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ORIGINAL ARTICLE

Associations of obesity with osteoporosis and metabolic syndrome in Korean postmenopausal women: a cross-sectional study using national survey data

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Abstract

Summary In a representative sample of 3058 Korean postmenopausal women, we studied which types of obesity were more or less desirable for developing concomitant osteoporosis and metabolic syndrome (MS), with the goal of helping clinicians identify steps to reduce patients' risk. Different definitions of obesity showed different relationships with osteoporosis and MS in this population.

Purpose To examine sample characteristics, prevalence, and the risk of osteoporosis and metabolic syndrome among four groups of postmenopausal women classified by obesity.

Methods Data from the Korea National Health and Nutrition Examination Survey were analyzed using the Rao-Scott chi-square test, analysis of variance, and multinomial logistic regression analysis. The four groups included body mass index (BMI)-based obese, waist circumference (WC)-based obese, BMI-, and WC-based obese, and non-obese women, using BMI and WC cutoffs for obesity of ≥ 25 kg/m^2 and ≥ 80 cm, respectively.

Results The prevalence of osteoporosis and MS was 40.8% and 48.5%, respectively. Age, socioeconomic status, smoking status, and hormone therapy use differed among the obese groups. The odds ratios of simultaneously having both osteoporosis and MS in the BMI- and WC-based obese, BMI-based obese, WC-based obese, and non-obese groups were 7.39 (95% confidence interval [CI] = 4.83–11.31), 0.74 (95% CI = 0.27–1.98), 7.07 (95% CI = 4.72–10.58), and 1, respectively.

Conclusions The findings demonstrate the most and the least desirable types of obesity in terms of risk for both osteoporosis and MS. Public health practitioners may consider the type of obesity to reduce or prevent both conditions in postmenopausal women.

Keywords Metabolic syndrome · Obesity · Osteoporosis · Postmenopausal

Introduction

Postmenopausal women have an increased risk for osteoporosis and/or metabolic syndrome due to hormonal changes [1–4]. Osteoporosis is a skeletal disease characterized by low bone density and poor bone quality [5]. Approximately 42 to 48% of postmenopausal women have osteoporosis [1, 3]. Metabolic syndrome refers having three or more of the following conditions: elevated waist circumference (WC), elevated triglycerides, reduced high-density lipoprotein, elevated blood pressure, and elevated fasting glucose [6]. The prevalence of metabolic syndrome in postmenopausal women has been found to be 13.5 to 37% [2, 7], and the odds ratio for metabolic syndrome in postmenopausal women compared with premenopausal women was 3.5 [7]. In postmenopausal women, osteoporosis increases the risk for bone fracture, which can be considered an adverse effect of osteoporosis [5] and poor quality of life [8]. Metabolic syndrome has several adverse effects in postmenopausal women, including increased risk for subclinical atherosclerosis [9]; breast cancer [10]; and all-cause, cardiovascular disease-related, and cardiac disease-related mortality [11]. Thus, both osteoporosis and metabolic syndrome need to be managed effectively in postmenopausal women.

Obesity is a modifiable factor associated with both osteoporosis and metabolic syndrome. Body mass index (BMI) and

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WC are two indicators of obesity that have been commonly used in research. BMI, as a continuous variable, was positively associated with hip bone mineral density (BMD) in postmenopausal women [12]. As a categorical variable, obesity (BMI > 27 kg/m^2) was positively associated with femoral BMD [13]. When BMI was further categorized, overweight (25 to 29.9 kg/m^2) and obesity (BMI > 30 kg/m^2), compared with normal weight or non-obesity (BMI < 25 kg/m^2), were associated with lower odds ratios for osteoporosis of the total hip and femoral neck [14]. After menopause, obesity (BMI ≥ 30 kg/m^2) delayed osteoporosis for 5 to 9 years, which was attributed to high baseline BMD [15]. In addition, a lower WC (< 88 cm), compared with a higher WC (≥ 88 cm), was associated with a higher rate of osteoporosis in postmenopausal women [16]. Thus, overall, obesity has been associated with higher levels of BMD and lower rates of osteoporosis in the literature.

