Prevalence of sarcopenia and sarcopenic obesity in Korean adults:

The Korean Sarcopenic Obesity Study (KSOS)

Tae Nyun Kim[1], Sae Jeong Yang[1], Hye Jin Yoo[1], Kang Il Lim[1], Hyun Joo Kang[2], Wook Song[3], Ji A Seo[1], Sin Gon Kim[1], Nan Hee Kim[1], Sei Hyun Baik[1], Dong Seop Choi[1], Kyung Mook Choi[1]

[1]Division of Endocrinology and Metabolism, Department of Internal Medicine, Korea University College of Medicine, Seoul, Korea, [2]Sports Medicine, Division of Physical Education, Soonchunhyang University, A-San, Korea, [3]Health and Exercise Science Laboratory, Institute of Sports Science, Department of Physical Education, Seoul National University, Seoul, Korea

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Address all correspondence and requests for reprint to: Dr. Kyung mook Choi, Division of Endocrinology and Metabolism, Department of Internal Medicine, Korea University Guro Hospital, 80 Guro-Dong, Guro-Gu, Seoul 152-050, Korea. E-mail: medica7@gmail.com, Tel.: 822-2626-3043, Fax: 822-2626-1096

Abstract

Context: Sarcopenic obesity (SO), a combination of excess weight and reduced muscle mass and/or strength, is suggested to be associated with an increased risk of adverse health outcomes.

Objectives: To examine the prevalence and characteristics of Sarcopenic and SO defined by using different indices such as Appendicular Skeletal muscle Mass (ASM)/height^2 and Skeletal Muscle Index (SMI (%): skeletal muscle mass (kg)/weight (kg) × 100) for Korean adults.

Methods: 591 participants were recruited from the Korean Sarcopenic Obesity Study (KSOS) which is an ongoing prospective observational cohort study. Analysis was conducted in 526 participants (328 women, 198 men) who had complete data on body composition using Dual X-ray absorptiometry and computed tomography.

Results: The prevalence of sarcopenia and SO increases with aging. Using two or more standard deviations (SD) of ASM/height^2 below reference values from young, healthy adults as a definition of sarcopenia, the prevalence of sarcopenia and SO was 6.3% and 1.3% in men and 4.1% and 1.7% in women over 60 years of age. However, using two or more SD of SMI, the prevalence of sarcopenia and SO was 5.1% and 5.1% respectively in men and 14.2% and 12.5% respectively in women. As defined by SMI, subjects with SO had 3 times the risk of metabolic syndrome (OR = 3.03, 95% confidence interval (CI) = 1.26-7.26) and subjects with non-sarcopenic obesity had approximately 2 times the risk of metabolic syndrome (OR = 1.89, 95%

CI = 1.18-3.02) compared with normal subjects.

Conclusion: Obese subjects with relative sarcopenia were associated with a greater likelihood for metabolic syndrome. As Koreans were more obese and aging, the prevalence of SO and its impact on health outcomes are estimated to be rapidly grow. Further research is requested to establish the definition, cause and consequences of SO.

Introduction

The epidemiological trends that represent our generation are the obesity epidemic and the aging of the population (1). Aging promotes a progressive loss of muscle mass and strength called sarcopenia from Greek for 'poverty of flesh' (2). Sarcopenia leads to functional impairment and physical disability (3). Moreover, aging and physical disability due to sarcopenia are also related with an increase in visceral obesity which is an important factor in the development of metabolic syndrome and cardiovascular disease (4). Therefore, sarcopenia and visceral obesity in the elderly may synergistically increase their effect on physical disability, metabolic disorders, cardiovascular disease and mortality (5). Combination of excess body fat and reduced muscle mass and/or strength with aging was recently defined as sarcopenic obesity (SO). Surplus energy intake, physical inactivity, low-grade inflammation and changes of hormones such as growth hormone and testosterone may be all related to the development of SO (5). Since the obese elderly population is continuously increasing, the impact of SO is estimated to be dramatic in the next decade (2).

Korea is rapidly becoming a society with an elderly population as in other developed countries. According to Korea National Statistical Office, 7.2% of the Korean population was aged 65 and older (percentage of elderly) in 2000. The percentage is expected to rise to 19.1% in 2025, and 34.4% in 2050 (6). The speed at which Korea is becoming an older, aged society is

unprecedented among the other OECD countries. Therefore, the research of SO is essential for

the development of public health programs for the elderly Korean population.

