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ORIGINAL RESEARCH

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A cross-sectional study of the relationship between normal weight obesity and metabolic syndrome in older Korean adults

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Abstract

Body mass index (BMI) has the disadvantage of being unable to differentiate between the distribution and quantity of fat mass and lean mass. Normal weight obesity (NWO) is a distinct phenotype characterized by excessive body fat despite a normal BMI. The purpose of this study was to look at the relationship between NWO and metabolic syndrome in a cross-sectional design of older Korean adults aged ≥65 years. The current study used data from the 2008–2011 Korea National Health and Nutrition Examination Survey (1609 males and 2238 females). NWO was defined as a BMI of 18.5 to 24.9 kg/m^2 with a body fat of ≥26.0% in men and body fat of ≥36.0% in women. Metabolic syndrome was defined according to the revised National Cholesterol Education Program definition, with a modified waist circumference threshold of ≥90 cm for men or ≥85 cm for women. People with NWO had an increased risk of metabolic syndrome (odds ratio, OR = 2.357, 95% confidence interval, 95% CI = 1.747–3.179, $p < 0.001$ in men; OR = 1.885, 95% CI = 1.434–2.399, $p < 0.001$ in women) compared to people with normal weight non-obesity (OR = 1). However, after controlling the age, education, income, smoking, heavy alcohol consumption, serum vitamin D, physical activity, fat-to-lean mass ratio, and intake of carbohydrates, fats, and proteins, the increased risk of NWO for metabolic syndrome was no longer significant in both genders. The current findings suggest that NWO is significantly and positively related to the risk of metabolic syndrome in older Korean adults.

Keywords

Normal-weight obesity; Metabolic syndrome; Lifestyle risk factors; Older adults

1. Introduction

Obesity is an abnormal accumulation of fat, and a multifactorial health condition leading to increased morbidity and mortality [1]. Body mass index (BMI) cutoff points tailored to age, gender and ethnicity are used to determine obesity [2, 3]. However, regardless of the cutoff point(s) used, BMI has a significant flaw being unable to differentiate between the distribution and quantity of fat mass and lean mass, both of which are strongly associated with the metabolic complications of obesity [4, 5]. Obese but metabolically healthy individuals are less likely to develop metabolic disorders than obese and metabolically unhealthy individuals, implying that body fat distribution is more important than fat mass itself [6].

The term "normal weight obesity (NWO)" is a distinct phenotype characterized by excessive body fat despite a normal BMI [7]. Due to BMI disadvantages, recent research has focused on NWO as a novel biomarker of cardiometabolic problems [8]. NWO is strongly linked to cardiometabolic risk profiles including high levels of inflammatory cytokines, insulin resistance, oxidative stress, unfavorable lipid profiles, more visceral fat, and low lean mass [7, 8]. A recent meta-analysis [9] reviewed and summarized the clinical importance of NWO.

Obesity can manifest itself in different phenotypes, ranging from seemingly lean individuals to those suffering from morbid obesity. Despite having a lower proportion of BMI-based obesity, Asians show a higher prevalence of metabolic disorders than Caucasians [10, 11]. This disparity could be explained due to the excessive body fat in otherwise thin Asian phenotypes with a normal BMI [7, 12]. Aging is associated with an increase in fat mass, a decrease in muscle mass [9], and an increase in physical functional impairment [10], all of which may contribute to the development of NWO. However, NWO is an unknown health condition in geriatric populations. We hypothesized that NWO is significantly and positively related to the risk and prevalence of metabolic syndrome in older adults. The current study aimed to investigate the link between NWO and metabolic syndrome in older Korean adults.

2. Materials and methods

2.1 Data source and ethics

The data used in the current study was obtained from the Fourth and Fifth Korea National Health and Nutrition Examination Surveys (KNHNES) conducted in South Korea from 2008 to 2011. The KNHANES was administered by the Korea Centers for Disease Control and Prevention. The KNHANES sampling protocol was designed to include a complex, stratified, multistage probability cluster survey of a sample of the noninstitutionalized civilian population in South Korea. The national public database contains detailed information on the KNHNES from 2008 to 2011 (https://www.cdc.gov/nchs/nhanes/about_nhanes.htm; accessed on 10 December 2022).

2.2 The inclusion and exclusion criteria for the data source

The inclusion criteria were: (1) an age of 65 years or older and (2) the availability of the data used in the study. Exclusion criteria included: (1) underweight (a BMI of <18.5 kg/m^2), (2) no body composition data or no metabolic risk factors, and (3) physician-diagnosed arthritis, liver cirrhosis, thyroid disease or cancers.

As shown in Fig. 1, we included 6370 participants aged 65 and above (2647 males and 3723 females) from the 2008–2011 KNHNES dataset. We then excluded those who were underweight (n = 199), those who did not have dual x-ray absorptiometry (n = 1334) or no vitamin D (n = 176), and finally those having arthritis (n = 627), liver cirrhosis (n = 8), thyroid disease (n = 28), or any type of cancer (n = 151). The remaining 3847 participants (1609 males and 2238 females) were included in the final analyses. The sample size was calculated using G*Power software (version 3.1.9.7; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) to detect a significant difference in the number of metabolic syndrome risk factors between NWNO (n = 225) and NWO (n = 225), with an effect size of 0.40, a statistical power of 95%, and a probability of alpha error of 0.01.

2.3 Variables

2.3.1 Measurement of body composition

Body composition was measured with whole-body DXA (Hologic, Bedford, MA, USA). Trained technologists standardized daily quality control of the DXA instrument by a spine phantom provided by the manufacturer. Total and trunk lean mass (LM) as well as total and trunk fat mass (FM) were measured. Total body fat (%) was calculated by dividing total FM by body weight and multiplying by 100. The fat-to-lean mass ratio (FMR) was calculated by dividing the total FM by the total LM.

2.3.2 Definition of normal-weight obesity

NWO was detected by the previously proposed cutoffs of BMI and body fat for Korean populations [8]: a BMI between 18.5 and 24.9 kg/m^2 and high body fat ($\geq$26.0% in men and $\geq$36.0% in women). Normal-weight non-obesity (NWNO) was defined as having a BMI between 18.5 and 24.9 kg/m^2 and normal body fat ($<$26.0% in men and $<$36.0% in women). Obesity (OB) was defined as having a BMI of $\geq$25 kg/m^2.

