Original Article

J Prev Med Public Health 2016;49:35-44 • http://dx.doi.org/10.3961/jpmph.15.055

pISSN 1975-8375 eISSN 2233-4521

Journal of Preventive Medicine & Public Health

Associations of Sarcopenia and Sarcopenic Obesity With Metabolic Syndrome Considering Both Muscle Mass and Muscle Strength

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Objectives: We investigated the associations of sarcopenia-defined both in terms of muscle mass and muscle strength-and sarcopenic obesity with metabolic syndrome.

Methods: Secondary data pertaining to 309 subjects (85 men and 224 women) were collected from participants in exercise programs at a health center in a suburban area. Muscle mass was measured using bioelectrical impedance analysis, and muscle strength was measured via handgrip strength. Sarcopenia based on muscle mass alone was defined as a weight-adjusted skeletal muscle mass index more than two standard deviations below the mean of a sex-specific young reference group (class II sarcopenia). Two cut-off values for low handgrip strength were used: the first criteria were <26 kg for men and <18 kg for women, and the second criteria were the lowest quintile of handgrip strength among the study subjects. Sarcopenic obesity was defined as the combination of class II sarcopenia and being in the two highest quintiles of total body fat percentage among the subjects. The associations of sarcopenia and sarcopenic obesity with metabolic syndrome were evaluated using logistic regression models.

Results: The age-adjusted risk ratios (RRs) of metabolic syndrome being compared in people with or without sarcopenia defined in terms of muscle mass were 1.25 (95% confidence interval [CI], 1.06 to 1.47, $p=0.008$) in men and 1.12 (95% CI, 1.06 to 1.19, $p<0.001$) in women, which were found to be statistically significant relationships. The RRs of metabolic syndrome being compared in people with or without sarcopenic obesity were 1.31 in men (95% CI, 1.10 to 1.56, $p=0.003$) and 1.17 in women (95% CI, 1.10 to 1.25, $p<0.001$), which were likewise found to be statistically significant relationships.

Conclusions: The associations of sarcopenia defined in terms of muscle mass and sarcopenic obesity with metabolic syndrome were statistically significant in both men and women. Therefore, sarcopenia and sarcopenic obesity must be considered as part of the community-based management of non-communicable diseases.

Key words: Sarcopenia, Metabolic syndrome X, Association, Muscle strength

Received: September 22, 2015 Accepted: November 21, 2015

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INTRODUCTION

Community-based health services in Korea include the registration and management of hypertension and diabetes mellitus patients, maternal and pediatric health care, mental health care, home visits by health care providers, the management of infectious diseases, health promotion, and metabolic syndrome services [1]. The aim of the registration and management of hy-

pertension and diabetes mellitus patients is to reduce mortality by increasing the control rate of hypertension and diabetes [2]. However, the hypertension control rate in Korea has been at a standstill since 2007 [3]. The hypertension control rate is highest among patients in their fifties, and decreases in patients in their sixties or older [4]. According to the most recent annual report on causes of death in Korea, the mortality rate of hypertension-related disease showed no appreciable changes in 2013 [5]. However, it increases rapidly in patients over 70 years of age, and sarcopenia is thought to be a reason for the pattern of increased mortality observed in this age group [6].

Sarcopenia refers to the progressive loss of muscle mass with increasing age [7]. The most important cause of sarcopenia is the loss of muscle mass that occurs during the aging process [8]. Muscle mass is constant from the ages of 25 to 40 years, but decreases by approximately 25% between the ages of 40 and 75 years [9]. Sarcopenia inhibits physical activity, threatens the ability of individuals to lead independent daily lives, and causes death [10]. In particular, the loss of appetite, which is accompanied by decreased physical activity, can cause nutritional deficiencies and accelerate the loss of skeletal muscle mass [11]. Sarcopenic obesity refers to elevated body fat mass combined with reduced muscle mass [12].

Sarcopenia will become increasingly prevalent as the elderly population increases worldwide [13]. The impacts of sarcopenia include increased morbidity [14], disability [15], health management costs [16], and mortality [17]. Sarcopenia and sarcopenic obesity contribute to increasing mortality in that they increase the risk of metabolic syndrome and cardiovascular disease [18]. Since skeletal muscles are primary sites for glucose uptake and deposition [19], sarcopenia increases insulin resistance, thereby progressively inducing diabetes and metabolic syndrome [20]. In addition, the myokines secreted in skeletal muscles impact the adipokines secreted in adipose tissue, working to prevent insulin resistance [21]. For these reasons, increasing the whole-body muscle mass improves insulin sensitivity [22]. Furthermore, sarcopenia makes arteries stiff and can cause hypertension [23].