However, a higher WC was associated with having metabolic syndrome in postmenopausal women (94.9 vs. 88.3, $p = .001$) [17]. In addition, obese postmenopausal women had higher rates of metabolic syndrome than non-obese postmenopausal women (66% vs. 22%) [18]. Increases in BMI, as a continuous variable, were associated with increases in metabolic syndrome (odds ratio 1.29, 95% confidence interval 1.20, 1.39) [19]. Thus, the overall findings of prior studies show opposite directions in the relationships of obesity with osteoporosis and metabolic syndrome among postmenopausal women. The opposite directions of these relationships cause difficulties in managing obesity with the goal of simultaneously reducing or preventing both osteoporosis and metabolic syndrome in this population.

As shown, both indicators of obesity (BMI and WC) have been commonly associated with BMD, osteoporosis, fractures, and metabolic syndrome. Although the overall findings were relatively consistent, it is not true for the directionality of the associations [17]. In some studies, the relationships of obesity to BMD and osteoporosis differed depending on the indicator of obesity that was used. For instance, body weight was positively associated with BMD, but WC showed a negative association with BMD [20]. In addition, BMI did not differ between an osteoporotic fracture group and a non-fracture group, but WC did. In addition to the opposite directions of the relationships of obesity with osteoporosis and metabolic syndrome, differences in the relationships of obesity with these outcomes depending on the choice of indicator cause further difficulties in managing obesity to reduce the risk of both conditions. Thus, the relationships of obesity with osteoporosis and metabolic syndrome need to be examined further, considering both indicators of obesity. Considering the adverse effects of both osteoporosis and metabolic syndrome on health outcomes, it is critical to manage obesity to reduce the prevalence of both conditions among postmenopausal women. However, few researchers have examined the relationships of obesity to both osteoporosis and metabolic syndrome at the same time. In addition, considering the different relationships of obesity to osteoporosis and fracture depending on the choice of an obesity indicator, it is critical to consider both indicators of obesity simultaneously. Some studies have included both indicators and examined their relationships with osteoporosis [20], but they did not consider the combination of those two indicators.

Therefore, the purpose of this study was to examine the relationships of obesity with both osteoporosis and metabolic syndrome by considering both indicators of obesity together. We addressed this goal by examining the prevalence of osteoporosis and metabolic syndrome among four groups defined in terms of obesity as follows: a BMI- and WC-based obese group (BMI ≥ 25 kg/m^2 and WC ≥ 80 cm), a BMI-based obese group, a WC-based obese group, and a non-obese group, using data from the Korea National Health and Nutrition Examination Survey (KNHANES). The first specific aim was to examine the differences in sample characteristics among the four groups of obese participants. The second specific aim was to examine the prevalence and risk for osteoporosis and metabolic syndrome among the four groups of obese participants.

Methods

Study design, setting, and sample

This was a cross-sectional comparative study using secondary data analysis to examine the relationships of obesity with both osteoporosis and metabolic syndrome among postmenopausal women using data from the 2008–2011 KNHANES conducted by the Korea Centers for Disease Control and Prevention (KCDC). The KNHANES uses a systematic sampling method considering residential area, sex, and age, as well as standardized assessment methods. A trained staff collected data through direct physical examinations, personal interviews of individuals who underwent physical examinations to identify their history of various diseases or medical conditions, clinical and laboratory tests, and related measurement procedures. In the 2008–2011 survey, 37,753 individuals (men 17,195 and women 20,558) participated (Fig. 1). For this study, data were extracted from the dataset as follows. The inclusion criteria were community-dwelling postmenopausal women. Postmenopausal status was defined as responding "No" to the question of "Do you have menstrual period during the previous 12 months". The exclusion criteria were postmenopausal women with missing data (bone densitometry results, responses to diet-related questions, and muscle and fat results) and those with cancer, chronic kidney failure, or liver cirrhosis to avoid confounding effects on the relationships examined in this study. No significant differences were found between the

