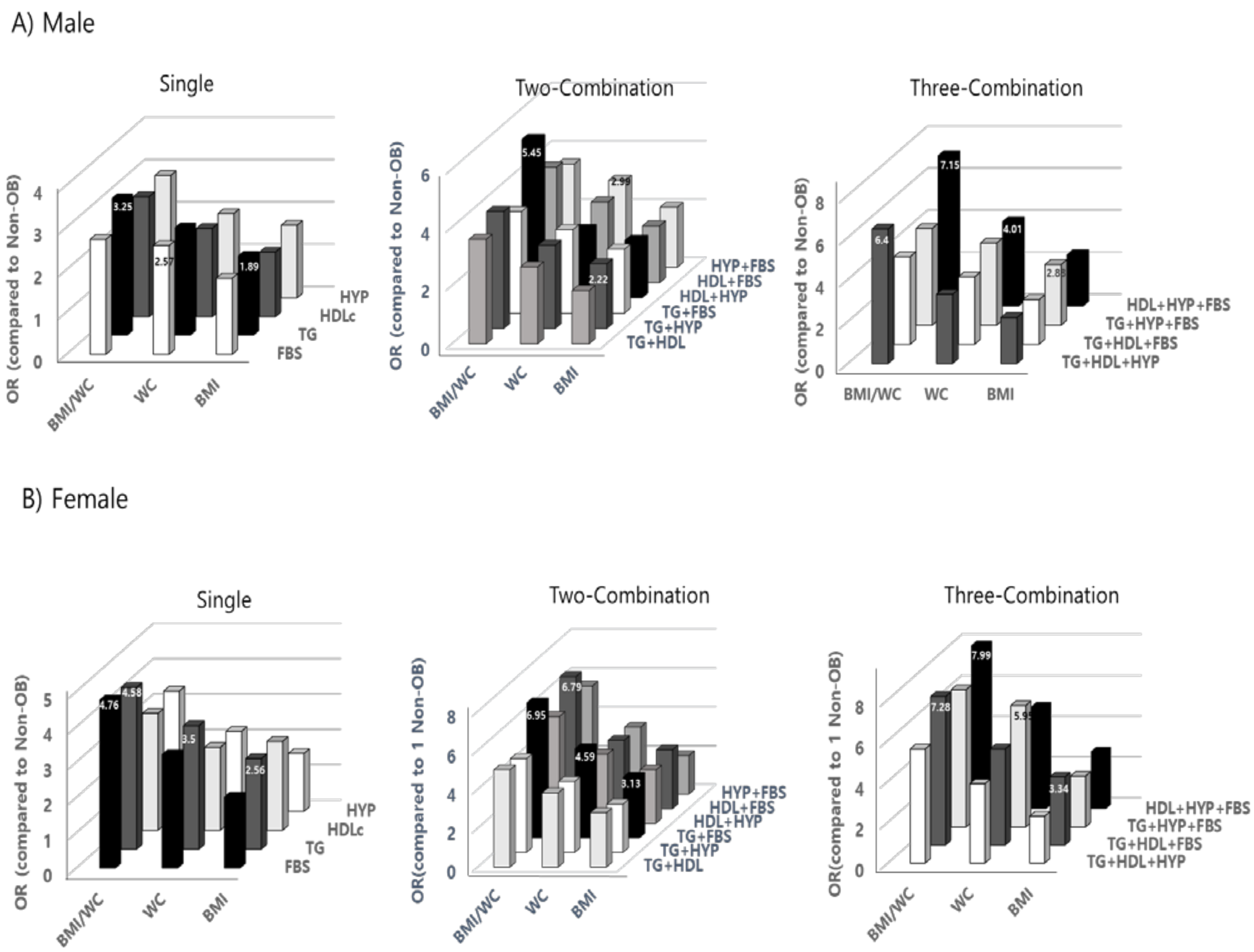

Figure 2. Effect of metabolic syndrome criteria on the relative risk (Odds ratio; OR) of developing obesity phenotypes in males (A) and females (B). The odds ratio was the relative risk compared to that in the Non-OB group with a 95% confidential interval. (BMI or WC criteria were excluded among the five criteria of MetSyn because they were used to be classified groups.) The criteria for FBS (FBS≥ 100 mg/dL or hypoglycemic agent, insulin medication), TG (≥ 150 mg/dL), HDLc (< 40mg/dL for male and 50 mg/dL for female) and SBP/DBP(SBP≥ 130mmHg or DBP≥ 85mmHg or hypotensive agent medication) were applied.