2.3.3 Definition of metabolic syndrome

The National Cholesterol Education Program definition [13] was used to determine the presence of metabolic syndrome, along with the adoption of a Korean-specific waist circumference (WC) threshold [14]. They are as follows: (1) WC of $\geq$90 cm in men or $\geq$85 cm in women; (2) fasting blood glucose (FBG) of $\geq$100 mg/dL or use of anti-diabetic drugs or diagnosis of diabetes; (3) triglycerides (TG) of $\geq$150 mg/dL or diagnosis of dyslipidemia or use of lipid-lowering drugs; (4) low high-density lipoprotein cholesterol (HDLC) ($<$40 mg/dL in men and $<$50 mg/dL in women); and/or (5) high resting systolic blood pressure (SBP) of $\geq$130 mmHg and diastolic blood pressure (DBP) of $\geq$85 mmHg or use of antihypertensive agents or diagnosed hypertension.

2.3.4 Covariates

The covariates of the study were age (years); sex (male *vs.* female); education (elementary/less, middle/high school or

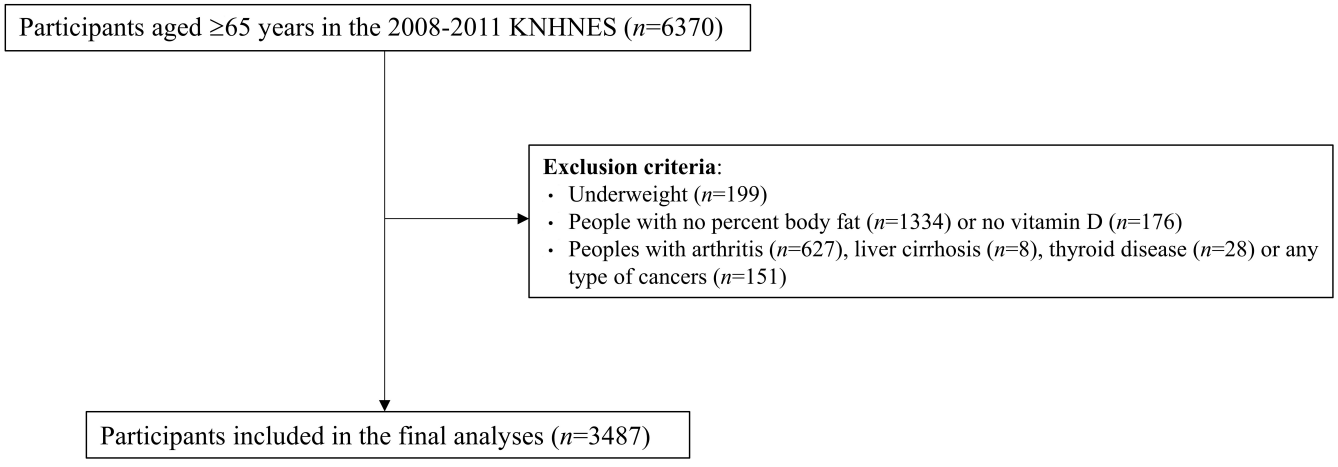

FIGURE 1. Selection of study participants. KNHNES: Korea National Health and Nutrition Examination Survey.

college/better); monthly income (in Korean won); smoking (past/current smoker *vs.* non-smoker); heavy alcohol consumption (≥7 drinks per week for males or ≥5 drinks per week for females); and nutrient intake of carbohydrates (g/day), fats (g/day), and proteins (g/day). Serum vitamin D levels (25-hydroxyvitamin D, 25(OH)D, ng/mL) were also determined by a gamma counter (1470 Wizard, Perkin-Elmer, Turku, Finland) with a radioimmunoassay kit (Lot # 113300B, DiaSorin, Stillwater, MN, USA). The Korean version of the International Physical Activity Questionnaire-Short Form (https://sites.google.com/view/ipaq) was used to track physical activity (moderate to vigorous) in terms of duration (min per session) and frequency (days per week), with activity measured in minutes per week. Detailed information regarding the covariates is available elsewhere [15].

2.4 Statistical analyses

Before conducting statistical analyses, quantile-quantile plots were used to confirm the normality of the data distribution. Analysis of variance (ANOVA), followed by Tukey's *post hoc* test, was used to test the mean group differences (in mean and standard deviation) of continuous variables. The chi-square test was used to test the group differences (in number and percentage) in discontinuous variables. One-way ANOVA with *post hoc* contrast was used to test incremental linear trends in the prevalence of each metabolic syndrome component according to body composition phenotype (from NWNO to NWO and OB). The odds ratio (OR) and 95% confidence interval (CI) of NWO and OB for metabolic syndrome were calculated using Binary logistic regression, with NWNO serving as a control. SPSS-PC software (version 27, SPSS, Chicago, IL, USA) was used for statistical significance ($p = 0.05$).

3. Results

ANOVA and chi-squared test revealed that men were younger, more educated, and more likely to smoke and drink heavily than women (Table 1). Men had higher LM and WC, and nutritional intake of carbohydrates, fats and proteins, but had lower BMI, percent body fat, FM and FMR than women. In terms of metabolic risk factors, men had higher SBP, liver enzymes of alanine aminotransferase (ALT) and aspartate aminotransferase (AST), and vitamin D levels, but lower total cholesterol (TC), TG and HDLC levels than women.

As shown in Tables 2A,2B,2C, ANOVA and chi-squared test helped compare body fatness, health behaviors, nutrient intake, and metabolic risk factors according to body composition phenotypes. People with NWO were more physically active, had higher BMI, percent body fat, WC and FMR, and higher DBP, FBG, HDLC, TC and AST, but had lower carbohydrate intake and serum vitamin D than people with NWNO. People with NWO smoked more and had lower BMI, WC, FMR, DBP, TC, AST and serum vitamin D than people with OB (Table 2A). Limited to men, people with NWO had higher BMI, WC, percent body fat, FMR, SBP, FBG, TC, TG and AST, but were less likely to drink heavily and had lower carbohydrate intake, HDLC and serum vitamin D than people with NWNO. People with NWO had lower BMI, WC, fat intake and protein intake than people with OB, but higher percent body fat, FMR and HDLC (Table 2B). Limited to women, NWO patients were more active and had higher BMI, WC, percent body fat, FMR and TC than NWNO patients. NWO female patients were more physically active and had lower BMI, WC, SBP, DBP, FBG, ALT and AST than OB female patients (Table 2C).

The chi-squared test was used to compare the prevalence of individual metabolic risk factors according to body composition phenotypes (Table 3). In the total group, individuals with NWO had a higher prevalence of all the components of metabolic syndrome than individuals with NWNO. Moreover, individuals with NWO were less likely to have abdominal obesity, hyperglycemia, decreased HDLC, and hypertension than OB patients. Men with NWO showed a higher prevalence of all the components of metabolic syndrome than men with NWNO, and a lower prevalence of all the components of metabolic syndrome than men with OB. Similarly, NWO women had a higher prevalence of abdominal obesity, hyperglycemia, hypertriglyceridemia and hypertension than NWNO women, but a lower prevalence of all metabolic syndrome components than OB women.