The social cost of sarcopenia in the US was estimated at 18.5 billion US dollars in 2000 [16], making the further study of sarcopenia necessary. No clinical definition of sarcopenia or agreement regarding the diagnostic criteria currently exists, it is not included in the International Classification of Disease 9th revision, and no treatment guidelines have been published [8]. The European Working Group on Sarcopenia in Older People (EWGSOP) defined sarcopenia as low muscle mass in combination with low muscle strength or low physical performance. However, in the most studies, sarcopenia has been defined only as low muscle mass [15,24]. Although no standard diagnostic criteria exist, the Asian Working Group has suggested that the cut-off values for low muscle strength should be <26 kg in men and <18 kg in women [25]. However, the Asian Working Group has also used the lowest quintile of handgrip strength among subjects, meaning that the cut-off values for low muscle strength are not clearly defined.

In the previous study in the US, sarcopenia among both obese and non-obese subjects was found to increase insulin resistance significantly in both men and women [26]. In a study conducted in the Korean population, sarcopenia was found to be related with metabolic syndrome in non-obese subjects [27]. In another study conducted in the Korean population, sarcopenic obesity was found to significantly increase the risk of metabolic syndrome [28]. However, those studies only investigated muscle mass, not muscle strength. Increasing muscle mass does not improve mobility unless muscle strength also increases [29]. The EWGSOP has suggested that only considering muscle mass is not recommended, and that muscle strength should also be considered because muscle mass and muscle strength do not have a linear relationship [8]. It is necessary to evaluate the association between sarcopenia and metabolic syndrome considering both muscle mass and muscle strength. Our study evaluated the associations of sarcopenia and sarcopenic obesity with metabolic syndrome in a suburban area, based on an assessment of both muscle mass and muscle strength.

METHODS

Study Population

We used secondary data from a suburban health center that runs a nutrition education program and an exercise program as part of the registration and management of hypertension and diabetes mellitus patients. The data were collected from 309 subjects (85 men and 224 women) who were at least 40 years old before they started a voluntary exercise program, among a total of 1120 civilians who participated in a nutrition education program. Bioelectrical impedance analysis (BIA) and hand grip strength data were collected. In order to calculate the cut-off values for sarcopenia, data were collected from a young reference group composed of volunteer health counselors at the health center (aged 18 to 40 years; 273 subjects;

157 men, 116 women). We used data collected from January 2013 to July 2015. The Chung-Ang University institutional review board (IRB) approved this study protocol (IRB no. 1041078-201505-HRBM-090-01).

Anthropometric Measurements

In the young reference group, BIA, height, and body weight were measured, whereas BIA and body weight were measured in the older adults. Body weight and height were measured with the subjects dressed in light clothing and barefoot. Body mass index was defined as weight (kg) divided by height squared (m^2). BIA was performed using the Inbody system (Inbody 720, Biospace, Seoul, Korea) with an operating frequency of 50 kHz at 800 μA. The study subjects stood upright with their arms abducted apart from their trunk and legs slightly spread. Skeletal muscle mass was calculated using the BIA equation used in a previous study [30]

SM (kg) = [0.401 × (height^2/resistance) + (3.825 × gender) - (0.071 × age) + 5.102], where height is in cm and resistance is in ohms. The gender was zero for the women, and one for the men. The height-adjusted skeletal mass index (SMI) was calculated by dividing by height squared (m^2) [31], and the weight-adjusted SMI was calculated by dividing by weight (kg) and multiplying by 100 [15]. Since muscle mass does not change significantly from 18 to 40 years of age [9], sarcopenia was defined with reference to this age group. Class I sarcopenia was defined as a weight-adjusted SMI between one and two standard deviations below the mean of the gender-specific young reference group [32]. Class II sarcopenia was defined as a weight-adjusted SMI more than two standard deviations below the mean of the gender-specific young reference group. Sarcopenic obesity was defined as weight-adjusted class II sarcopenia in combination with being in the two highest quintiles of total body fat percentage, corresponding to the criteria used by Zoico et al. [12].

Muscle strength was evaluated by hand grip strength using a grip strength dynamometer (Biospace, Seoul, Korea) [8]. The grip strength dynamometer was capable of measuring from 5 kg to 100 kg in intervals of 0.1 kg. One investigator measured all subjects with the same machine. The subjects stood upright, holding the dynamometer with maximum force. All measurement was measured twice in both hands, and the highest of the four values was selected. The Asian Working Group has suggested that low muscle strength be defined as < 26 kg for men and < 18 kg for women [25]. Our study used these values. Another cut-off value of low muscle strength used by the Asian Working Group is the lowest quintile of muscle strength among study subjects. We also used this criterion.

Definition of Metabolic Syndrome

Metabolic syndrome was defined following the criteria outlined by the National Cholesterol Education Program Adult Treatment Panel III. Subjects with three or more of the following five criteria were regarded as having metabolic syndrome: i) central obesity (waist circumference cut-off values of ≥ 90 cm for men and ≥ 85 cm for women), ii) hypertriglyceridemia (triglycerides ≥ 150 mg/dL or use of triglyceride-lowering medication), iii) hypo-high-density lipoprotein cholesterolemia (< 40 mg/dL for men, < 50 mg/dL for women), iv) hypertension (systolic blood pressure ≥ 130 mmHg or diastolic blood pressure ≥ 85 mmHg, or the use of antihypertensive medication), and v) dysglycemia (fasting plasma glucose ≥ 100 mg/dL, the use of anti-hyperglycemic medication, or previously diagnosed type 2 diabetes) [33].