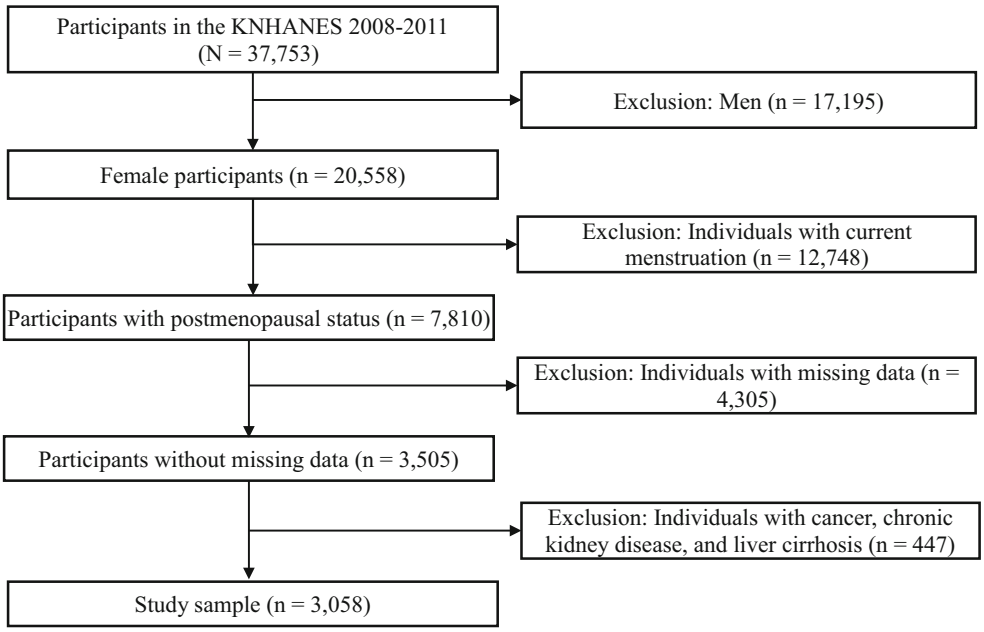

Fig. 1 Flow chart of participant selection from the KNHANES data. KNHANES, Korea National Health and Nutrition Examination Survey

included and excluded women according to residential area ($\chi 2 = 2.2$, $p = .14$), socioeconomic status ($\chi^2 = 1.9$, $p = .38$), smoking status ($\chi^2 = 0.7$, $p = .41$), alcohol consumption ($\chi^2 = 0.3$, $p = .85$), physical activity ($\chi^2 = 5.7$, $p = .06$), or hormone therapy ($\chi^2 = 3.0$, $p = .08$). However, significant differences between the included and excluded women were found according to age ($\chi^2 = 30.9$, $p < .001$), living arrangement ($\chi^2 = 20.7$, $p = .001$), and parental fracture history ($\chi^2 = 70.3$, $p < .001$).

Measurements

In the KNHANES, osteoporosis was determined by the lumbar spine 1–4 and femoral neck BMD based on dual-energy X-ray absorptiometry (DISCOVERY QDR-4500W, Hologic Inc., Bedford, MA, USA). The sample was categorized into two groups based on the diagnostic criteria of the World Health Organization for menopausal women and men aged 50 or older: osteoporosis = *T*-score of any of the two BMDs ≤ -2.5; normal = *T*-score of both BMDs > -2.5 [21].

The presence of metabolic syndrome was determined based on the Asia-Pacific criteria of the National Cholesterol Education Program-Adult Treatment Panel III (NCEP-ATP 3) [22]. The specific criteria were high blood pressure determined by systolic blood pressure ≥ 130 mmHg, diastolic blood pressure ≥ 85 mmHg, or the present use of antihypertensive medications; high fasting glucose determined by a fasting glucose level ≥ 110 mg/dL or the present use of insulin or oral diabetic medications; high triglycerides determined by triglyceride levels ≥ 150 mg/dL or the present use of lipid-lowering medications; low high-density lipoprotein-C (HDL-C) determined by an HDL-C level < 50 mg/dL or present use of relevant medications; and central obesity determined by WC ≥ 80 cm. Postmenopausal women who had three out of the five criteria were categorized as having metabolic syndrome.

Obesity was determined by BMI and WC. BMI was calculated by dividing weight in kilograms by squared height in meters (kg/m^2). A BMI ≥ 25 kg/m^2 was defined as obese. WC was assessed by rulers. A WC ≥ 80 cm was defined as obese. The sample was categorized into four obesity groups based on BMI and WC: a BMI- and WC-based obese group (BMI ≥ 25 kg/m^2 and WC ≥ 80 cm), a BMI-based obese group (BMI ≥ 25 kg/m^2 and WC < 80 cm), a WC-based obese group (BMI < 25 kg/m^2 and WC ≥ 80 cm), and a non-obese group (BMI < 25 kg/m^2 and WC < 80 cm).