The number of metabolic syndrome risk factors according to body composition-based phenotypes are shown in Fig. 2A–C. For the total group, univariate analysis of variance showed that there was a significant incremental trend ($F = 12.308$, $df = 9$, $p < 0.001$) in the number of individual metabolic risk factors according to body composition phenotypes (from NWNO to NWO and OB, Fig. 2A). For both genders, there were significant incremental trends ($F = 6.368$, $df = 8$, $p < 0.001$ in men, Fig. 2B; $F = 5.130$, $df = 8$, $p < 0.001$ in women, Fig. 2C) in the number of individual metabolic risk factors across the body composition phenotypes.

Age, sex (in total only), education, physical activity, smoking, and dietary intake of carbohydrates, fats and proteins were included as covariates in the analyses.

Logistic regression analyses (Table 4) were used to estimate the ORs and 95% CIs of body composition phenotypes for metabolic syndrome. Individuals with NWO had a higher risk of metabolic syndrome (OR = 2071, 95% CI = 1.704–2.516 in total; OR = 2.357, 95% CI = 1.747–3.179 in men; OR = 1.885, 95% CI = 1.434–2.399 in women) compared to their counterparts with NWNO (OR = 1). The OR of NWO for metabolic syndrome was statistically significant in the total group (OR = 2.335, 95% CI = 1.783–2.911), men (OR = 2.774, 95% CI = 1.974–3.898), and women (OR = 2.075, 95% CI = 1.550–2.777) after adjusting for demographics, health behaviors, and nutrient intake parameters. A statistically significant OR of NWO for metabolic syndrome was observed in the total group (OR = 1.368, 95% CI = 1.040–1.800) even after additionally adjusted for FMR. Similarly, individuals with OB had a higher risk of metabolic syndrome (OR = 5.900, 95% CI = 5.060–6.881 in total; OR = 5.972, 95% CI = 4.647–7.765 in men; OR = 5.450, 95% CI = 4.478–6.633 in women) than people with NWNO (OR = 1). The OR of OB for metabolic syndrome was statistically significant in the total group (OR = 6.181, 95% CI = 5.172–7.386), men (OR = 5.842, 95% CI = 4.370–7.808), and women (OR = 6.333, 95% CI = 5.044–7.952) after adjusting for demographics, health behaviors, and nutrient intake parameters. Even after adjusting for FMR,

TABLE 1. Descriptive statistics of study participants.

Variables	Men (n = 1609)	Women (n = 2238)	Total (n = 3847)	F/χ^2	η^2	*df*	*p*-value
Age (yr)	71.6 ± 4.6	72.1 ± 4.7	71.9 ± 4.8	13.064	0.003	1	<0.001
Education, n (%)							
Elementary or lower	797 (50.4)	1911 (86.9)	2708 (71.6)				
Middle/high school	595 (37.6)	260 (11.8)	855 (22.6)	624.637	0.399	2	<0.001
College or higher	189 (12.0)	28 (1.3)	217 (5.7)				
Current/past smoker	920 (57.8)	125 (5.6)	1045 (27.5)	1263.584	0.576	1	<0.001
Heavy drinking, n (%)	326 (22.4)	60 (2.7)	386 (10.5)	358.847	0.313	1	<0.001
Physical activity, min/week	146 ± 176	170 ± 168	159 ± 172	1.828	0.005	1	0.177
Body composition							
Body mass index (kg/m^2)	23.4 ± 2.6	24.3 ± 5.6	23.9 ± 3.0	81.171	0.021	1	<0.001
Body fat (%)	23.0 ± 5.2	34.4 ± 5.6	29.6 ± 7.8	41.546	0.011	1	<0.001
Waist circumference (cm)	85.6 ± 8.1	83.8 ± 9.1	84.6 ± 8.8	4186.836	0.521	1	<0.001
Fat mass (g)	13,821 ± 4577	18,283 ± 5355	16,417 ± 5503	732.372	0.160	1	<0.001
Lean mass (g)	44,334 ± 5426	32,042 ± 4109	37,185 ± 7677	6392.871	0.624	1	<0.001
Fat-to-lean mass ratio	0.31 ± 0.10	0.57 ± 0.14	0.46 ± 0.18	3890.773	0.503	1	<0.001
Nutrient intake							
Carbohydrates (g/day)	330.9 ± 115.0	274.0 ± 102.7	297.7 ± 111.6	242.3	0.063	1	<0.001
Fats (g/day)	28.0 ± 26.0	17.6 ± 15.3	21.9 ± 21.1	226.853	0.059	1	<0.001
Proteins (g/day)	63.9 ± 32.2	45.0 ± 24.1	52.9 ± 29.3	403.029	0.101	1	<0.001
Metabolic risk factors							
Systolic BP (mmHg)	130.6 ± 17.4	132.4 ± 17.6	131.7 ± 17.6	9.714	0.003	1	<0.001
Diastolic BP (mmHg)	76.6 ± 9.9	76.6 ± 9.9	76.6 ± 9.9	0.002	0.001	1	0.908
FBG (mg/dL)	105.8 ± 29.2	103.7 ± 25.1	104.6 ± 26.9	5.182	0.001	1	0.087
TC (mg/dL)	181.4 ± 34.5	200.2 ± 36.9	192.3 ± 37.1	235.48	0.063	1	<0.001
TG (mg/dL)	143.3 ± 100.8	147.8 ± 84.0	145.9 ± 91.6	2.146	0.001	1	0.048
HDLC (mg/dL)	44.6 ± 11.3	46.1 ± 10.2	45.5 ± 10.7	17.386	0.005	1	<0.001
ALT (IU/L)	25.2 ± 14.4	23.1 ± 8.8	24.0 ± 11.6	30.726	0.009	1	<0.001
AST (IU/L)	21.6 ± 13.6	19.1 ± 10.2	20.1 ± 11.9	39.832	0.008	1	<0.001
Serum vitamin D (ng/mL)	21.7 ± 7.5	18.9 ± 7.6	20.1 ± 7.6	115.168	0.032	1	<0.001

BP: blood pressure; FBG: fasting blood glucose; TC: total cholesterol; TG: triglycerides; HDLC: high-density lipoprotein cholesterol; ALT: alanine aminotransferase; AST: aspartate transaminase. Heavy drinking was defined as seven drinks per day for men and five drinks per day for women.