Table 1. Characteristics and anthropometric data of the young reference group[1]

Characteristic	Young reference group	
	Men (n = 157)	Women (n = 116)
Age (y)	25.5 ± 2.9	26.1 ± 4.6
Weight (kg)	74.5 ± 10.5	54.3 ± 6.9
Height (cm)	175.6 ± 5.3	161.9 ± 4.6
Waist circumference (cm)	92.8 ± 63.4	73.0 ± 6.0
Body mass index (kg/m^2)	24.1 ± 3.0	20.7 ± 2.6
Lean body mass (kg)	58.0 ± 5.9	39.6 ± 3.9
Skeletal muscle mass (kg)	35.1 ± 3.6	21.0 ± 2.3
Height-adjusted skeletal muscle mass index (kg/m^2)	11.4 ± 1.1	8.0 ± 0.8
Weight-adjusted skeletal muscle mass index	47.6 ± 4.7	38.9 ± 3.3
Cut-off values for height-adjusted sarcopenia (kg/m^2)		
Class I sarcopenia[2]	10.4	7.2
Class II sarcopenia[3]	9.3	6.4
Cut-off values for weight-adjusted sarcopenia		
Class I sarcopenia	42.9	35.6
Class II sarcopenia	38.2	32.2

Values are presented as mean ± standard deviation.
[1]The young reference group comprised a gender-specific group from 18 to 40 years old.
[2]Participants with class I sarcopenia were those with a height-adjusted or weight-adjusted skeletal muscle mass index between one and two standard deviations below the mean of the gender-specific young reference group.
[3]Participants with class II sarcopenia were those with a height-adjusted or weight-adjusted skeletal muscle mass index more than two standard deviations below the mean of the gender-specific young reference group.

Statistical Analysis

Data were analyzed using SPSS version 23.0 (IBM Corp., Armonk, NY, USA). To calculate the power, G*Power version 3.1 was used. The associations of sarcopenia and sarcopenic obesity with metabolic syndrome were obtained from logistic regression models. The dependent variable was metabolic syndrome, and the independent variables were low muscle mass only, low muscle strength only, the presence of both low muscle mass and low muscle strength, sarcopenic obesity, and age. Risk ratios (RRs) with 95% confidence intervals (CIs) were calculated after controlling for age. A p-value <0.05 was considered statistically significant in the analysis.

RESULTS

Characteristics of the Study Population

The cut-off values of height-adjusted class I sarcopenia in the young reference group were 10.4 kg/m^2 in men and 7.2 kg/m^2 in women (Table 1). The cut-off values of weight-adjusted class I sarcopenia in the young reference group were 42.9 in men and 35.6 in women. The cut-off values of height-adjusted class II sarcopenia in the young reference group were 9.3 kg/m^2 in men and 6.4 kg/m^2 in women, and the cut-off values of weight-adjusted class II sarcopenia in the young reference group were 38.2 in men and 32.2 in women.

Table 2. Characteristics and anthropometric data of subjects more than 40 years of age

Characteristic	Older adults	
	Men (n=85)	Women (n=224)
Age (y)	70.7±6.3	66.4±7.2
Weight (kg)	65.0±6.5	60.7±9.4
Waist circumference (cm)	88.7±7.2	92.4±7.5
Total fat percentage (%)	23.3±7.0	34.7±7.5
Systolic blood pressure (mmHg)	136.7±18.9	131.0±16.0
Diastolic blood pressure (mmHg)	72.8±12.0	73.4±10.6
Blood glucose (mg/dL)	156.8±57.4	146.3±52.8
High density lipoprotein cholesterol (mg/dL)	41.4±11.0	42.1±20.7
Triglycerides (mg/dL)	197.3±92.0	241.2±122.7
Hypertension	54 (63.5)	150 (67.0)
Diabetes mellitus	27 (31.8)	75 (33.5)
Both hypertension and diabetes mellitus	14 (16.5)	40 (17.9)
Neither hypertension nor diabetes	18 (21.2)	39 (17.4)
Metabolic syndrome	40 (47.1)	166 (74.1)
Hand grip strength (kg)	31.4±8.0	19.3±5.3
Cut-off values for the two highest quintiles of total fat (%)	25.8	36.5
Cut-off values for the lowest quintile of handgrip strength (kg)	24.7	14.9

Values are presented as mean±standard deviation or number (%).