Several definitions of sarcopenia and SO have already been proposed in western countries.

Baumgartner et al. defined sarcopenia as reduction in appendicular skeletal muscle mass (ASM)

divided by height squared (ASM/height^2) of two standard deviations or more below the normal

means for younger reference group measured using Dual X-ray Absorptiometry (DXA). They

reported that the prevalence of SO was 4.4% in men and 3.0% in women over 60 years of age in

the New Mexico Aging Process Study (7). In community-dwelling elderly women in Verona,

Zoico et al. reported that the prevalence of SO was 12.4% defining SO as the two lower

quintiles of muscle mass plus two higher quintiles of fat mass (8). Using the same definition,

Davison et al. reported that the prevalence of SO was 9.6% in men and 7.4% in women from the

bioelectrical impedance analysis (BIA) data of NHANES III (9). In addition, Janssen et al.

proposed the definition of sarcopenia as skeletal muscle index (SMI (%); skeletal muscle mass

(kg)/weight (kg) × 100) of one or two standard deviations below the mean for the younger

reference group although they did not examine the prevalence of SO (3). Recently, Newman et

al. proposed the new criteria for sarcopenia based on the amount of lean mass being lower than

expected for a given amount of fat mass using residuals from linear regression models (10). In

most of previous studies for SO, obesity was defined as the two highest quintiles of total body

fat mass obtained using DXA (8, 9). The prevalence of SO may vary depending on the criteria,

reference populations and definition used.

In spite of the growing importance of SO, only a few studies evaluating the definition and

prevalence of SO was performed in Caucasian populations and there have been no previous

studies in non-Caucasian populations. Furthermore, there was very scanty report about

relationship between SO and metabolic disorders. Therefore, we examined the prevalence of

sarcopenia and SO using different definitions in Korean adults. In addition, according to SO as

defined by different indices such as ASM/height^2 and SMI, we compared the anthropometric

and metabolic parameters, and explored the association between SO and metabolic syndrome.

Materials and methods

Subjects

This study is part of the Korean SO Study (KSOS) which is an ongoing epidemiologic study supported by Korea Science and Engineering Foundation (KOSEF). This is a prospective observational cohort study enrolled between September 2007 and August 2008, and a total of 591 healthy volunteers aged 20-88 years old were recruited from residents in Seoul, Korea. The KSOS was planned to examine the prevalence of SO in Korean adults and to evaluate the effect of SO on metabolic disorders and likely health outcomes. All participants were apparently healthy and had no history of cardiovascular disease (myocardial infarction, unstable angina, stroke or cardiovascular revascularization), any type of diabetes, stage 2 hypertension (resting blood pressure, $\geq 160/100$ mmHg), malignant disease or severe renal or hepatic disease. Subjects taking medications that might affect body weight or body composition were excluded. Analysis was conducted on 526 participants (328 women, 198 men) who had complete data on body composition. Among them, young healthy volunteers (aged 20-40; 145 subjects; 54 men, 91 women) were considered as the sex-specific young reference group. All participants provided written informed consent and the Korea University Institutional Review Board, in accordance with the Declaration of Helsinki of the World Medical Association, approved this study protocol.

Anthropometric and laboratory measurements

BMI was calculated as weight in kilograms divided by the square of the height in meters. Waist circumference was measured at the midpoint between the lower border of the rib cage and iliac crest. All blood samples were obtained in the morning after a 12-hour overnight fast, and were immediately stored at -80 °C for subsequent assays. Serum triglycerides and HDL cholesterol were determined enzymatically using a chemistry analyzer (Hitachi 747; Tokyo, Japan). A glucose oxidase method was used to measure plasma glucose.

Definition of metabolic syndrome

Metabolic syndrome was defined based on the National Cholesterol Education Program's ATP-III (11) definition. In the present study, we used the definition of abdominal obesity recommended by the WHO Western Pacific Region which is a waist circumference ≥90 cm in males and ≥80 cm in females.