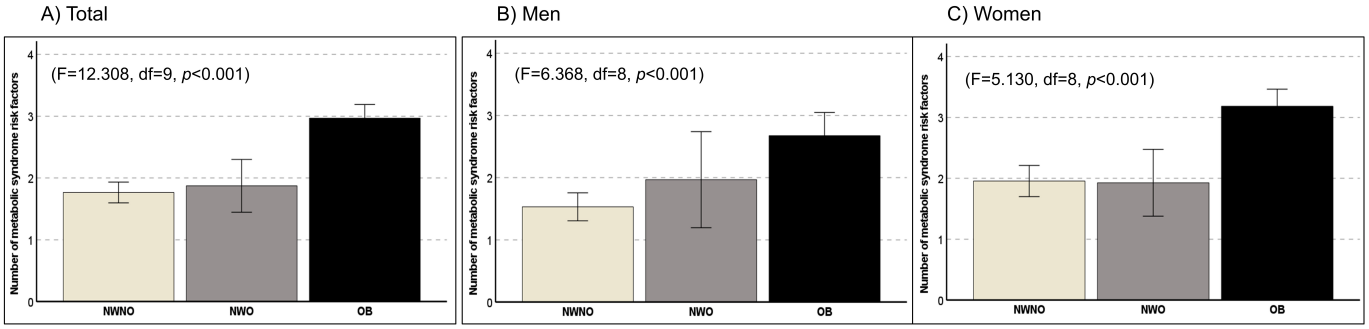

FIGURE 2. The number of individual metabolic risk factors according to body composition phenotypes in total (A), men (B), and women (C). NWNO: normal weight non-obesity; NWO: normal weight obesity; OB: obesity.

TABLE 2A. Physical and lifestyle characteristics of study participants according to body composition phenotype in total group.

Variables	NWNO (n = 2017)	NWO (n = 553)	OB (n = 1277)	Pairwise	F/χ^2	η^2	*df*	*p*-value
Health behaviors								
Past/current smokers, n (%)	583 (29.2)	163 (30.0)	299 (23.6)	b, c	14.355	0.055	2	0.001
Physical activity (min/week)	148 ± 167	237 ± 197	160 ± 169	a, c			2	0.026
Heavy drinking, n (%)	204 (10.7)	46 (8.7)	136 (11.0)		2.343	0.025	2	0.310
Body fatness								
Body mass index (kg/m^2)	22.0 ± 1.7	23.4 ± 1.2	27.3 ± 2.1	a, b, c	3466.087	0.643	2	<0.001
Waist circumference (cm)	79.6 ± 6.7	84.6 ± 5.7	92.4 ± 6.7	a, b, c	1482.318	0.436	2	<0.001
Body fat (%)	25.4 ± 6.4	34.0 ± 5.8	34.4 ± 6.7	a	905.059	0.320	2	<0.001
FMR	0.36 ± 0.13	0.56 ± 0.15	0.57 ± 0.17	a, b	904.321	0.297	2	<0.001
Nutrient Intake								
Carbohydrates (g/day)	303.3 ± 116.1	286.3 ± 94.3	293.8 ± 110.8	a	5.053	0.003	2	0.004
Fats (g/day)	21.7 ± 22.4	21.6 ± 19.4	22.4 ± 19.6		0.530	0.001	2	0.589
Proteins (g/day)	53.2 ± 29.9	51.6 ± 25.5	52.9 ± 29.7		0.584	0.001	2	0.558
Metabolic risk factors								
Systolic BP (mmHg)	130.8 ± 17.8	131.5 ± 17.9	133.2 ± 16.9	b	7.318	0.004	2	0.001
Diastolic BP (mmHg)	75.8 ± 10.2	76.3 ± 9.7	77.8 ± 9.6	a, b	15.673	0.008	2	<0.001
FBG (mg/dL)	102.1 ± 25.7	105.6 ± 30.6	107.9 ± 26.8	a, b	17.042	0.010	2	<0.001
TC (mg/dL)	189.4 ± 36.2	196.3 ± 37.3	194.8 ± 37.9	a, b	11.254	0.006	2	<0.001
TG (mg/dL)	138.3 ± 91.8	147.4 ± 83.5	157.2 ± 93.4	b	15.427	0.009	2	<0.001
HDLC (mg/dL)	46.6 ± 11.0	44.9 ± 10.6	43.9 ± 10.0	a, b	23.271	0.013	2	<0.001
ALT (U/L)	24.0 ± 13.0	22.9 ± 7.4	24.5 ± 10.4	c	3.554	0.002	2	0.029
AST (U/L)	18.5 ± 10.0	20.2 ± 11.8	22.7 ± 14.0	a, b, c	46.025	0.026	2	<0.001
Serum vitamin D (ng/mL)	21.1 ± 7.8	18.6 ± 7.2	19.1 ± 7.3	a, b	35.868	0.020	2	<0.001

NWNO: normal weight non-obesity; NWO: normal weight obesity; OB: obesity; FMR: fat-to-lean mass ratio; BP: blood pressure; FBG: fasting blood glucose; TC: total cholesterol; TG: triglycerides; HDLC: high-density lipoprotein cholesterol; ALT: alanine aminotransferase; AST: aspartate transaminase. Heavy drinking was defined as seven drinks per day for men and five drinks per day for women. Significant differences were tested by Tukey's post hoc according to body composition-based phenotypes; (a): NWNO vs. NWO, (b) NWNO vs. OB, and (c) NWO vs. OB.

the OR of OB for metabolic syndrome remained significant in the total group (OR = 3.882, 95% CI = 3.104–4.854) and men (OR = 3.068, 95% CI = 2.152–4.373). Finally, a median age-based sensitivity analysis showed that the strength of the relationship between body composition-based phenotypes and metabolic syndrome was comparable between the two age groups (**Supplementary Table 1**).

4. Discussion

This population-based cross-sectional study aimed to investigate the relationship between NWO and metabolic syndrome in a representative sample of Korean older adults revealed that NWO is associated with a higher prevalence of various metabolic risk factors. The study indicates that a high FMR may play a role in the pathology of the metabolic syndrome associated with NWO. Taken together, the current study suggests that NWO is a novel risk factor for obesity-related metabolic complications among geriatric populations.

Evidence suggests that NWO is an independent risk factor for metabolic syndrome in different populations, supporting our findings. Romero-Corral *et al.* [16] showed that NWO was associated with a higher prevalence of dyslipidemia, hypertension and cardiovascular disease, as well as an increased risk of metabolic syndrome in American adults by analyzing data from the National Health and Nutrition Examination Survey (NHANES) III (n = 6171). Batsis *et al.* [10] by a secondary analysis of the NHANES III data found that NWO was linked to a higher risk of physical limitations in older American women. This implies that physical disability has a significant role in the development of obesity and metabolic complications.