The characteristics of the adult subjects older than 40 are shown in Table 2. The average age was 70.7 years in men and 66.4 years in women. The average body weight was 65.0 kg in men and 60.7 kg in women. A total of 63.5% of the men and 67% of the women had hypertension, while 31.8% of the men and 33.5% of the women had diabetes, 16.5% of the men and 17.9% of the women had both hypertension and diabetes, 21.2% of the men and 17.4% of the women had neither hypertension nor diabetes, and 47.1% of the men and 74.1% of the women had metabolic syndrome. The cut-off value for belong to the two highest quintiles of total body fat percentage was 25.8% in men and 36.5% in women. The cut-off value for lowest quintile of handgrip strength was 24.7 kg in men and 14.9 kg in women.

Associations of Sarcopenia and Sarcopenic Obesity With Metabolic Syndrome

The associations of sarcopenia and sarcopenic obesity with metabolic syndrome in men are shown in Table 3. The age-adjusted RR of metabolic syndrome being compared in people with or without sarcopenia defined in terms of muscle mass alone was 1.25 (95% CI, 1.06 to 1.47, $p=0.008$), which was statistically significant. The age-adjusted RR of metabolic syndrome in people with or without sarcopenia defined in terms of muscle strength alone was 0.94 (95% CI, 0.79 to 1.12, $p=0.479$), which was not statistically significant. The RR of metabolic syndrome being compared in people with or without sarcopenia defined in terms of both muscle mass and muscle strength was 1.20 (95% CI, 0.97 to 1.49, $p=0.064$), which was not statistically significant. The age-adjusted RR of metabolic syndrome being compared in people with or without sarcopenic obesity was 1.31 (95% CI, 1.10 to 1.56, $p=0.003$), which was statistically significant.

The associations of sarcopenia and sarcopenic obesity with metabolic syndrome in women are presented in Table 3. The age-adjusted RR of metabolic syndrome being compared in people with or without sarcopenia defined in terms of muscle mass alone was 1.12 (95% CI, 1.41 to 12.18, $p<0.001$), which was statistically significant. The age-adjusted RR of metabolic syndrome being compared in people with or without sarcopenia defined in terms of muscle strength only was 0.98 (95% CI,

Table 3. Age-adjusted associations of sarcopenia (using the following definitions: low muscle mass[1] only, low muscle strength-1[2] only, low muscle mass and low muscle strength-1, low muscle strength-2[3] only, and low muscle mass and low muscle strength-2), sarcopenic obesity[4], and metabolic syndrome by gender

	Metabolic syndrome	No metabolic syndrome	RR (95% CI)	*p*-value
Men	40	45		
Muscle mass				
Normal	32	43	1.00 (reference)	
Low	8	2	1.25 (1.06, 1.47)	0.008
Muscle strength-1				
Normal	33	34	1.00 (reference)	
Low	7	11	0.94 (0.79, 1.12)	0.48
Muscle mass and muscle strength-1				
Normal	29	33	1.00 (reference)	
Low	3	1	1.20 (0.97, 1.49)	0.06
Muscle strength-2				
Normal	33	34	1.00 (reference)	
Low	7	11	0.94 (0.79, 1.12)	0.48
Muscle mass and muscle strength-2				
Normal	29	33	1.00 (reference)	
Low	3	1	1.20 (0.97, 1.49)	0.06
Sarcopenic obesity				
Normal	33	43	1.00 (reference)	
Abnormal	7	2	1.31 (1.10, 1.56)	0.003
Women	166	58		
Muscle mass				
Normal	126	54	1.00 (reference)	
Low	40	4	1.12 (1.06, 1.19)	<0.001
Muscle strength-1				
Normal	106	36	1.00 (reference)	
Low	60	22	0.98 (0.91, 1.05)	0.78
Muscle mass and muscle strength-1				
Normal	82	36	1.00 (reference)	
Low	16	4	1.05 (0.94, 1.18)	0.33
Muscle strength-2				
Normal	133	46	1.00 (reference)	
Low	33	12	0.98 (0.89, 1.07)	0.73
Muscle mass and muscle strength-2				
Normal	101	46	1.00 (reference)	
Low	8	4	0.94 (0.78, 1.14)	0.89
Sarcopenic obesity				
Normal	126	55	1.00 (reference)	
Abnormal	40	3	1.17 (1.10, 1.25)	<0.001

Multiple logistic regression was performed, adjusting for age.
RR, risk ratio; CI, confidence interval.
[1]Low muscle mass refers to participants with class II sarcopenia, defined as a weight-adjusted skeletal muscle mass index more than two standard deviations below the mean of the gender-specific young reference group.
[2]Low muscle strength-1 refers to participants whose handgrip strength was less than 26 kg in men and less than 18 kg in women.
[3]Low muscle strength-2 refers to participants whose handgrip strength was less than 24.7 kg in men and less than 14.9 kg in women.
[4]Sarcopenic obesity refers to participants with class II sarcopenia, as defined by a weight-adjusted skeletal muscle mass index more than two standard deviations below the mean of the gender-specific young reference group, as well as falling into the two highest quintiles of total body fat percentage.