Other variables that may be related to osteoporosis (or osteoporotic fracture) and/or metabolic syndrome were also extracted from the data, as follows: age [7, 14], height [23], living arrangement and socioeconomic status [23], smoking status [23], alcohol [24], physical activity [23, 25], hormone therapy and parental fracture history [23], serum vitamin D levels [26], daily protein [27], calcium [23], sodium and calorie intake [1], and total muscle mass and total body fat mass [28, 29]. The total muscle and body fat mass of the participants were also measured using dual-energy X-ray absorptiometry. Data on residential areas were collected as a sample characteristic.

Statistical analysis

The weighted data were used to examine the relationships of obesity with osteoporosis and metabolic syndrome. The tests for BMD were conducted between July 2008 and May 2011,

and the weighted BMD for 2008 was 108/580, for 2009 and 2010 was 200/580, and for 2011 was 80/580. The Rao-Scott chi-square test was used to compare categorical sample characteristics among the four groups. Analysis of variance and the Bonferroni ad hoc test were used to compare continuous sample characteristics among the groups. Multinomial logistic regression analysis was used to examine the odds ratios for the risk of simultaneously having both conditions, osteoporosis only, and metabolic syndrome only in each obesity group, controlling for covariates (age; height; living arrangement; socioeconomic status; smoking status; alcohol; physical activity; hormone therapy; serum vitamin D; daily protein, calcium, sodium, and calorie intake; and muscle-to-fat ratio). The significance level was set at $p < .05$. For all analyses, SAS 9.4 was used (SAS Institute, Cary, NC, USA).

Results

Sample characteristics among obesity groups

Among the 3058 postmenopausal women, 1075 (weighted frequency = 1,446,563) were in the BMI- and WC-based obese group, 55 (weighted frequency = 66,092) in the BMI-based obese group, 761 (weighted frequency = 1,093,301) in the WC-based obese group, and 1167 (weighted frequency = 1,672,305) in the non-obese group. Of the sociodemographic and clinical characteristics, age, socioeconomic status, smoking status, and hormone therapy significantly differed among the groups (Table 1). The non-obese group contained younger women (50–59 years), more women with higher education and income, and more women who used hormone therapy and smoked. The WC-based obese group was the tallest group, while the BMI-based obese group was the shortest group. The non-obese group had the lowest total muscle and body fat mass and the highest muscle-to-fat ratio, while the BMI- and WC-based obese group had the highest total muscle and body fat mass and the lowest muscle-to-fat ratio (Table 2). There were no differences among the groups in residential area, living arrangement, alcohol intake, physical activity, parental fracture history, or nutritional intake (Tables 1 and 2).

Comparisons of osteoporosis and metabolic syndrome among the obesity groups

Differences in osteoporosis and metabolic syndrome among the obesity groups were examined using the Rao-Scott chi-square test using weighted data (Table 3). The prevalence of osteoporosis was higher in both the WC-based obese group (BMI < 25 kg/m^2 and WC ≥ 80 cm, 45.3%) and the non-obese group (BMI < 25 kg/m^2 and WC < 80 cm, 43.6%), and lower in the BMI- and WC-based obese group (BMI ≥ 25 kg/m^2 and WC ≥ 80 cm, 34.8%) and the BMI-based obese group (BMI < 25 kg/m^2 and WC < 80 cm, 30.0%) than their counterparts ($\chi^2 = 18.9$, $p < .001$). The prevalence of metabolic syndrome was higher in the BMI- and WC-based obese group (73.5%) and the WC-based obese group (63.2%) and lower in the BMI-based obese group (28.7%) and the non-obese group (18.0%) ($\chi^2 = 559.5$, $p < .001$).

In the multinomial logistic regression analysis, the odds ratios for both osteoporosis and metabolic syndrome in the BMI- and WC-based obese group (7.39, 95% CI = 4.83–11.31) and the WC-based obese group (7.07, 95% CI = 4.72–10.58) were higher, but the odds ratio in the BMI-based obese group (0.74, 95% CI = 0.27–1.98) was not significantly higher than that in the non-obese group. The odds ratios for having only osteoporosis in the four groups were 0.66 (0.44–1.00), 0.79 (95% CI = 0.53–1.20), 0.42 (0.18–0.99), and 1, respectively. The odds ratios for having only metabolic syndrome were 14.31 (9.21–22.25), 6.99 (95% CI = 4.56–10.71), 1.85 (0.76–4.53), and 1, respectively, in the four groups (Table 4).