Similarly, NWO was significantly associated with an increased risk of cardiometabolic disorders and hyperglycemia in Iranian sedentary women aged 20–35 years [17] and an increased risk of hypertension, dyslipidemia and diabetes in Japanese middle-aged adults who underwent health examinations [18]. Coelho *et al.* [19] found that individuals with

TABLE 2B. Physical and lifestyle characteristics of study participants according to body composition phenotype in men only.

Variables	NWNO (n = 953)	NWO (n = 240)	OB (n = 416)	Pairwise	F/χ^2	η^2	*df*	*p*-values
Health behaviors								
Past/current smokers, n (%)	524 (55.4)	146 (61.6)	670 (56.7)		5.240	0.057	2	0.073
Physical activity (min/week)	114 ± 177	149 ± 176	151 ± 177		0.027	0.001	2	0.973
Heavy drinking, n (%)	183 (21.4)	36 (15.6)	218 (20.2)	a, c	14.852	0.101	2	0.001
Body fatness								
Body mass index (kg/m^2)	22.0 ± 1.7	23.3 ± 1.3[a]	26.8 ± 1.5[ab]	a, b, c	1305.490	0.619	2	<0.001
Waist circumference (cm)	81.6 ± 6.4	86.7 ± 5.4[a]	94.2 ± 5.9[ab]	a, b, c	613.631	0.448	2	<0.001
Body fat (%)	20.1 ± 3.7	28.2 ± 2.9[a]	26.7 ± 4.0[ab]	a, b, c	726.831	0.475	2	<0.001
FMR	0.26 ± 0.06	0.41 ± 0.06[a]	0.38 ± 0.09[ab]	a, b, c	751.386	0.483	2	<0.001
Nutrient Intake								
Carbohydrates (g/day)	335.5 ± 122.2	312.6 ± 91.3[a]	331.0 ± 109.6	a	3.592	0.005	2	0.028
Fats (g/day)	27.2 ± 27.4	25.9 ± 24.1	30.9 ± 23.4	c	3.595	0.005	2	0.028
Proteins (g/day)	63.3 ± 33.0	60.3 ± 27.9	67.2 ± 32.2[b]	c	3.611	0.005	2	0.027
Metabolic risk factors								
Systolic BP (mmHg)	129.5 ± 17.5	132.9 ± 18.4[a]	132.1 ± 16.4[a]	a, b	5.257	0.007	2	0.005
Diastolic BP (mmHg)	75.9 ± 9.9	77.0 ± 10.4	77.9 ± 9.5[a]	b	6.025	0.007	2	0.002
FBG (mg/dL)	103.7 ± 27.8	110.3 ± 37.8[a]	107.9 ± 26.2[b]	a, b	5.983	0.008	2	0.003
TC (mg/dL)	179.8 ± 33.7	185.7 ± 37.7[a]	182.7 ± 34.2[b]	a, b	2.990	0.004	2	0.051
TG (mg/dL)	132.5 ± 93.5	149.7 ± 94.9	164.1 ± 115.7[a]	b	14.116	0.018	2	<0.001
HDLC (mg/dL)	46.5 ± 11.5	43.2 ± 10.9[a]	41.0 ± 9.9[ab]	a, b, c	35.086	0.045	2	<0.001
Serum vitamin D (ng/mL)	22.5 ± 7.7	19.9 ± 6.8[a]	20.7 ± 7.0[a]	a, b	15.363	0.020	2	<0.001
ALT (U/L)	25.6 ± 16.6	24.0 ± 8.0	25.2 ± 11.1		1.000	0.001	2	0.368
AST (U/L)	19.8 ± 11.2	22.7 ± 13.9[a]	25.0 ± 17.3[a]	a, b	21.374	0.028	2	<0.001

NWNO: normal weight non-obesity; NWO: normal weight obesity; OB: obesity; FMR: fat-to-lean mass ratio; BP: blood pressure; FBG: fasting blood glucose; TC: total cholesterol; TG: triglycerides; HDLC: high-density lipoprotein cholesterol; ALT: alanine aminotransferase; AST: aspartate transaminase. Heavy drinking was defined as seven drinks per day for men and five drinks per day for women. Significant differences were tested by Tukey's post hoc according to body composition-based phenotypes; (a): NWNO vs. NWO, (b) NWNO vs. OB, and (c) NWO vs. OB.

NWO had a higher incidence rate of metabolic syndrome at the ages of 37–39 years in a birth cohort study of 787 subjects born in 1978–1979. Mohammadian Khonsari *et al.* [7] in a meta-analysis of 177,792 participants aged 13–75 years drawn from 25 previously published articles showed that NWO was significantly associated with an increased risk of dyslipidemia, hyperglycemia, diabetes and hypertension, as well as metabolic syndrome. Further, NWO is associated with poorer outcomes in non-diabetic patients with chronic kidney disease [20], poor cardiometabolic profiles in clinically stable older patients with chronic obstructive pulmonary disease [21], and an increased risk of cancer [22] and death from coronary artery disease [23]. Hence the current and previous studies indicate that NWO is a preclinical stage of metabolic disorders that should be monitored for early intervention.

The link between NWO and metabolic syndrome can be explained in several ways. First, the NWO phenotype is characterized by high-fat accumulation and low skeletal muscle mass, contributing to a clustering of metabolic risk factors, such as dyslipidemia, impaired glucose metabolism, insulin resistance, decreased serum vitamin D, increased inflammatory cytokines, and oxidative stress, and increased susceptibility of metabolic syndrome [24, 25]. Second, unhealthy lifestyles, such as physical inactivity, physical disability, poor physical fitness, poor diet, smoking and heavy alcohol consumption may contribute to the NWO phenotype and metabolic problems [26–28]. Unlike previous studies, our findings showed that people with NWO smoked less while maintaining similar phys-

TABLE 2C. Physical and lifestyle characteristics of study participants according to body composition phenotype in women only.