0.91 to 1.05, $p=0.783$), which was not statistically significant. The RR of metabolic syndrome being compared in people with or without sarcopenia defined in terms of both muscle mass and muscle strength was 1.05 (95% CI, 0.94 to 1.18, $p=0.335$), which was not statistically significant. The RR of metabolic syndrome being compared in people with or without sarcopenia defined only in terms of muscle strength was 0.98 (95% CI, 0.89 to 1.07, $p=0.732$), which was not statistically significant, and when defined in terms of both muscle mass and muscle strength, the RR was 0.94 (95% CI, 0.78 to 1.14, $p=0.889$), which was not statistically significant. The age-adjusted RR of metabolic syndrome being compared in people with or without sarcopenic obesity was 1.17 (95% CI, 1.10 to 1.25, $p<0.001$), which was statistically significant.

DISCUSSION

Our study evaluated associations of sarcopenia, defined in terms of muscle mass only, muscle strength only, or muscle mass together with muscle strength, and sarcopenic obesity with metabolic syndrome. The association between sarcopenia defined only in terms of muscle mass and metabolic syndrome was statistically significant in both men and women (RR in men, 1.25; 95% CI, 1.06 to 1.47, $p=0.008$; RR in women, 1.12; 95% CI, 1.06 to 1.19, $p<0.001$). The associations between sarcopenia defined in terms of muscle strength alone using two distinct cut-off values with metabolic syndrome were not statistically significant in either men or women. When the Asian Working Group cut-off values of <26 kg for men and <18 kg for women were used, the RR was 0.94 (95% CI, 0.79 to 1.12, $p=0.479$) in men and 0.98 (95% CI, 0.91 to 1.05, $p=0.783$) in women, whereas when the lower quintile was used, the RR was 0.94 (95% CI, 0.79 to 1.12, $p=0.479$) in men and 0.98 (95% CI, 0.89 to 1.07, $p=0.732$) in women. Many study subjects had normal muscle mass and low muscle strength, or had low muscle mass and normal muscle strength. Muscle strength does not predict metabolic syndrome, because the relationship between muscle mass and muscle strength is not linear. The associations between sarcopenia defined in terms of muscle mass and muscle strength using two distinct cut-off values were not statistically significant in either men or women. When sarcopenia was defined in terms of muscle mass and the Asian Working Group cut-off values of muscle strength, the RR of sarcopenia and metabolic syndrome was 1.20 (95% CI, 0.97 to 1.49, $p=0.064$) in men and 1.05 (95% CI, 0.94 to 1.18, $p=0.335$) in women. When sarcopenia was defined in terms of muscle mass and the lowest quintile of muscle strength, the corresponding RRs were 1.20 (95% CI, 0.97 to 1.49, $p=0.064$) for men and 0.94 (95% CI, 0.78 to 1.14, $p=0.889$) for women. Sarcopenia was only found to have a significant relationship with metabolic syndrome when defined in terms of muscle mass alone, suggesting that muscle mass is more significant than muscle strength in the context of metabolic syndrome. The association between sarcopenic obesity and metabolic syndrome was statistically significant in both men and women (RR in men, 1.31; 95% CI, 1.10 to 1.56, $p=0.003$; RR in women, 1.17; 95% CI, 1.10 to 1.25, $p<0.001$). The confidence intervals in men were larger than in women because the sample size of men was small and the differences between the maximum and minimum values of muscle mass and muscle strength were large, reflecting the fact that individual anthropometric parameters vary more in Korean men than in Korean women. In the data from the Korea National Health and Nutrition Examination Survey (KNHANES), the standard deviations of height and weight were larger in men than in women [32]. We used the lowest quintile of study subjects as an additional cut-off value for defining low muscle strength [25]. Since no men had a grip strength between 24.7 kg and 26 kg, the prevalence ratios for the two different cut-off values did not change. A possible reason that the relationship was statistically insignificant in men was that sample size of men satisfying the both criteria of low muscle strength and low muscle mass was small. The power ($1-\beta$) of men when sarcopenia was defined using muscle mass alone was 0.16, compared to 0.14 when sarcopenia was defined both in terms of muscle mass and muscle strength. Further studies with more subjects are therefore needed.

In our study, 47.1% of men and 74.1% of women had metabolic syndrome. A previous study reported the prevalence of metabolic syndrome to be 18.8% in adults more than 20 years old and 43.1% in adults more than 70 years old [34]. The proportion of metabolic syndrome was higher in our study. The positive predictive value increases as the prevalence of the disease increases. More sarcopenic patients may have been present in our study due to the presence of more patients with metabolic syndrome. The prevalence of class II sarcopenia in our study was 19.6%, which is higher than the values reported by other studies of the Korean population [28,32].