Discussion

The findings of this study demonstrate that different definitions of obesity showed different relationships with osteoporosis and metabolic syndrome among postmenopausal women, allowing an identification of the most and least desirable types of obesity for both conditions in this population. In the multinomial regression analysis, BMI-based obesity was associated with a lower likelihood of simultaneously having both osteoporosis and metabolic syndrome and having only osteoporosis, and a higher likelihood of having only metabolic syndrome, but these trends did not show statistical differences from the non-obese group. WC-based obesity was associated with a higher likelihood of simultaneously having both osteoporosis and metabolic syndrome and of having only metabolic syndrome. Both BMI- and WC-based obesity were associated with a lower likelihood of having osteoporosis, but the greatest likelihood of simultaneously having both osteoporosis and metabolic syndrome and of having metabolic syndrome. The findings provide valuable information for the management of obesity with the goal of reducing and preventing both osteoporosis and metabolic syndrome, which are prevalent conditions [1–3, 7] that cause considerable adverse health outcomes in postmenopausal women [5, 8–11]. It has been difficult to manage obesity with the goal of reducing the risk for both osteoporosis and metabolic syndrome because of the opposite directions of the relationship of obesity with these two conditions [14, 15, 17, 18].

The prevalence of osteoporosis based on weighted data in this study was high (40.8%) and is comparable with the

Table 1 Comparisons of sample characteristics across obesity groups: categorical variables

Characteristics		Obesity groups								χ^2	*p* value
		BMI- and WC-based obesity (BMI ≥ 25 kg/m^2 & WC ≥ 80 cm) (*n* = 1075, 35.2%; *N* = 1,446,563, 33.8%)		BMI-based obesity (BMI ≥ 25 kg/m^2 & WC < 80 cm) (*n* = 55, 1.8% *N* = 66,092, 1.5%)		WC-based obesity (BMI < 25 kg/m^2 & WC ≥ 80 cm) (*n* = 761, 24.8% *N* = 1,093,301, 25.6%)		Non-obesity (BMI < 25 kg/m^2 & WC < 80 cm) (*n* = 1167, 38.2% *N* = 1,672,305, 39.1%)			
		n (%)	*N* (%)	*n* (%)	*N* (%)	*n* (%)	*N* (%)	*n* (%)	*N* (%)		
Age (years)	50–59	335 (32.0)	532,834 (29.6)	20 (1.9)	28,033 (1.6)	217 (20.7)	387,066 (21.5)	474 (45.3)	850,949 (47.3)	55.9	< .001
	60–69	438 (38.9)	529,570 (39.0)	25 (2.2)	29,182 (2.2)	305 (27.1)	381,215 (28.1)	359 (31.9)	416,669 (30.7)		
	≥ 70	302 (34.1)	384,159 (34.2)	10 (1.1)	8876 (0.8)	239 (27.0)	325,021 (28.9)	334 (37.7)	404,687 (36.0)		
Residential area	Urban	691 (34.8)	983,320 (32.7)	45 (2.3)	52,053 (1.7)	481 (24.2)	745,754 (24.8)	769 (38.7)	1,224,741 (40.7)	6.3	.10
	Rural	384 (35.8)	463,243 (36.4)	10 (0.9)	14,039 (1.1)	280 (26.1)	347,547 (27.3)	398 (37.1)	447,564 (35.2)		
Living arrangement	With husband	693 (34.6)	923,972 (32.7)	42 (2.1)	49,370 (1.7)	499 (24.9)	715,744 (25.3)	769 (38.4)	1,134,752 (40.2)	7.3	.30
	With non-spouse	180 (33.5)	308,681 (34.3)	5 (0.9)	9049 (1.0)	146 (27.2)	248,497 (27.6)	206 (38.4)	332,848 (37.0)		
	Alone	202 (39.0)	213,910 (38.5)	8 (1.5)	7674 (1.4)	116 (22.4)	129,060 (23.2)	192 (37.1)	204,704 (36.9)		
Socio-economic status[a]	Third (highest)	94 (24.7)	136,674 (22.3)	7 (1.8)	7379 (1.2)	69 (18.1)	107,020 (17.4)	211 (55.4)	363,057 (59.1)	65.9	< .001
	Second	298 (33.4)	450,404 (32.1)	20 (2.2)	21,053 (1.5)	252 (28.2)	401,386 (28.6)	323 (36.2)	531,665 (37.9)		
	First (lowest)	683 (38.3)	859,485 (38.0)	28 (1.6)	37,660 (1.7)	440 (24.7)	584,895 (25.9)	633 (35.5)	777,583 (34.4)		
Smoking status	No	1017 (35.6)	1,365,380 (34.5)	53 (1.9)	64,252 (1.6)	708 (24.8)	1,008,897 (25.5)	1078 (37.7)	1,522,359 (38.4)	8.1	.04
	Yes	58 (28.7)	81,183 (25.6)	2 (1.0)	1840 (0.6)	53 (26.2)	84,404 (26.6)	89 (44.1)	149,946 (47.2)		
Alcohol consumption	< 1/month	792 (34.1)	1,065,057 (33.6)	44 (1.9)	47,539 (1.5)	586 (25.2)	828,143 (26.1)	901 (38.8)	1,233,399 (38.9)	6.1	.41
	1–4/month	229 (40.8)	313,779 (37.2)	9 (1.6)	12,027 (1.4)	133 (23.7)	198,562 (23.5)	190 (33.9)	318,955 (37.8)		
	≥ 2/week	54 (31.0)	67,727 (26.0)	2 (1.1)	6526 (2.5)	42 (24.1)	66,596 (25.5)	76 (43.7)	119,951 (46.0)		
Physical activity	Low	529 (35.9)	701,828 (34.8)	27 (1.8)	30,096 (1.5)	375 (25.5)	532,554 (26.4)	542 (36.8)	752,734 (37.3)	9.7	.14
	Moderate	338 (36.0)	479,182 (35.3)	13 (1.4)	16,895 (1.2)	237 (25.2)	342,515 (25.3)	351 (37.4)	517,098 (38.1)		
	High	208 (32.2)	265,554 (29.1)	15 (2.3)	19,100 (2.1)	149 (23.1)	218,233 (24.1)	274 (42.4)	402,473 (44.5)		
Hormone therapy	No	998 (35.3)	1,354,270 (34.2)	51 (1.8)	63,272 (1.6)	712 (25.2)	1,027,681 (25.9)	1068 (37.8)	1,516,160 (38.3)	9.7	.020
	Yes	77 (33.6)	92,294 (29.1)	4 (1.7)	2820 (0.9)	49 (21.4)	65,620 (20.7)	99 (43.2)	156,144 (49.3)		
Parental fracture history	No	915 (35.9)	1,299,701 (34.4)	51 (2.0)	58,751 (1.6)	628 (24.6)	921,373 (25.8)	955 (37.5)	1,360,879 (38.1)	4.0	.27
	Yes	160 (31.4)	216,862 (30.6)	4 (0.8)	7341 (1.0)	133 (26.1)	171,929 (24.3)	212 (41.7)	311,426 (44.0)		