Variables	NWNO (n = 1064)	NWO (n = 313)	OB (n = 861)	Pairwise	F/χ^2	η^2	*df*	*p*-values
Health behaviors								
Past/current smokers, n (%)	59 (5.6)	17 (5.5)	76 (5.6)		0.016	0.001	2	0.954
Physical activity (min/week)	152 ± 156	273 ± 198[a]	164 ± 165[b]	a, c	4.898	0.049		0.008
Heavy drinking, n (%)	21 (2.0)	11 (3.6)	32 (2.4)		3.878	0.042	2	0.107
Body fatness								
Body mass index (kg/m^2)	22.0 ± 1.7	23.5 ± 1.2[a]	27.5 ± 2.3[ab]	a, b, c	2069.879	0.649		<0.001
Waist circumference (cm)	77.7 ± 6.5	83.0 ± 5.4[a]	91.6 ± 6.9[ab]	a, b, c	1064.754	0.489		<0.001
Body fat (%)	30.2 ± 4.1	38.5 ± 2.5[a]	38.1 ± 4.0[a]	a, b	1161.649	0.510		<0.001
FMR	0.46 ± 0.09	0.67 ± 0.08[a]	0.66 ± 0.12[a]	a, b	1118.521	0.500		<0.001
Nutrient Intake								
Carbohydrates (g/day)	274.5 ± 102.1	266.5 ± 91.7	276.2 ± 107.0		0.968	0.001		0.380
Fats (g/day)	16.7 ± 15.0	18.3 ± 13.8	18.4 ± 16.0[a]	b	3.260	0.003		0.039
Proteins (g/day)	44.1 ± 23.4	44.9 ± 21.3	46.2 ± 25.9		1.781	0.002		0.169
Metabolic risk factors								
Systolic BP (mmHg)	131.9 ± 18.0	130.6 ± 17.4	133.7 ± 17.2[b]	c	4.219	0.004		0.015
Diastolic BP (mmHg)	75.8 ± 10.4	75.7 ± 9.0	77.8 ± 9.6[ab]	b, c	10.807	0.010		<0.001
FBG (mg/dL)	100.7 ± 23.6	101.9 ± 22.8	107.9 ± 27.0[ab]	b, c	18.958	0.019		<0.001
TC (mg/dL)	198.4 ± 36.2	204.5 ± 34.9[a]	200.0 ± 38.2	a	3.156	0.003		0.043
TG (mg/dL)	143.7 ± 90.0	145.6 ± 73.6	153.7 ± 79.7[a]	b	3.149	0.003		0.043
HDLC (mg/dL)	46.7 ± 10.6	46.2 ± 10.2	45.4 ± 9.8[a]	b	3.610	0.004		0.027
Serum vitamin D (ng/mL)	19.8 ± 7.7	17.6 ± 7.3[a]	18.3 ± 7.4[b]	a, b	13.197	0.013		<0.001
ALT (U/L)	22.4 ± 8.1	22.0 ± 6.8	24.2 ± 10.0[ab]	b, c	11.236	0.011		<0.001
AST (U/L)	17.3 ± 8.6	18.3 ± 9.5	21.5 ± 11.8[ab]	b, c	39.365	0.038		<0.001

NWNO: normal weight non-obesity; NWO: normal weight obesity; OB: obesity; FMR: fat-to-lean mass ratio; BP: blood pressure; FBG: fasting blood glucose; TC: total cholesterol; TG: triglycerides; HDLC: high-density lipoprotein cholesterol; ALT: alanine aminotransferase; AST: aspartate transaminase. Heavy drinking was defined as seven drinks per day for men and five drinks per day for women. Significant differences were tested by Tukey's post hoc according to body composition-based phenotypes; (a): NWNO vs. NWO, (b) NWNO vs. OB, and (c) NWO vs. OB.

ical activity and nutrient intakes of proteins, fats and carbohydrates as those with NWNO. A well-designed cohort study is needed to confirm the impact of unhealthy lifestyle factors on the NWO phenotype in older adults. Third, circulating myokines and hormone abnormalities are linked to the NWO phenotype, and these factors interact to promote the onset of the metabolic syndrome [29–32]. Finally, the increased blood ALT levels in this study across different body composition types suggest that NWO people have non-alcoholic fatty liver disease (NAFLD) [33]. Stefan *et al.* [34] proposed that besides dysregulated adipokines and myokines, dysregulated hepatokines such as increased Fetuin-A are important for linking the NAFLD liver to metabolic syndrome by modulating glucose and lipid metabolism as well as subclinical inflammation.

There are some limitations to this study. First, the cross-sectional nature of the study involving older adults only limits our ability to provide any cause-and-effect explanation for the current findings. A cohort study with a large sample size, including both young and middle-aged adults, will be required to investigate any causal relationship between NWO and metabolic syndrome. Second, the relationship between lifestyle choices and NWO was unexpectedly skewed in the opposite direction of previous research. Hence, the possibility that previously unknown covariates may influence the relationship between NWO and metabolic syndrome cannot be ruled out. Lastly, since this study was cross-sectional, a bi-directional relationship between phenotype and metabolic syndrome cannot be ignored.

TABLE 3. Prevalence of individual metabolic syndrome risk factors according to body composition phenotype.

Variables	NWNO (n = 2017)	NWO (n = 553)	OB (n = 1277)	Pairwise	χ^2	η^2	*df*	*p*-value
Total (n = 3847)								
Abdominal obesity	233 (11.6)	185 (33.5)	1044 (81.8)	a, b, c	1641.302	0.653	2	<0.001
Hyperglycemia	729 (36.1)	246 (44.5)	679 (53.2)	a, b, c	93.099	0.156	2	<0.001
Hypertriglyceridemia	668 (33.1)	225 (40.7)	595 (46.6)	a, b	60.959	0.126	2	<0.001
Decreased HDLC	918 (45.5)	283 (51.2)	768 (60.1)	a, b, c	66.963	0.132	2	<0.001
Hypertension	1001 (49.6)	330 (59.7)	889 (69.6)	a, b, c	129.027	0.183	2	<0.001
Men (n = 1609)								
Abdominal obesity	91 (9.5)	74 (30.8)	319 (76.7)	a, b, c	620.632	0.621	2	<0.001
Hyperglycemia	385 (40.4)	121 (50.4)	235 (56.5)	a, b, c	32.344	0.142	2	<0.001
Hypertriglyceridemia	290 (30.4)	89 (37.1)	184 (44.2)	a, b, c	24.789	0.124	2	<0.001
Decreased HDLC	284 (29.8)	98 (40.8)	210 (50.5)	a, b, c	55.235	0.185	2	<0.001
Hypertension	440 (46.2)	149 (62.1)	271 (65.1)	a, b, c	50.354	0.177	2	<0.001
Women (n = 2238)								
Abdominal obesity	142 (13.3)	111 (35.5)	725 (84.2)	a, b, c	981.235	0.662	2	<0.001
Hyperglycemia	344 (32.3)	125 (39.9)	444 (51.6)	a, b, c	73.028	0.181	2	<0.001
Hypertriglyceridemia	378 (35.5)	136 (43.5)	411 (47.7)	a, b, c	29.927	0.116	2	<0.001
Decreased HDLC	634 (59.6)	185 (59.1)	558 (64.8)	b, c	6.385	0.053	2	<0.001
Hypertension	561 (52.7)	618 (71.8)	181 (57.8)	a, b, c	73.773	0.182	2	0.041

NWNO: normal-weight non-obesity; NOW: normal-weight obesity; OB: obesity. Hyperglycemia: fasting blood glucose >100 mg/dL or drug treatment for impaired fasting glucose. Hypertriglyceridemia: triglycerides ≥150 mg/dL or drug treatment for high serum triglycerides. Hypertension: systolic blood pressure ≥130 mmHg and/or diastolic blood pressure ≥85 mmHg or drug treatment for hypertension. Decreased high-density lipoprotein cholesterol (HDLC) of <40 mg/dL for men or <50 mg/dL for women. The comparison of categorical variables among groups was performed using a Chi-square test. Significant differences were tested by Tukey's post hoc according to body composition-based phenotypes; (a): NWNO vs. NWO, (b) NWNO vs. OB, and (c) NWO vs. OB.