In a previous study in the US, sarcopenia among obese and non-obese people was found to increase insulin resistance by 1.39 times in men and 1.16 times in women [26]. In a study

conducted in the Korean population, sarcopenia was found to increase the risk of metabolic syndrome by two times in non-obese people [27]. In another Korean study, metabolic syndrome was found to be three times more common in men with sarcopenic obesity and two times more common in women with sarcopenic obesity [28]. Discrepancies may exist among studies due to diverse definitions of sarcopenia and sarcopenic obesity. In our study, sarcopenic obesity was defined as the two highest quintiles of total body fat percentage [12,28]. Using waist circumference, as in other studies [32], would have been inappropriate because waist circumference is a parameter used to define metabolic syndrome. The two highest quintiles of total body fat percentage were an appropriate metric because significantly more functional limitations have been found in subjects with the two highest quintiles of total body fat percentage [12]. Kim et al. [28] used the two highest quintiles of total body fat percentage, and found that sarcopenic obesity was associated with a threefold increased risk of metabolic syndrome. The associations of sarcopenia and sarcopenic obesity with metabolic syndrome were different among men and women. These results might be explained by gender differences in age-related changes in body composition. We found no statistically significant associations between muscle strength and metabolic syndrome. The prevalence ratios were 0.94 in men and 0.98 in women. These results were inconsistent with those of a previous study conducted in the UK [35]. The values of hand grip strength in the UK subjects were approximately 10 kg higher than those observed among the Korean subjects, making it inappropriate to apply the results of the UK study to the Korean population. In addition, people previously diagnosed with diabetes were excluded in that study, which reflects an error in the study design because diabetes is one of the criteria for metabolic syndrome [33]. Therefore, further study is needed with a larger sample size from the general population. The expression of the glucose transporter 4 transporter protein, which is involved in glucose uptake, has been found to be related to the volume of skeletal muscle fibers [36]. However, the relationship between glucose uptake and the contractile strength of skeletal muscle has not been elucidated, and further research is necessary to clarify the mechanisms involved.

Sarcopenia develops as part of the aging process, and can itself be a cause of low physical activity [8]. Low physical activity may, in turn, worsen sarcopenia and lead to sarcopenic obesity. Loss of muscle mass and low physical activity leads to a reduction of total energy expenditure [37]. Therefore, fat, especially visceral fat, is accumulated in the body. As visceral fat is accumulated and skeletal muscles, which are insulin-response target tissues, become less prevalent, metabolic syndrome would be expected to progress. Furthermore, larger quantities of visceral fat worsen insulin resistance and secrete pro-inflammatory adipokines that directly participate in catabolic reactions [38]. This vicious cycle worsens sarcopenia and metabolic syndrome. In addition, sarcopenia leads to stiffened arteries and can cause hypertension [23].

In this study, the prevalence of weight-adjusted class II sarcopenia defined by muscle mass alone was 12.8% in men and 19.6% in women. Sarcopenia defined in terms of both muscle mass and muscle strength was present in 5.8% of men and 8.9% of women. Our study is the first to calculate cut-off values of weight-adjusted SMI using BIA, and our findings can therefore be used as baseline data for further studies. Sarcopenia increased in prevalence with age. The prevalence of weight-adjusted class II sarcopenia defined only in terms of muscle mass measured by appendicular skeletal muscle mass (ASM) using dual-energy X-ray absorptiometry (DEXA) in the KNHANES was 12.4% in men and 11.8% in women, which was similar to the findings of our study for men but higher than we found among women [32]. In a study conducted in Korea, the height-adjusted ASM was 6.3% in men and 4.1% in women, which was lower than the findings of our study [28]. The prevalence of height-adjusted sarcopenia using BIA in Taiwan was found to be 23.6% in men and 18.6% in women [24]. The prevalence of weight-adjusted sarcopenia using BIA in the US was found to be 7% in men and 10% in women [15]. Low muscle mass and low muscle mass or low physical performance using BIA in Japan was found to be present in 11.3% of men and 10% of women [39]. These discrepancies may have been due to the use of height- or weight-adjustment and differences in the study populations [24]. The height-adjusted method that is commonly used among white and black population are inappropriate in Asian population [32]. The weight-adjusted definition of sarcopenia is more strongly associated with metabolic syndrome in Asian population. Therefore, sarcopenia should be defined depending on the racial background of the study participants.

Magnetic resonance imaging (MRI) and computerized tomography are the gold standard for diagnosing sarcopenia [8]. However, these methods are inappropriate to use in field surveys due to their high cost [30]. DEXA has been used recently, but is also inappropriate in field surveys because it involves radiation exposure and the equipment is generally fixed in the

hospital [25]. Recently, BIA was determined to have good reproducibility as a replacement for MRI in Asians [24]. In addition, BIA is non-invasive, involves no radiation exposure, involves equipment that is easy to transport, and is quick and easy to perform in comparison with DEXA [25]. Therefore, BIA may be an alternative for measuring muscle mass in large-scale epidemiological examinations [24].

Sarcopenia can affect mortality [17], morbidity [14], and disability [15]. Therefore, the management of sarcopenia should be prioritized in community-based health services. It has been proven that exercise and protein supplements are effective in managing sarcopenia [40]. Nutritional education and exercise programs can be implemented on the community level. However, people with low socioeconomic status may experience difficulty in privately engaging in lifestyle interventions that require purchasing products. Intervention programs should therefore target this subgroup.