Computed tomography

Abdominal visceral fat area (VFA), subcutaneous fat area (SFA) and mid-thigh muscle area (MTMA) were measured with computed tomography (CT) scans (Brilliance 64, Philips Medical

Systems; Cleveland, Ohio). With the subject in the supine position, a 3-mm CT slice scan was acquired at the L4 to L5 level to measure VFA and total abdominal fat area (TFA). Cross-sectional surface area (in cm^2) of different abdominal fat compartments was calculated at this slice using a commercially available CT software (Rapidia 2.8; INFINITT, Seoul, Korea), which determined adipose tissue area electronically by setting the attenuation values for a region of interest within a range of -190 to -30 Hounsfield units. VFA was quantified by determining the intra-abdominal cavity at the internal aspect of the abdominal and oblique muscle walls surrounding the cavity and the posterior aspect of the vertebral body. SFA was calculated by subtracting VFA from TFA. A cross-sectional scan of the same thickness was obtained for the left thigh halfway between the pubic symphysis and the inferior condyle of the femur as described previously and skeletal muscle areas fell within a range of 0 to 100 HU (12).

VFA to MTMA ratio (VMR) were calculated by dividing the VFA by MTMA respectively (13).

Dual-energy x-ray absorptiometry and bioelectrical impedance analysis

A Whole body DXA scan was performed to measure total and regional lean mass (kg) and total body fat (kg) and total body fat percentage (%) using fan-beam technology (Hologic Discovery A, Hologic; Bedford, MA, USA). ASM was calculated as the sum of skeletal muscle in arms and legs (14). Total skeletal muscle mass (kg) was obtained from ASM by using the

predictive equation of Kim et al (15). SMI (%) was obtained by the total skeletal muscle mass

adjusted by weight as described by Janssen et al (3). Bioelectrical impedance analysis using the

Inbody 3.0 (Biospace, Seoul, Korea) was used to estimate total body water and free fat mass

(FFM) by measuring the resistance of the body to a small alternating electric current.

Definitions of sarcopenia and sarcopenic obesity

First, sarcopenia was defined as the ASM/height^2 less than two standard deviations (SD)

below the sex-specific normal mean for younger reference group (7) or the two lower quintile in

all of the study population (8, 9). Alternatively, sarcopenia was defined as the SMI of two

standard deviations below the sex-specific mean value for young reference group from the

entire study population (3). Lastly, residual method was defined as the reference values the sex-

specific lower 20% of the distribution of residuals between measured ASM and ASM which is

predicted by linear regression analysis used to model the relationship between ASM as a

dependent variable, and age, height (meters) and total fat mass (kg) as the independent variables

(10). A positive residual means a relatively muscular individual, whereas negative residual is

indicative of a relatively sarcopenic individual (16).

Obesity was defined as values greater than the median total fat percentage for each sex (7) or

the upper two quintiles for total body fat percentage of the study population (8, 9). SO was

defined as high total body fat percentage plus low relative skeletal muscle mass in the same

subjects according to other previous studies (7-9). We classified four sarcopenia/obesity groups

using the criteria that SMI of 2SD below the value of the young reference group plus upper two

quintiles for total body fat percentage. The four groups included normal body fat and muscle

mass, sarcopenia (and normal body fat), obesity (and normal muscle mass) and SO.

Statistical analysis

Data are expressed as the mean ± SD or median and inter-quartile range (25%-75%) or as

percentage. Differences between groups were tested using a Student *t*-test or the Mann-Whitney

U test, and the Chi-square test was used to test for differences in the distribution of categorical

variables. Each variable was examined for normal distribution and any positively-skewed

variables were log transformed. Odds ratio (OR) (95% CI), predicting metabolic syndrome

based on different indices for SO, were obtained from logistic regression models after

controlling for potential covariates like gender and age. A *P-v*alue <0.05 was considered

statistically significant in all analyses. All statistical results were based on two-sided tests. Data

were analyzed using SPSS for Windows (Version 12.0; SPSS Inc.; Chicago, IL, USA).