3.4. Balanced diets, food patterns, and nutrition in different Obesity types

Since the lowest K-scores were observed in males with BMI/WC and females with high BMI obesity types, obesity belonging to BMI/WC or BMI obese types have been used the unbalanced diets. However, there were no statistical differences among terciles (Q1–Q3) levels of the K-scores according to obesity types in both males and females. (Data not shown) The males took FI-4 (fruits) instead of FI-1 (grains) as carbohydrates, and females ate diversely, although the K-score was highest in males and females with high WC. When six-FI groups classification were divided into 23 subdivision foods, males with abdominal obesity (WC type) had a pattern of high intake of grains, white rice, fish/seafood, vegetables, and sugars, and low intake of meats, pizza/hamburgers, plant oils, and beverages. This corresponded with nutrient intake in males with high WC, such as high-carbohydrate, sodium, and fibers, with low-fat intake, including PUFA and MUFA. Females with WC took FI-3 (vegetables) and FI-5 (milk/milk products) and diets consisting of high amounts of white rice and kimchi and low amounts of milk/milk products. This corresponded with high carbohydrate and low PUFA, and w-6FA seen in females with WC type.

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Males with BMI/WC ate low intake of FI-4 type (fruits) and high intkaes of noodles, meats, plant oils, and beverages and this corresponded with high-fat intake, including PUFA(w-6). Females with BMI/WC ate low amounts of FI-2 (meat), FI-3 (vegetables), and FI-5 (milk/milk products). Compared to males, females with high BMI/WC ate a variety of food; however, carbohydrates, protein, and fat intakes were lower than that of the non-OB group, and this pattern was not different for the WC group (Table 3).

The results of factor analysis showed that the two food patterns of "high carbohydrates" and "high sodium" with low intake of PUFA-rich foods were seen in the groups with BMI/WC or WC obesity without gender differences. (Data not shown) We concluded that reducing foods with high carbohydrate and sodium for both men and women with high WC but reducing fat/oils and beverages for males with high BMI/WC were recommended. Moreover, high quality of protein (meats, dairy products) and PUFA(w-6)/MUFA were recommended for females BMI/WC type to reduce obesity.

Table 3. Status of the intake of balanced diets (K-scores), six-primary food (FI), and 23-subdivision foods and nutrition according to the obesity phenotypes in Korea.