One of the limitations of this study is its cross-sectional design. Further study is needed with more subjects in order to identify the causal relationship between sarcopenia and metabolic syndrome. Second, selection bias may have been present because the data were obtained from volunteer participants visiting a health center. Third, the physical performance of the subjects was not evaluated.

In conclusion, the associations of sarcopenia defined only in terms of muscle mass and sarcopenic obesity with metabolic syndrome were found to be statistically significant in both men and women. The associations of sarcopenia defined in terms of muscle strength only and sarcopenia defined in terms of both muscle mass and muscle strength with metabolic syndrome were not statistically significant in either men or women. Further studies with more study subjects are necessary. For these reasons, sarcopenia, and especially sarcopenic obesity, should be considered in the management of non-communicable diseases by community-based health services.

ACKNOWLEDGEMENTS

This research was supported by 2014 research grants from Chung-Ang University.

CONFLICT OF INTEREST

The authors have no conflicts of interest associated with the material presented in this paper.

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REFERENCES

1. Shim MS, Lee MS, Oh NR, Kang KH. A study on duty awareness of public health-center workers. J Korea Conver Soc 2010;1(1):83-91 (Korean).
2. Byun DH, Kim EJ, Park MB, Son HR, Park HK, Kim CB. Accessible strategy of the registration & management of hypertension and diabetes mellitus patients through the public-private partnership: policy implications fron the Hongcheon-gun case. Korean J Health Educ Promot 2013;30(4):111-123 (Korean).
3. Ministry of Health and Welfare. Korea health statistics 2013: Korea National Health and Nutrition Examination Survey (KNHANES VI-1). Sejong: Ministry of Health and Welfare; 2014, p. 52 (Korean).
4. Korea University Research and Business Foundation. Ansan community-based cohort study. Cheongju: Korea Centers for Disease Control and Prevention; 2013, p. 84 (Korean).
5. Statistics Korea. Annual report on the causes of death statistics 2013. Daejeon: Statistics Korea; 2014, p. 12 (Korean).
6. Hong S, Choi WH. Clinical and physiopathological mechanism of sarcopenia. Korean J Med 2012;83(4):444-454 (Korean).
7. Rosenberg IH. Sarcopenia: origins and clinical relevance. J Nutr 1997;127(5 Suppl):990S-991S.
8. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, et al. Sarcopenia: European consensus on definition and diagnosis: report of the European Working Group on Sarcopenia in Older People. Age Ageing 2010;39(4):412-423.
9. Balagopal P, Rooyackers OE, Adey DB, Ades PA, Nair KS. Effects of aging on in vivo synthesis of skeletal muscle myosin heavy-chain and sarcoplasmic protein in humans. Am J Physiol 1997;273(4 Pt 1):E790-E800.
10. Prado CM, Wells JC, Smith SR, Stephan BC, Siervo M. Sarcopenic obesity: a critical appraisal of the current evidence. Clin Nutr 2012;31(5):583-601.
11. Hwang J, Lee W. Aging and sarcopenia: resistance exercise and protein intake in the elderly. Ewha J Human Move Sci 2009;12:15-20 (Korean).
12. Zoico E, Di Francesco V, Guralnik JM, Mazzali G, Bortolani A,