Results

The characteristics of the study population

The characteristics of the all study subjects (20-88 years, n = 526) and young reference group (age 20-40 years, n=145) are detailed in Table 1. When men were compared with women, age, anthropometric indicators such as height, weight, BMI, visceral fat area (VFA), thigh muscle area (TMA), total lean body mass (LBM), ASM, ASM/height^2 and SMI were all greater in men than women. Total body fat percentage and HDL-cholesterol were significant greater in women. There were no differences between men and women for the subcutaneous fat area (SFA) and LDL-cholesterol.

Cut-off points for sarcopenia and obesity

For men, the cut-off values for sarcopenia were 7.40 kg/m^2 (ASM/height^2) and 35.71% (SMI) defined as less than 2SD below the sex-specific normal mean for the young reference group. For women corresponding limits were 5.14 kg/m^2 (ASM/height^2) and 30.70% (SMI). The cut-off values for the lower two quintile for the distribution of ASM/height^2 in our population were 8.81 kg/m^2 in men and 7.36 kg/m^2 in women, respectively. To calculate the cut-off value for the residual method, we first established the model of predicted ASM using multiple linear regression analysis by adjusting for height and total fat mass. Sex-specific equations were predicted as ASM (kg) = -31.23 + 32.84 x height (m) + 0.24 × total fat mass (kg) for the men

and predicted as ASM (kg) = -19.10 + 21.65 x height (m) + 0.20 × total fat mass (kg) for the women. As a result, sex-specific cut-off points of the lower 20% of distribution of residuals were -1.87 for the men and -1.62 for the women.

The cut-off values of obesity defined as the two highest quintiles of the total body fat percentage were 20.21% for the men and 31.71% for the women, respectively. These cut-off values for obesity in both men and women approximately corresponded to a BMI of 25 kg/m^2 according to a previous Korean study (17).

Prevalence of sarcopenia

The prevalence of sarcopenia in Korean men and women was estimated using four different methods (Table 2). When we used a cut-off point of 2 SD for ASM/height^2 in the young reference group to define sarcopenia, the prevalence in Korean men and women aged more than 60 years was 6.3% and 4.1%, respectively. When the cut-off point for sarcopenia was used as the lower two quintiles for ASM/height^2, the prevalence of sarcopenia was much higher in both men and women (54.4% and 40.5%, respectively). Using the lowest 20th percentile of the residuals for ASM adjusted fat mass and height, the prevalence of sarcopenia in men and women of all ages was distributed evenly. When we used cutoff point of 2 SD for SMI in young reference group to define sarcopenia, the prevalence in the Korean men and women aged more

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than 60 years was 5.1% and 14.2%, respectively.

Prevalence of sarcopenic obesity

The prevalence of SO in Korean men and women was estimated using three different

methods (Table 3). When we used a cut-off point of 2 SD for ASM/height^2 plus the median of

the total body fat percentage to define SO (Baumgartner's method), the prevalence in Korean

men and women aged more than 60 years in the KSOS was 1.3% and 0.8%. These results might

be seen through the gender difference of age-related body compositional changes. Interestingly,

the loss in appendicular skeletal muscle was greater in men than in women whereas intra-

abdominal fat accumulation in women was greater than in men with aging (Fig. 1). The

prevalence of SO (as defined by Zoico et al.) was higher in both women and men when using

Zoico's method than by using other methods and was much higher especially in elderly men.

When we use the new definition of SO (below -2SD of SMI plus two higher quintile of total

body fat percentage), the prevalence of SO was 5.1% in men age 60 or older and 12.5% in

women over 60 years of age.

Comparison of SO defined by ASM/height^2 index and SMI index

Table 4 displays the characteristics of women classified with SO using two different methods.

Women subjects identified with SO using Zoico's method were of similar age, BMI and metabolic parameters but significantly had other different body compositional parameters when compared with normal subjects. The SO group by the SMI index was older, fatter and had a greater number of metabolic risk factors than the normal group. The prevalence of metabolic syndrome was also higher in the SO group defined by the SMI index compared to the normal group (Fig 2). Although men had a lower occurrence of SO in the population, the characteristics of the two different SO groups in men mostly showed similar trends to those in the women participants.