	Male					Female				
	Non-OB	BMI/WC	WC	BMI	P-value1)	Non-OB	BMI/WC	WC	BMI	P-value
Six primary foods intake (K-scores/day)										
K-Score [2)]	26.22±0.15	25.83±0.19	26.96±0.51	26.51±0.28	.053	26.22±0.12^{a}	25.29±0.23^{b}	26.92±0.49^{c}	25.08±0.33^{ab}	.<.001
FI -1 [3)]	6.55±0.05	6.43±0.06	6.45±0.20	6.72±0.09	.055	6.36±0.04	6.28±0.08	6.48±0.18	6.16±0.10	.232
FI-2	5.16±0.06	5.28±0.07	5.53±0.20	5.14±0.11	.204	5.17±0.04^{b}	4.80±0.08^{a}	5.11±0.20^{ab}	4.87±0.13^{ab}	<.001
FI-3	5.68±0.05	5.56±0.07	5.84±0.20	5.69±0.10	.417	5.22±0.04^{a}	5.32±0.08^{a}	5.91±0.19^{b}	5.24±0.12^{a}	.002
FI-4	2.13±0.06^{b}	1.85±0.07^{a}	2.03±0.22^{b}	2.13±0.11^{b}	.009	2.26±0.05	2.1±0.09	2.05±0.20	1.97±0.12	.083
FI-5	1.74±0.06	1.84±0.08	1.98±0.24	1.83±0.11	.615	2.49±0.05^{b}	2.14±0.10^{a}	2.31±0.24^{ab}	2.05±0.15^{a}	.001
FI-6	4.95±0.06	4.87±0.07	5.13±0.19	5.01±0.10	.474	4.72±0.05	4.64±0.09	5.07±0.23	4.79±0.12	.330
Individual intake of 23-subdivided foods belongs to FI-1 to FI-6 (g)										
Grains	42.2±1.4^{a}	39.9±1.7^{a}	50.8±6.5^{b}	36.5±1.9^{a}	.047	45.5±1.0	47.5±2.0	44.9±3.5	45.2±2.9	.828
White rice	173.4±1.8^{a}	164.2±2.2^{a}	197.4±7.2^{b}	174.4±3.5^{a}	<.001	111.6±1.0^{a}	120.9±2.1^{b}	133.9±5.1^{c}	114.4±3.0^{ab}	<.001
Noodles	50.6±1.5^{ab}	59.6±2.3^{b}	52.6±6.1^{ab}	48.8±2.8^{a}	.003	34.3±0.9	38.3±1.9	33.1±3.6	39.1±2.7	.088
Flour/bread	32.8±1.2	29.8±1.5	31.4±4.4	28.6±2.1	.269	30.7±0.8	28.4±1.6	23.5±3.2	26.7±2.2	.068
Pizza	18.9±1.0^{b}	15.9±1.2^{ab}	9.9±2.4^{a}	12.7±1.3^{ab}	.003	13.1±0.5	10.8±1.1	8.6±2.0	11.5±1.5	.080
Potatoes	37±1.5	36.1±2.0	26.5±4.4	32.7±2.5	.192	38.4±1.3	42.3±3.0	39.3±5.6	33.8±3.2	.283
Meats	172.1±3.4^{b}	182.5±4.9^{b}	146.5±10.1^{a}	173.7±6.5^{b}	.042	105.1±1.8	105.3±5.2	93.9±7.2	112.5±5.8	.347
Fish/seafood	127.8±2.9^{a}	139.4±4.4^{a}	168.9±13.5^{b}	138.5±5.6^{a}	.001	101.4±1.9	96.5±4.1	99.9±8.7	102.7±5.4	.678
Eggs	34.0±0.9	35.4±1.1	32.0±2.7	32.9±1.5	.518	30.1±0.6	27.6±1.1	28.6±2.4	28.5±1.5	.176
Legumes	39.7±1.4	40.0±2.1	41.6±4.1	39.7±2.4	.987	33.0±0.9	28.5±1.8	32.1±3.8	29.4±2.4	.108
Vegetables	236.7±3.4^{a}	249.9±4.8^{ab}	268.9±12.7^{b}	244.1±6.5^{a}	.022	202.8±2.4	208.1±5.5	205.6±9.6	214.8±7.3	.362
Kimchi	122.6±2.0	128.5±2.9	133.7±8.1	129.2±3.9	.168	80.1±1.1^{a}	90.3±2.5^{b}	101.5±5.6^{c}	78.5±3.0^{a}	<.0001
Seaweeds	28.9±1.6	26.7±1.8	33.2±6.0	33.4±3.3	.255	28.6±1.2	25.4±2.4	31.8±6.4	25.9±2.8	.470
Mushrooms	7.8±0.4	9.0±0.6	8.2±1.3	8.0±0.8	.423	8.7±0.4	8.1±0.8	6.0±0.9	8.0±0.9	.354
Seasonings	51.1±0.9	52.2±1.2	50.3±2.5	51.0±2.1	.879	35.7±0.5	35.1±1.1	35.3±2.0	39.1±1.9	.123
Fruits(g)	161.9±4.4	150.5±5.9	186.0±18.4	160.9±8.2	.152	204.7±3.6	190.1±6.9	205.7±15.0	203.6±11.2	.338
Milk/dairy products	83.6±2.6	78.9±3.5	72.1±8.4	81.8±5.0	.535	97.8±1.9^{b}	74.8±3.2^{a}	78.5±7.9^{a}	79.6±5.0^{a}	<.0001
Animal oils	0.4±0.0	0.3±0.0	0.4±0.2	0.3±0.1	.323	0.3±0.0	0.2±0.0	0.2±0.1	0.2±0.0	.053
Plant oils	8.2±0.2^{ab}	8.9±0.2^{b}	7.3±0.5^{a}	8.5±0.3^{b}	.010	6.4±0.1^{b}	5.8±0.2^{ab}	5.4±0.4^{a}	6.4±0.3^{b}	.010
Nuts/seeds	6.8±0.7	6.4±0.6	7.3±1.4	6.0±0.6	.890	7.3±0.4	8.2±0.9	11.3±2.6	7.5±0.9	.3±2
Sugar/sweets	11.5±0.4^{b}	10.0±0.4^{a}	11.6±1.6^{b}	11.4±0.7^{b}	.042	10.6±0.2^{b}	8.5±0.4^{a}	9.0±1.1^{b}	9.9±0.9^{b}	.002
Beverages	149.4±4.3^{b}	154.9±6.1^{b}	106.5±12.4^{a}	138.8±9.3^{b}	.031	108.8±2.7	102.0±5.3	97.0±10.3	102.2±7.0	.478
Alcohol	213.0±7.5	204.7±9.5	197.9±25.0	211.7±14.5	.881	80.2±3.4	69.4±6.0	104.3±18.3	75.3±8.4	.153
Nutrients intake (g)										
Energy (Kcal)	2423.6±16.5	2412.9±23.8	2434.1±54.3	2347.1±30.9	.169	1740.5±10.3	1711.1±20.8	1788.8±42.4	1713.4±25.6	.260
CH2O	339.10±2.20^{b}	330.13±3.30^{ab}	350.2±9.70^{b}	323.7±4.20^{a}	.002	260.8±1.57^{a}	265.06±3.4^{ab}	278.98±6.62^{b}	258.8±4.18^{a}	.035
Protein	87.55±0.75	89.47±1.09	89.51±2.38	88.58±1.68	.452	63.57±0.46^{b}	60.96±0.89^{a}	62.45±1.98^{ab}	65.41±1.46^{b}	.018
Fat	57.79±0.69^{ab}	59.37±0.98^{b}	52.39±2.08^{a}	56.36±1.31^{ab}	.012	43.73±0.44^{b}	39.50±0.82^{a}	39.76±1.75^{ab}	40.69±1.06^{ab}	<.001
SFA	18.43±0.25	18.53±0.34	16.97±0.79	17.65±0.45	.101	14.08±0.17^{b}	12.61±0.33^{a}	12.77±0.63^{ab}	12.70±0.39^{a}	<.001
PUFA	14.51±0.19^{ab}	15.03±0.25^{b}	13.09±0.54^{a}	14.35±0.36^{ab}	.009	11.12±0.12^{b}	10.21±0.22^{a}	9.97±0.48^{ab}	10.51±0.30^{ab}	.001
MUFA	18.76±0.26^{ab}	19.35±0.38^{b}	16.79±0.78^{a}	18.41±0.51^{ab}	.023	13.87±0.15^{b}	12.45±0.29^{a}	12.52±0.63^{ab}	13.11±0.40^{ab}	<.001