Guariento S, et al. Physical disability and muscular strength in relation to obesity and different body composition indexes in a sample of healthy elderly women. Int J Obes Relat Metab Disord 2004;28(2):234-241.
13. World Health Organization. Ageing and life-course [cited 2009 Apr 30]. Available from: http://www.who.int/ageing/en/.
14. Sayer AA, Dennison EM, Syddall HE, Gilbody HJ, Phillips DI, Cooper C. Type 2 diabetes, muscle strength, and impaired physical function: the tip of the iceberg? Diabetes Care 2005;28(10): 2541-2542.
15. Janssen I, Heymsfield SB, Ross R. Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. J Am Geriatr Soc 2002;50(5):889-896.
16. Janssen I, Shepard DS, Katzmarzyk PT, Roubenoff R. The healthcare costs of sarcopenia in the United States. J Am Geriatr Soc 2004;52(1):80-85.
17. Gale CR, Martyn CN, Cooper C, Sayer AA. Grip strength, body composition, and mortality. Int J Epidemiol 2007;36(1):228-235.
18. Stenholm S, Harris TB, Rantanen T, Visser M, Kritchevsky SB, Ferrucci L. Sarcopenic obesity: definition, cause and consequences. Curr Opin Clin Nutr Metab Care 2008;11(6):693-700.
19. Klip A, Pâquet MR. Glucose transport and glucose transporters in muscle and their metabolic regulation. Diabetes Care 1990;13(3):228-243.
20. Reaven GM. Banting lecture 1988. Role of insulin resistance in human disease. Diabetes 1988;37(12):1595-1607.
21. Walsh K. Adipokines, myokines and cardiovascular disease. Circ J 2009;73(1):13-18.
22. Solerte SB, Gazzaruso C, Bonacasa R, Rondanelli M, Zamboni M, Basso C, et al. Nutritional supplements with oral amino acid mixtures increases whole-body lean mass and insulin sensitivity in elderly subjects with sarcopenia. Am J Cardiol 2008; 101(11A):69E-77E.
23. Sanada K, Miyachi M, Tanimoto M, Yamamoto K, Murakami H, Okumura S, et al. A cross-sectional study of sarcopenia in Japanese men and women: reference values and association with cardiovascular risk factors. Eur J Appl Physiol 2010;110(1): 57-65.
24. Chien MY, Huang TY, Wu YT. Prevalence of sarcopenia estimated using a bioelectrical impedance analysis prediction equation in community-dwelling elderly people in Taiwan. J Am Geriatr Soc 2008;56(9):1710-1715.
25. Chen LK, Liu LK, Woo J, Assantachai P, Auyeung TW, Bahyah KS, et al. Sarcopenia in Asia: consensus report of the Asian Working Group for Sarcopenia. J Am Med Dir Assoc 2014;15(2): 95-101.
26. Srikanthan P, Hevener AL, Karlamangla AS. Sarcopenia exacerbates obesity-associated insulin resistance and dysglycemia: findings from the National Health and Nutrition Examination Survey III. PLoS One 2010;5(5):e10805.
27. Moon SS. Low skeletal muscle mass is associated with insulin resistance, diabetes, and metabolic syndrome in the Korean population: the Korea National Health and Nutrition Examination Survey (KNHANES) 2009-2010. Endocr J 2014;61(1):61-70.
28. Kim TN, Yang SJ, Yoo HJ, Lim KI, Kang HJ, Song W, et al. Prevalence of sarcopenia and sarcopenic obesity in Korean adults: the Korean sarcopenic obesity study. Int J Obes (Lond) 2009; 33(8):885-892.
29. Lauretani F, Russo CR, Bandinelli S, Bartali B, Cavazzini C, Di Iorio A, et al. Age-associated changes in skeletal muscles and their effect on mobility: an operational diagnosis of sarcopenia. J Appl Physiol (1985) 2003;95(5):1851-1860.
30. Janssen I, Heymsfield SB, Baumgartner RN, Ross R. Estimation of skeletal muscle mass by bioelectrical impedance analysis. J Appl Physiol (1985) 2000;89(2):465-471.
31. Janssen I, Baumgartner RN, Ross R, Rosenberg IH, Roubenoff R. Skeletal muscle cutpoints associated with elevated physical disability risk in older men and women. Am J Epidemiol 2004; 159(4):413-421.
32. Kim YS, Lee Y, Chung YS, Lee DJ, Joo NS, Hong D, et al. Prevalence of sarcopenia and sarcopenic obesity in the Korean population based on the Fourth Korean National Health and Nutritional Examination Surveys. J Gerontol A Biol Sci Med Sci 2012; 67(10):1107-1113.
33. Grundy SM, Cleeman JI, Daniels SR, Donato KA, Eckel RH, Franklin BA, et al. Diagnosis and management of the metabolic syndrome: an American Heart Association/National Heart, Lung, and Blood Institute Scientific Statement. Circulation 2005; 112(17):2735-2752.
34. Park E, Choi SJ, Lee HY. The prevalence of metabolic syndrome and related risk factors based on the KNHANES V 2010. J Agric Med Community Health 2013;38(1):1-13 (Korean).
35. Sayer AA, Syddall HE, Dennison EM, Martin HJ, Phillips DI, Cooper C, et al. Grip strength and the metabolic syndrome: findings from the Hertfordshire Cohort Study. QJM 2007;100(11): 707-713.
36. Gaster M, Vach W, Beck-Nielsen H, Schrøder HD. GLUT4 expression at the plasma membrane is related to fibre volume

in human skeletal muscle fibres. APMIS 2002;110(9):611-619.
37. Roubenoff R. Sarcopenic obesity: the confluence of two epidemics. Obes Res 2004;12(6):887-888.
38. Roubenoff R. Catabolism of aging: is it an inflammatory process? Curr Opin Clin Nutr Metab Care 2003;6(3):295-299.
39. Tanimoto Y, Watanabe M, Sun W, Sugiura Y, Tsuda Y, Kimura M, et al. Association between sarcopenia and higher-level functional capacity in daily living in community-dwelling elderly subjects in Japan. Arch Gerontol Geriatr 2012;55(2):e9-e13.
40. Tieland M, Dirks ML, van der Zwaluw N, Verdijk LB, van de Rest O, de Groot LC, et al. Protein supplementation increases muscle mass gain during prolonged resistance-type exercise training in frail elderly people: a randomized, double-blind, placebo-controlled trial. J Am Med Dir Assoc 2012;13(8):713-719.