Odds ratio from logistic regression models predicting metabolic syndrome, based on different indices for SO

Association between metabolic syndrome and ASM/height^2 or SMI indices was shown in Table 5. A low SMI was associated with greater presence of metabolic syndrome among men and women age 40 and older. When SO was defined using ASM/height^2 index, subjects with SO did not show a significantly increased risk of metabolic syndrome compared to normal subjects. However, using the SMI index, subjects with SO had 3 times the risk of metabolic syndrome (OR = 3.03, 95% confidence interval (CI) = 1.26-7.26) and subjects with non-sarcopenic obesity had approximately 2 times the risk of metabolic syndrome (OR = 1.89, 95%

CI = 1.18-3.02) compared with normal subjects after adjustment for age and gender.

Discussion

The present study examined the prevalence of sarcopenia and SO in Korean men and women using different criteria. There was an apparent discrepancy of prevalence according to definition of sarcopenia.

In the New Mexico Aging Process Study (NMAPS) and New Mexico Elderly Health Survey (NMEHS), it was first described by Baumgartner that the prevalence of SO in participants aged 60 years and over was 3.0% of women and 4.4% of men, respectively. The prevalence increases from about 2% in participants 60 to 69 years of age to 10% in those over 80 years (7). The prevalence of SO in people aged 60 and older from KSOS were very low as based on Baumgartner's definition. There could be several reasons for low prevalence in the present study. First, participants in our study were younger (mean age 66.1 years) and fatter (BMI 24.5 kg/m^2) than those in the Baumgartner's study. Second, although the cut-off point of ASM/height^2 of the young reference group are similar in men (18, 19), the cut-off point of ASM/height^2 in women of the present study is 5% lower compared with previous study based on Caucasian population (20). Third, there was a relatively small difference of muscle mass between young and elderly Korean women. Especially, in Korean women, aging was well

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associated with increased visceral fat accumulation rather than loss of skeletal muscle mass.

An alternative definition of SO was subsequently suggested by Davison et al. (9) and Zoico et al. (8), who defined SO by combination the upper two quintiles of total fat percentage and lower two quintile of ASM/height^2. When Zoico's definition of SO was used, the prevalence in participants aged more than 60 years were 16.5% of women and 20.3% of men in the present study. Cut-off point (7.3 kg/m^2) in ASM/height^2 for women in the present study was higher than 5.7 kg/m^2 in Zoico's study and 6.5 kg/m^2 in Davison's study. Although cut-off points (8.81 kg/m^2) in ASM/height^2 for men in the present study was similar to that (9.11 kg/m^2) in Davison's study, Cut-off point (20.21%) in total body fat percentage for men was much lower than that (37.17%) in their study. It was maybe due to racial difference between Asian and Caucasian and relatively younger study population included in this study.

ASM/height^2 index is highly correlated with BMI (r = 0.74; P <0.001) as current criterion of obesity after adjusting for age and gender. Thus, this index primarily identified thin people as sarcopenic and could have a limitation of underestimating sarcopenia in overweight or obese subjects (16). To overcome this limitation, criteria for the sarcopenia proposed by Newman et al. are based on residuals (ASM adjusted for height and body mass) and the 20th percentile of the distribution of residuals was used as the cut-off point for sarcopenia. Newman et al. observed that 11.5% of men and 14.4% of obese (BMI >30kg/m^2) women were defined as being

sarcopenic using the method of residual. Using the lower 20% of residual, the prevalence of

sarcopenia in the present study was 22.3% for women and 15.4% for men age 60 and over. In

addition, Janssen et al. proposed to convert absolute skeletal muscle mass (kg) to percentage

skeletal muscle mass (SMI) (10). Using the cut-off points of 2SD below the mean for SMI for

the young reference group, the prevalence of sarcopenia in people age 60 and over was 14.2% in

women and 5.1% in men in the present study. These results were similar to the Janssen's study

where the prevalence for sarcopenia was 10% in women and 7% in men. Newman's or Janssen's

definition can classify sarcopenia across the entire weight range of a person from thin to obese

although there is no previous study describing the prevalence of SO using these definitions of

sarcopenia. If residuals or SMI indices were adopted to identify individuals with sarcopenia, the

prevalence of sarcopenia is expected to be higher especially in those who are obese or are

women when compared to the ASM/height^2 index.