TABLE 4. Odds ratios and 95% confidence intervals of metabolic syndrome according to body composition phenotype.

	NWNO	NWO	*p*-value	OB	*p*-value
Total					
Model 1	1	2.071 (1.704–2.516)	<0.001	5.900 (5.060–6.881)	<0.001
Model 2	1	2.335 (1.783–2.911)	<0.001	6.181 (5.172–7.386)	<0.001
Model 3	1	1.368 (1.040–1.800)	0.025	3.882 (3.104–4.854)	<0.001
Men					
Model 1	1	2.357 (1.747–3.179)	<0.001	5.972 (4.647–7.675)	<0.001
Model 2	1	2.774 (1.974–3.898)	<0.001	5.842 (4.370–7.808)	<0.001
Model 3	1	1.214 (0.783–1.881)	0.386	3.068 (2.152–4.373)	0.019
Women					
Model 1	1	1.885 (1.434–2.399)	<0.001	5.450 (4.478–6.633)	<0.001
Model 2	1	2.075 (1.550–2.777)	<0.001	6.333 (5.044–7.952)	<0.001
Model 3	1	1.268 (0.885–1.819)	0.196	4.046 (3.017–5.426)	0.082

NWNO: normal weight non-obesity; NWO: normal weight obesity; OB: obesity.
Model 1: unadjusted.
Model 2: adjusted for age, sex, education, income, smoking, heavy drinking, physical activity, serum vitamin D, and dietary intake of proteins, fats and carbohydrates.
Model 3: adjusted for model 2 plus total body fat-to-muscle ratio.

Despite these limitations, this is the first study exploring the impact of NWO on metabolic syndrome in older Korean adults through DXA-based body composition data. The participants consisted of older healthy individuals without any chronic diseases. Hence, these findings are clinically relevant to design strategies for reducing the global increase in morbidity and mortality due to obesity.

5. Conclusions

In conclusion, this cross-sectional study examined the association between NWO and metabolic syndrome in older Korean adults and showed that NWO is associated with the clustering of individual metabolic risk factors and an increased risk of metabolic syndrome. Given the limitations of BMI as a diagnostic tool for overweight and obese patients, these findings suggest that people with NWO should be monitored in clinical settings for early intervention.

ABBREVIATIONS

BMI, body mass index; NOW, normal weight obesity; NWNO, normal weight non-obesity; OB, obesity; KNHNES, Korea National Health and Nutrition Examination Survey; DXA, dual x-ray absorptiometry; FM, fat mass; LM, lean mass; FMR, fat-to-lean mass; WC, waist circumference; FBG, fasting blood glucose; TG, triglycerides; TC, total cholesterol; HDLC, high-density lipoprotein cholesterol; SBP, systolic blood pressure; DBP, diastolic blood pressure; OR, odds ratio; CI, confidence interval.

AVAILABILITY OF DATA AND MATERIALS

The datasets used and analyzed during this study are available from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTIONS

JK—methodology; validation; investigation; data curation; writing-original draft preparation. SK—investigation; data curation; writing-original draft preparation. HK—conceptualization; methodology; validation; investigation; data curation; writing-original draft preparation; supervision; project administration. All authors have read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The Institutional Review Board of the Korean Institute for Health and Social Affairs reviewed and approved this study (approval no. 2008-04EXP-01-C, 2009-01CON-03-2C, 2010-02CON-21-C and 2011-02CON-06-C). Informed consent was obtained from all participants. This study protocol was approved by the ethics committee of the Institutional Review Board and was performed in accordance with the Declaration of Helsinki.

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CONFLICT OF INTEREST

The authors declare no conflict of interest. Hyunsik Kang is serving as one of the Editorial Board members of this journal. We declare that Hyunsik Kang had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to DM.

SUPPLEMENTARY MATERIAL

Supplementary material associated with this article can be found, in the online version, at https://oss.jomh.org/files/article/1784853886732779520/attachment/Supplementary%20material.docx.

REFERENCES

[1] Lin X, Li H. Obesity: epidemiology, pathophysiology, and therapeutics. Frontiers in Endocrinology. 2021; 12: 706978.

[2] Caleyachetty R, Barber TM, Mohammed NI, Cappuccio FP, Hardy R, Mathur R, *et al*. Ethnicity-specific BMI cutoffs for obesity based on type 2 diabetes risk in England: a population-based cohort study. The Lancet Diabetes & Endocrinology. 2021; 9: 419–426.

[3] Bawadi H, Hassan S, Shanbeh Zadeh A, Sarv H, Kerkadi A, Tur JA, *et al*. Age and gender specific cut-off points for body fat parameters among adults in Qatar. Nutrition Journal. 2020; 19: 75.

[4] Sergi TE, Bode KB, Hildebrand DA, Dawes JJ, Joyce JM. Relationship between body mass index and health and occupational performance among law enforcement officers, firefighters, and military personnel: a systematic review. Current Developments in Nutrition. 2023; 7: 100020.

[5] Wong JC, O'Neill S, Beck BR, Forwood MR, Khoo SK. Comparison of obesity and metabolic syndrome prevalence using fat mass index, body mass index and percentage body fat. PLOS ONE. 2021; 16: e02454.

[6] Blüher M. Metabolically healthy obesity. Endocrine Reviews. 2020; 41: bnaa004.

[7] Mohammadian Khonsari N, Khashayar P, Shahrestanaki E, Kelishadi R, Mohammadpoor Nami S, Heidari-Beni M, *et al*. Normal weight obesity and cardiometabolic risk factors: a systematic review and meta-analysis. Frontiers in Endocrinology. 2022; 13: 857930.

[8] Kim MK, Han K, Kwon HS, Song KH, Yim HW, Lee WC, *et al*. Normal weight obesity in Korean adults. Clinical Endocrinology. 2014; 80: 214–220.