n-3 FA	2.05±0.03	2.18±0.05	2.00±0.11	2.14±0.07	.125	1.69±0.03	1.64±0.05	1.75±0.13	1.59±0.06	.380
n-6 FA	12.46±0.16[b]	12.84±0.22[b]	11.09±0.47[a]	12.22±0.32[ab]	.006	9.43±0.11[b]	8.56±0.19[a]	8.28±0.41[a]	8.89±0.26[ab]	<.001
Na	4.32±0.04[ab]	4.48±0.06[b]	4.5±0.15[ab]	4.21±0.08[a]	.026	3.02±0.03	3.08±0.06	3.17±0.12	3.04±0.08	.445
Fibers)	25.93±0.25[a]	26.24±0.35[ab]	28.53±0.93[b]	25.56±0.46[a]	.032	22.3±0.21	22.81±0.38	24.7±0.91	22.48±0.53	.063

1) Superscript(a,b,c,d) ; Statistical significances by the Bonferroni method with P<.0083 (.05/6=.0083)

2) K-Score scoring; According to Kcalories based on the standard recommendation for 6 major Foods intake (FI), each FI group is scored form 0-10 depending on the weight degree of correspondence with recommendation, and the sum of total was calculated.

3) Six major FI Groups in Korean Food Balance Wheel & individual K-scores based on serving numbers according to recommended calories in FIs, such as FI-1: Grains (300kcal), FI-2: Meats/Fish/Eggs/Beans (100kcal), FI-3: Vegetables (15kcal), FI-4: Fruits (50kcal), FI-5: Milk/Dairy products (125kcal), FI-6: Oils/Sugars (45kcal).

4. Discussion

Globally, obesity prevalence is strongly influenced by gender differences. In 2019, male obesity increased by two times (43.1%) the level in 1988 (26.8%) in Korea compared to female obesity without changing [1]. Since sociocultural, environmental, and psychological mechanisms are associated with gender norms and differences, obesity depends on OB-En, such as lifestyles, race, gender, diets, family history, metabolic abnormalities, and genetics [28]. Gender studies should be conducted to make different treatment guidelines for males and females. Because of strong effectors of obesity, OB-En, defining obesity phenotypes and which factors are clustered in types is also a big problem to solve.