BMI, body mass index; *WC*, waist circumference; *n*, unweighted frequency; *N*, weighted frequency

p values were obtained by the Rao-Scott chi-square test

[a] Tertiles: Third, ≥ 12 years of schooling and household income ≥ average. Second, ≥ 12 years of schooling or household income ≥ average. First, < 12 years of years of schooling and household income < average

Table 2 Comparisons of sample characteristics across obesity groups: continuous variables

Characteristics	Obesity group				*F*	*p* value
	BMI- and WC-based obesity Mean (SE)	BMI-based obesity Mean (SE)	WC-based obesity Mean (SE)	Non-obesity Mean (SE)		
Height (cm)	152.9 (0.2) [a]	149.9 (0.9) [b]	154.0 (0.2) [c]	152.7 (0.2) [d]	12.4	< .001
Serum vitamin D (ng/mL)	18.5(0.3)	16.8(0.8)	18.4(0.3)	18.7(0.3)	1.60	.19
Protein intake per day (g)	51.1 (1.0)	50.8 (3.0)	50.8 (1.0)	50.9 (0.9)	0.02	.99
Calcium intake per day (mg)	430.9 (21.3)	457.6 (52.1)	406.5 (12.0)	419.5 (11.6)	0.58	.63
Sodium intake per day (g)	3.8 (0.1)	4.3 (0.4)	3.7 (0.1)	3.7 (0.1)	0.90	.44
Calorie intake per day (kcal)	1530.1 (24.3)	1462.1 (62.2)	1548.2 (28.0)	1515.8 (21.0)	0.62	.60
Total muscle mass (g)	37,677 (123.5) [a]	36,602 (293.9) [b]	34,137 (112.6) [c]	32,625 (98.3) [d]	451.98	< .001[#]
Total body fat mass (g)	24, 234 (145.2) [a]	21,742 (466.3) [b]	19,026 (141.5) [c]	15,542 (129.7) [d]	788.46	< .001[#]
Muscle-to-fat ratio (g/g*100)	159.5 (1.2) [a]	173.8 (4.4) [b]	183.5 (2.1) [b]	222.1 (2.4) [c]	224.83	< .001[#]