[9] Ji T, Zhang L, Tang Z, Sun F, Li Y, Ma L. Prevalence of normal-weight obesity in community-dwelling Chinese older adults: results from the Beijing Longitudinal Study of Aging. Diabetes, Metabolic Syndrome and Obesity. 2020; 13: 1611–1617.

[10] Batsis JA, Sahakyan KR, Rodriguez-Escudero JP, Bartels SJ, Lopez-Jimenez F. Normal weight obesity and functional outcomes in older adults. European Journal of Internal Medicine. 2014; 25: 517–522.

[11] Martinez KE, Tucker LA, Bailey BW, LeCheminant JD. Expanded normal weight obesity and insulin resistance in us adults of the national health and nutrition examination survey. Journal of Diabetes Research. 2017; 2017: 9502643.

[12] Di Renzo L, Galvano F, Orlandi C, Bianchi A, Di Giacomo C, La Fauci L, *et al*. Oxidative stress in normal-weight obese syndrome. Obesity. 2010; 18: 2125–2130.

[13] Grundy SM, Brewer HB Jr, Cleeman JI, Smith SC Jr, Lenfant C; American Heart Association; National Heart, Lung, and Blood Institute. Definition of metabolic syndrome: report of the National Heart, Lung, and Blood Institute/American Heart Association conference on scientific issues related to definition. Circulation. 2004; 109: 433–438.

[14] Lee SY, Park HS, Kim DJ, Han JH, Kim SM, Cho GJ, *et al*. Appropriate waist circumference cutoff points for central obesity in Korean adults. Diabetes Research and Clinical Practice. 2007; 75: 72–80.

[15] Oh K, Kim Y, Kweon S, Kim S, Yun S, Park S, *et al*. Korea national health and nutrition examination survey, 20th anniversary: accomplishments and future directions. Epidemiology and Health. 2021; 43: e2021025.

[16] Romero-Corral A, Somers VK, Sierra-Johnson J, Korenfeld Y, Boarin S, Korinek J, *et al*. Normal weight obesity: a risk factor for cardiometabolic dysregulation and cardiovascular mortality. European Heart Journal. 2010; 31: 737–746.

[17] Ashtary-Larky D, Niknam S, Alipour M, Bagheri R, Asbaghi O, Mohammadian M, *et al*. Are women with normal-weight obesity at higher risk for cardiometabolic disorders? Biomedicines. 2023; 11: 341.

[18] Shirasawa T, Ochiai H, Yoshimoto T, Nagahama S, Kobayashi M, Ohtsu I, *et al*. Associations between normal weight central obesity and cardiovascular disease risk factors in Japanese middle-aged adults: a cross-sectional study. Journal of Health, Population and Nutrition. 2019; 38: 46.

[19] Coelho CCNDS, Bragança MLBM, de Oliveira BR, Bettiol H, Barbieri MA, Cardoso VC, *et al*. Incidence of metabolic syndrome in adults with healthy weight, normal weight obesity, and overweight/obesity. Nutrition. 2021; 85: 111134.

[20] Lin T, Lim P, Hung S. Normal-weight obesity and clinical outcomes in nondiabetic chronic kidney disease patients: a cohort study. The American Journal of Clinical Nutrition. 2018; 107: 664–672.

[21] Beijers RJHCG, van de Bool C, van den Borst B, Franssen FME, Wouters EFM, Schols AMWJ. Normal weight but low muscle mass and abdominally obese: implications for the cardiometabolic risk profile in chronic obstructive pulmonary disease. Journal of the American Medical Directors Association. 2017; 18: 533–538.

[22] Liu B, Giffney HE, Arthur RS, Rohan TE, Dannenberg AJ. Cancer risk in normal weight individuals with metabolic obesity: a narrative review. Cancer Prevention Research. 2021; 14: 509–520.

[23] Sharma S, Batsis JA, Coutinho T, Somers VK, Hodge DO, Carter RE, *et al*. Normal-weight central obesity and mortality risk in older adults with coronary artery disease. Mayo Clinic Proceedings. 2016; 91: 343–351.

[24] Kim J, Lee Y, Kye S, Chung Y, Lee O. Association of serum vitamin D with osteosarcopenic obesity: Korea National Health and Nutrition Examination Survey 2008–2010. Journal of Cachexia, Sarcopenia and Muscle. 2017; 8: 259–266.

[25] Oliveros E, Somers VK, Sochor O, Goel K, Lopez-Jimenez F. The concept of normal weight obesity. Progress in Cardiovascular Diseases. 2014; 56: 426–433.

[26] García-Hermoso A, Agostinis-Sobrinho C, Camargo-Villalba GE, González-Jiménez NM, Izquierdo M, Correa-Bautista JE, *et al*. Normal-weight obesity is associated with poorer cardiometabolic profile and lower physical fitness levels in children and adolescents. Nutrients. 2020; 12: 1171.

[27] Kobayashi M, Pattarathitwat P, Pongprajakand A, Kongkaew S. Association of normal weight obesity with lifestyle and dietary habits in young Thai women: a cross-sectional study. Obesity Pillars. 2023; 5: 100055.

[28] Stefan N. Metabolically healthy and unhealthy normal weight and obesity. Endocrinology and Metabolism. 2020; 35: 487–493.

[29] Huang WY, Chang CC, Chen DR, Kor CT, Chen TY, Wu HM. Circulating leptin and adiponectin are associated with insulin resistance in healthy postmenopausal women with hot flashes. PLOS ONE. 2017; 12: e0176430.

[30] Mazur-Bialy AI. Asprosin-a fasting-induced, glucogenic, and orexigenic adipokine as a new promising player. Will it be a new factor in the treatment of obesity, diabetes, or infertility? A review of the literature. Nutrients. 2021; 13: 620.

[31] Mehrabian S, Taheri E, Karkhaneh M, Qorbani M, Hosseini S. Association of circulating irisin levels with normal weight obesity, glycemic and lipid profile. Journal of Diabetes & Metabolic Disorders. 2015; 15: 17.

[32] You T, Wang X, Murphy KM, Lyles MF, Demons JL, Yang R, *et al*. Regional adipose tissue hormone/cytokine production before and after weight loss in abdominally obese women. Obesity. 2014; 22: 1679–1684.

[33] DiStefano JK, Gerhard GS. NAFLD in normal weight individuals. Diabetology & Metabolic Syndrome. 2022; 14: 45.

[34] Stefan N, Schick F, Birkenfeld AL, Häring H, White MF. The role of hepatokines in NAFLD. Cell Metabolism. 2023; 35: 236–252.

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