We classified three Korean obesity types, including "BMI/WC; heavy/abdominal obesity," "WC; tall /abdominal obesity" (normal Wt), and "BMI; short/heavy obesity" (non-abnormal obesity). Similarly to that in our study, four Korean obesity types were divided by anthropometric parameters of BMI and WC criteria; normal BMI/WC (BMI=18.5–24.9 and WC < 85 cm), obese BMI/normal WC (BMI ≥ 25 and WC < 85 cm), normal BMI/obese WC (BMI < 25 and WC ≥ 85 cm), and obese BMI/WC (BMI ≥ 25 and WC < 85 cm) [29,30]. For central obesity, WC, waist-hip-ratio (WHR), and waist-Ht-ratio (WHtR) were generally used by an international principle or modified according to race, gender, and age [31,32].

BMI/WC obesity type was the major factor for developing high risk of metabolic abnormalities with two or three combinations of MetSyn criteria rather than a single factor. Similarly, in WC type (abdominal obesity), the OR risk was increased by three combinations of MetSyn compared to BMI type (non-abdominal obesity), which did not change. According to Lee's study, abdominal obesity (BMI/WC and WC) was a high-risk factor in CVD, such as hypercholesterolemia, hypertriacylglycemia, and MetSyn disease [16]. Abdominal adiposity was a high-risk factor in Asian females compared to that in Caucasian females with similar BMI [33]. The NHANES Ⅲ report revealed that the prevalence of HYP, DM, DYS, and MetSyn was high in the population with high WC obesity type; however, differences in the risk of developing BMI/WC, WC, and BMI were not determined [10]. Moreover, WHtR for assessing abdominal obesity has been suggested to be significantly related to the risk of DM, CVD, DYS, MetSyn, or hyperglycemia in Spaniards [31]. We found that combining high BP and FBS with low HDLc was a high-risk factor for both BMI/WC and WC types; however, any combinations of MetSyn criteria did not change the OR for BMI type. In this study, since the risk for developing obesity or MetSyn was higher in abdominal obesity, BMI/WC or WC obesity type was relatively defined as metabolically unhealthy obesity compared to BMI type, metabolically healthy obesity.

The association between insufficient exercise and WC type and between skipping breakfast and the BMI/WC type implied unhealthy behavior among Korean adults, without gender differences. Individuals married without a spouse, working males who drink alcohol, individuals who do not exercise and skip breakfast may have a high risk of abdominal obesity (BMI/WC). Additionally, married but non-working females with lower education levels and unhealthy behaviors of insufficient exercise and skipping breakfast may have high risk of developing obesity. The KNHANES 2013–2017 revealed that 87.6% of Korean female adults misperceived their body image despite having a normal BMI between 18.5–25.0. This was related to unhealthy behaviors, such as smoking, insufficient sleep, and excessive body weight management [34]. Based on the data of patients with prediabetes and DM collected from the Korean Center for Disease Control and Prevention, the better the subjective health status, the higher the ratio of normal weight, proper sleep time, exercise, and eating out among health-related behaviors [35]. Sahakyan et al. reported that normal-weight individuals with obesity had much abdominal fat and reduced muscle mass, which may cause reduced energy consumption, poor aerobic fitness, and metabolic disorders [36].

Patients with BMI/WC had unhealthy dietary patterns of high intake of fat/oil and beverages (males) and low intake of protein products and PUFA (females). Dietary patterns increased the risk of obesity in WC type with high-carbohydrate/sodium/fibers, low PUFA for males, and high-white rice/kimchi and low-milk/milk products for females. However, the typical dietary pattern was not observed in BMI type. In factor analysis, the unhealthy foods patterns, such as "high carbohydrate" and "high sodium" with low intake of PUFA-rich foods, were observed in the groups with BMI/WC or WC obesity, without gender differences. Studies showed no relationship between food patterns and BMI; however, the Mediterranean dietary pattern improved BMI in the US population [37,38]. The individuals who ate western diets, including refined grains, French fries, processed red meats, and soft drinks, had increased BMI, WC, WHR, and fat % with low HDLc compared to those eating prudent/healthy diets (vegetables, eggs, seafood & non-hydrogenated fats) [39,40].