BMI, body mass index; *WC*, waist circumference; *SE*, standard error

p values were obtained by analysis of variance (ANOVA), adjusted for age

[#] *p* values were obtained by analysis of variance (ANOVA), adjusted for age and height

[a,b,c,d] Mean values within a row were significantly different by the Bonferroni post hoc test ($p < .05$)

prevalence of 42 to 48% in prior studies [1, 3]. The prevalence of metabolic syndrome based on weighted data in this study was likewise high (48.5%) and in fact is higher than the rates of 13.5 to 37% reported in prior studies [2, 7]. In Korean postmenopausal women [2], the prevalence of metabolic syndrome was 13.5%. In that prior study, even though similar criteria were used to determine metabolic syndrome, women with chronic diseases, such as cancer, diabetes, and hypertension, were excluded. In the prior study, the prevalence was calculated based on a sample who visited a single health promotion center between 2006 and 2009, while the prevalence in this study was calculated using a national and weighted dataset between 2008 and 2011. In a systematic literature review of 119 studies, the pooled prevalence in postmenopausal women was 37% [7], which is slightly lower than the rate observed in this study. The high prevalence of both osteoporosis and metabolic syndrome in menopausal or postmenopausal women confirms the urgent need for managing both osteoporosis and metabolic syndrome in this population.

The findings of this study suggest the most and the least desirable types of obesity for managing both osteoporosis and metabolic syndrome. Many prior studies have examined the relationships of obesity with osteoporosis and metabolic syndrome and found significant relationships, but the findings were not very helpful for managing both conditions because of the opposite directions of the relationships of obesity with osteoporosis and metabolic syndrome. For instance, obesity based on BMI or WC has been associated with higher BMD, a lower prevalence of osteoporosis, or delayed development of osteoporosis [12–16]. In contrast, obesity based on BMI or WC has been associated with increased development of metabolic syndrome [17–19]. In the prior studies, no researchers examined the relationships of obesity with both osteoporosis and metabolic syndrome by combining both indicators of obesity to generate four different types of obesity. Muscle mass and fat mass were regarded as common factors related to obesity, osteoporosis, and metabolic syndrome. For instance, only fat mass, regardless of muscle mass, was significantly associated with the

Table 3 Prevalence of osteoporosis and metabolic syndrome across obesity groups

Condition		Total *N* (%)	BMI- and WC-based obesity *N* (%)	BMI- based obesity *N* (%)	WC-based obesity *N* (%)	Non-obesity *N* (%)	χ^2	*p* value
Osteoporosis	No	2,530,674 (59.2)	942,651 (65.2)	46,251 (70.0)	597,863 (54.7)	943,908 (56.4)	18.9	< .001
	Yes	1,747,587 (40.8)	503,912 (34.8)	19,841 (30.0)	495,438 (45.3)	728,396 (43.6)		
Metabolic syndrome	No	2,203,304 (51.5)	382,616 (26.5)	47,115 (71.3)	402,066 (36.8)	1,371,507 (82.0)	559.5	< .001
	Yes	2,074,957 (48.5)	1,063,947 (73.5)	18,977 (28.7)	691,235 (63.2)	300,798 (18.0)		

BMI, body mass index; *WC*, waist circumference; *N*, weighted frequency

Table 4 Odds ratios for having osteoporosis and metabolic syndrome across obesity groups: multinomial logistic regression

	Both osteoporosis and metabolic syndrome vs. none			Osteoporosis only vs. none			Metabolic syndrome only vs. none		
	Odds ratio[a]	95% CI	*p* value	Odds ratio[a]	95% CI	*p* value	Odds ratio[a]	95% CI	*p* value
BMI- and WC-based obesity	7.39	4.83–11.31	<.001	0.66	0.44–1.00	.05	14.31	9.21–22.25	< .001
BMI-based obesity	0.74	0.27–1.98	.54	0.42	0.18–0.99	.05	1.85	0.76–4.53	.18
WC-based obesity	7.07	4.72–10.58	< .001	0.79	0.53–1.20	.27	6.99	4.56–10.71	< .001
Non-obesity	1			1			1		