Despite many obese persons with low muscle mass in relation to body weight have disability

and cardio-metabolic risk factors (10, 21), ASM/height^2 index does not identify most obese

people with sarcopenia. Thus, by using the SMI of 2SD below the value of the young reference

group (Janssen's index) and the upper two quintiles for the total body fat percentage (Zoico's

index), we present a new definition of SO. It may be enough to assume that subjects with SO

may lead to more functional limitations as well as to more metabolic disorders than lean

sarcopenic or non-sarcopenic obese individuals (22). Only a few studies have evaluated the combined effect of sarcopenia and obesity on the physical function and metabolic abnormality.

In NAMPS and NMEHS, Baumgartner et al. first described that there is an association between low relative muscle mass (ASM/height^2) and functional impairment and disability (7, 20). Longitudinal results from the NMAPS showed that subjects with SO at the baseline were two or three times more likely to develop instrumental disability during the 8-year follow-up period than lean sarcopenic or non-SO individuals (23). However, Zoico et al. showed that high body fat and high BMI values rather than low muscle mass were associated with functional limitation. Furthermore, they reported that among the different indices of sarcopenia, only SMI predicted functional impairment and disability (8). The association between SO and metabolic abnormalities remains unknown. In the cross sectional analysis of the NMAPS, the prevalence of the metabolic syndrome was highest in the group of non-sarcopenic obese subjects followed by that of SO subjects and was the lowest in the sarcopenic non-obese subjects (22). In the present study, we found that subjects with SO had significant increase in the number of components of metabolic syndrome compared to normal subjects. Furthermore, SO was independently associated with metabolic syndrome (OR =3.03, 95% CI = 1.26-7.26) after an adjustment for age and gender. Considering the increased morbidity and mortality in patients with metabolic syndrome (24), these results might be a basis for the future study of health

outcome in patients with SO.

It is likely that the loss of muscle mass and reduced strength (sarcopenia) causes reduced physical activity during aging. A reduction in muscle mass and physical activity levels decrease total energy expenditure which results in accumulation of fat mass especially visceral fat (2, 25). Along with visceral fat accumulation, loss of skeletal muscle which is the largest insulin-responsive target tissue produces insulin resistance which promotes metabolic syndrome. Moreover, increase in visceral fat may lead to augmented secretion of pro-inflammatory adipokines that further promote insulin resistance as well as potentially a direct catabolic effect on muscles. Thus, a vicious circle between muscle loss and fat gain may lead to more sarcopenia and then to further fat gain and inflammation (22). Subjects with SO, defined by Zoico's method, had similar BMI and metabolic parameters whereas subjects with SO defined by the new method using SMI index were associated with higher numbers of metabolic risk factors than normal subjects. Therefore, the definition of SO using SMI instead of ASM/height[2] might be more useful in examining the relationship between SO and metabolic syndrome in Korean adults.

Our study has several limitations that must be considered. First, the cross-sectional nature of this study precluded our ability to identify any cause-effect relationships. Second, all participants in the present study were relatively healthy, well-functioning men and women and

participants who had disabilities were excluded. Therefore, the present study may have underestimated the prevalence of SO. However, as the NMAPS cohort is composed of volunteers with relatively good health, we planned to explore the longitudinal effect of SO on metabolic abnormalities in conditions excluding other diseases in the present study.

In summary, we examined the prevalence of sarcopenia and SO in Korean men and women and found considerable difference of prevalence for sarcopenia and SO according to which definition is used. We found a significant association between SMI quintile and metabolic syndrome. In addition, our study showed that subjects with SO were associated with a greater likelihood of metabolic syndrome. Considering that the Korean population has become more and more obese and has aged during the past few decades, the prevalence of SO and its impact on health outcomes are estimated to be rapidly increasing in the near future. Further research is needed to establish the definition, cause and consequences of SO.