We found that the highest risk factor in the three combinations was HYP + HDLc + FBS in males and females compared to the non-OB and recommended diets/food patterns to reduce HYP and FBS and to increase HDLc to prevent obesity. From previous studies, high carbohydrate diets (> 70% of E) and traditional Korean diets for Korean were associated with an increased risk of obesity and CVD because of high TG, FBS, BP, and low HDLc [41]. Interestingly, low HDLc in obesity and MetSyn was associated with high carbohydrate diets, including refined grains, rather than high-fat diets in Korea [42,43]. Low carbohydrate diets significantly reduced Wt, WC, and fat %; however, the types of carbohydrate, refined/ unrefined grains, were a more important factor in increasing obesity than the total amount of carbohydrates [44,45]. Hypertensive patients with a high risk of MetSyn and CVD and individuals with obesity with high BMI & WC ate foods high in carbohydrates and cholesterol [46,47]. Replacing saturated and trans fatty acids with MUFA and PUFA contributed to preventing age-related long-term wt gain in US males and females [48]. Furthermore, high sodium intake was positively correlated with WC obesity type, and the risk of obesity in Korean patients with prediabetes adjusted by age and sex was 1.59 times higher in high sodium diets than in control [49]. Both cross-over and cohort studies have shown that if children had the mutants of salt-sensitive genes, the risk of obesity increased to 46.0 times without HYP; therefore, the studies for gene-diet interaction should be considered in the future [17,19,20].

Studies have found that insufficient diversity in dietary intake is one of the causes of mortality in CVD and cancer [50]. We developed K-Score, a concept similar to DQI-International based on Korean Food Balance Wheels, to indicate balanced diets, and it was easy to show health-related dietary factors. We reported that various OB-En factors, lifestyles, socioeconomic factors, clinics, and family history increased the K-Score without gender differences [25]. In this study, we analyzed 23 subdivision food patterns and nutrients because the WC obesity type had a higher K-Score than the non-OB. DDS was increased in the OB population with high BMI & WC because of high total energy intake in Korean and Sri Lankan adults [21,51]. Gu found no difference between DDS and obesity types (BMI/WC, BMI, WC, and non-OB) in Korean adults [22]. However, the individuals with obesity had lower DDS, calcium quality, and milk consumption than the control [52]. Mediterranean dietary pattern score was also developed to improve diets, lifestyle, and longevity [53]. The USDAC for Nutrition Policy and Promotion revised the HEI to estimate diet quality [54]. Although the pattern of food intake or DDS was not a good marker to evaluate obesity types, the evaluation methods for DDS, K-scoring, and nutrients quality would be improved. We strongly recommended reducing carbohydrate and sodium for WC type and reducing fat/oils and beverages for high BMI/WC type of males. Foods with high protein (meats, dairy products) and fats, including PUFA(w-6) and MUFA, were recommended to reduce obesity for BMI/WC type of females. We recommend reducing the intake of high-carbohydrate and sodium diets in WC individuals and fat/oils and beverages in BMI/WC individuals. Refraining from unhealthy behaviors, such as insufficient exercise and skipping breakfast, might reduce the risk of obesity and metabolic syndrome.

We concluded that the high BMI/WC was the metabolically worst obesity type, and its association with OB-En was similar to the WC type but not with BMI in Koreans. We found that the BMI indicator could be misleading in finding the association between OB-En and obesity prevalence. Although many researchers insist that the BMI is a flawed tool to evaluate metabolically healthy obesity with evidence, it is still used globally. The reasons for inaccurate measures of body fat and muscle mass, along with differences in sex, race, lifecycle, OB-En, and WC, WHR, and WHtR indicators, better explained obesity with DM and CVD in US and European than BMI [6,7,31,32]. However, there is a constant debate about the pros and cons of this method.

Therefore, proper methods for detecting body fat and various OB-En, including dietary habits/quality, should be developed to evaluate obesity phenotypes in the future. Additionally, the spectrum of the utilization of these methods might be extended in classifying obesity and developing prevention/therapy guidelines for chronic diseases, MetSyn, or CVD [55].

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Table S1: The recommended total energy intake and the recommended serving number by food group according to gender and age in the Korean Food Balance Wheels and Korean Dietary Score (K-Scores) in Korean adults aged 19-64 years old.

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Institutional Review Board Statement: The study was approved by the IRB of Konyang University (KYU 2022-09-005).

Informed Consent Statement: Since we collected the secondary data from the KNHANES (2015-2019), fast-track IRB was approved, and the consent form was not needed for this study.

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Conflicts of Interest: The authors declare no conflict of interest.

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