BMI, body mass index; *WC*, waist circumference

[a] Age, height, living arrangement, socioeconomic status, smoking status, alcohol, physical activity, hormone therapy, serum vitamin D levels, and daily protein, calcium, sodium, and calorie intake, and muscle-to-fat ratio were controlled

prevalence of metabolic syndrome in Korean adults [28]. Otherwise, in a meta-analysis on factors influencing osteoporosis in postmenopausal women, the effects of fat mass and lean mass on BMD were not different [29]. Both BMI- and WC-based obesity in this study were associated with the greatest total muscle and body fat mass and the lowest muscle-to-fat ratio, indicating that this group may correspond to a generally higher-risk profile. BMI-based obesity was associated with more total muscle and body fat mass than WC-based obesity; there were no statistically differences in the muscle-to-fat ratio between these two groups. We recommend further research to examine whether BMI-based obesity, compared with other types of obesity, is specifically associated with risk elevation.

Because of the opposite directions of these relationships, it was not possible for healthcare practitioners and postmenopausal women to know whether they needed to decrease or increase their BMI or WC to reduce the likelihood of developing osteoporosis and metabolic syndrome. Based on the findings of this study, clinicians may consider suggesting that postmenopausal women with WC-based obesity, but not those with BMI-based obesity, take steps to reduce their risk of simultaneously developing osteoporosis and metabolic syndrome. Healthcare practitioners also may consider suggesting that postmenopausal women with both BMI- and WC-based obesity should reduce their WC and recommend that non-obese women take steps to prevent the development of osteoporosis in advance. Further studies are also needed to identify ways of preventing the development of concomitant osteoporosis and metabolic syndrome, because such steps would be expected to reduce the frequency of bone fractures, improve quality of life, reduce the development of CVD and cancer, and reduce mortality, which are common adverse health effects of both osteoporosis and metabolic syndrome [5, 8–11]. Further studies are needed to determine the optimal range of BMI that can prevent or reduce the development of both osteoporosis and metabolic syndrome in postmenopausal women.

A major strength of this study is that it considered the relationships of obesity to both osteoporosis and metabolic syndrome using a large dataset. However, a limitation of this study is its use of a cross-sectional design, meaning that we could not examine causal relationships between obesity and osteoporosis and MS or explain the underlying biological mechanisms. Additional limitations relate to the generalizability of the findings of this study, since this study included only two of the three sites where BMD can be measured to diagnose osteoporosis. Moreover, this study excluded women with missing data. Although the enrolled and excluded groups were similar with respect to most demographic- and lifestyle-related variables, with significant differences only found for age, living arrangement, and parental fracture history, this consideration should be kept in mind when interpreting the results of this study. Furthermore, the BMI-based obesity group contained fewer participants than the other groups.

In conclusion, the findings of this study demonstrated the most and the least desirable types of obesity in terms of risk of osteoporosis and metabolic syndrome. BMI-based obesity was associated with a lower likelihood of having both osteoporosis and metabolic syndrome, while WC-based obesity was associated with a higher likelihood of having both conditions. Thus, public health practitioners may recommend that postmenopausal women with WC-based obesity, but not BMI-based obesity, take steps to reduce or prevent the development of both osteoporosis and metabolic syndrome. Further research is needed to determine the optimal BMI range for reducing or preventing the development of both osteoporosis and metabolic syndrome and whether BMI-based obesity actually leads to a reduced development of both conditions and their adverse effects on health outcomes. In addition, further research is required to discover the potential

biological mechanisms underlying these results and to explore their clinical relevance.

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Compliance with ethical standards

Ethical approval Approval of this study was obtained from the Institutional Review Board of E University (EUIRB2018–25) before this study commenced. The KCDC has opened the data of the KNHANES to the public. The research team downloaded the relevant non-identified data from the webpage after obtaining approval from the KCDC. This study was conducted in accordance with the statement of ethical principles for human research in the Helsinki Declaration. Written informed consent for the survey was obtained from all study participants by the trained staff of the KNHANES.

Conflict of interest None.

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