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Figure Legend

Fig. 1. Relationship between age and appendicular skeletal muscle mass (A; men: r= -0.529, P <0.001, women: r= -0.165, P = 0.003) or visceral fat area (B; men: r= 0.128, P = 0.077, women: r= 0.558, P <0.001) in the study subjects

Fig. 2. The difference of prevalence of the metabolic syndrome between subjects with sarcopenic obesity and normal subjects classified using two different definitions of sarcopenic obesity

Table 1. Clinical, anthropometric and metabolic characteristics of all study subjects (n = 526) and young reference subjects (n = 145)

	All study subjects			Young reference group		
	Men (n=198)	Women (n=328)	p	Men (n=54)	Women (n=91)	p
Age (years)	52.2 ± 14.4	51.2 ± 14.8	0.411	33.9 ± 5.2	31.2 ± 6.6	0.014
Anthropometry						
Height (cm)	170.0 ± 6.8	156.7 ± 5.6	<0.001	175.1 ± 5.9	160.2 ± 5.2	<0.001
Weight (kg)	73.1 ± 12.0	58.6 ± 9.2	<0.001	80.5 ± 13.9	57.6 ± 10.8	<0.001
BMI (kg/m^2)	25.2 ± 3.1	23.9 ± 3.7	<0.001	26.2 ± 3.1	22.4 ± 4.0	<0.001
Waist circumference (cm)	89.6 ± 7.9	82.3 ± 8.6	<0.001	92.0 ± 9.1	80.0 ± 10.0	<0.001
Metabolic parameters						
Systolic BP (mmHg)	125.9 ± 12.4	119.9 ± 13.9	<0.001	123.6 ± 12.2	110.2 ± 11.8	<0.001
Diastolic BP (mmHg)	82.9 ± 9.8	77.3 ± 9.9	<0.001	81.2 ± 9.6	71.7 ± 8.2	<0.001
Total cholesterol (mmol/L)	4.8 (4.1, 5.2)	4.8 (4.2, 5.4)	0.314	4.8 (4.2, 5.3)	4.3 (3.8, 4.7)	0.011
Triglyceride (mmol/L)	1.5 (1.1, 2.2)	1.1 (0.8, 1.6)	<0.001	1.7 (1.2, 3.0)	0.8 (0.6, 1.1)	<0.001
HDL cholesterol (mmol/L)	1.3 (1.0, 1.5)	1.5 (1.3, 1.7)	<0.001	1.3 (1.1, 1.5)	1.5 (1.3, 1.8)	<0.001
LDL cholesterol (mmol/L)	2.6 (2.0, 3.0)	2.6 (2.2, 3.3)	0.059	2.5 (1.9, 3.1)	2.2 (1.9, 2.7)	0.179
Fasting glucose (mmol/L)	5.5 ± 1.2	5.2 ± 0.8	0.001	5.2 ± 0.6	4.9 ± 0.4	<0.001
Computed tomography (CT)						
VFA (cm^2)	141.6 ± 59.8	103.1 ± 54.0	<0.001	130.1 ± 50.2	61.8 ± 33.4	<0.001
SFA (cm^2)	143.0 ± 69.9	192.2 ± 80.6	<0.001	183.9 ± 96.7	182.5 ± 80.0	0.926
MTMA (cm^2)	144.2 ± 33.4	97.3 ± 23.5	<0.001	162.5 ± 18.9	102.2 ± 20.0	<0.001
VMR	0.9 ± 0.4	1.0 ± 0.5	0.117	0.8 ± 0.3	0.6 ± 0.3	<0.001
Bioelectrical impedance analysis (BIA)						
Total body fat percentage (%)	21.3 ± 5.0	29.6 ± 6.2	<0.001	22.8 ± 5.6	28.3 ± 6.4	<0.001
Total body fat mass (kg)	16.1 ± 6.0	18.1 ± 6.1	<0.001	19.0 ± 7.9	17.1 ± 6.6	0.0128
Total lean body mass (kg)	54.7 ± 7.4	39.3 ± 4.2	<0.001	58.7 ± 7.4	39.3 ± 5.2	<0.001
Dual Energy X-ray Absorptiometry (DXA)						
ASM (kg)	27.0 ± 4.4	18.5 ± 2.6	<0.001	29.9 ± 3.4	18.7 ± 3.2	<0.001
ASM/height^2 (kg/m^2)	9.2 ± 1.3	7.6 ± 0.8	<0.001	9.8 ± 1.2	7.3 ± 1.1	<0.001
SMI (%)	37.0 ± 3.2	31.8 ± 3.3	<0.001	43.6 ± 3.9	37.7 ± 3.5	<0.001

Body mass index, BMI; Total fat area, TFA; Visceral fat area, VFA; Subcutaneous fat area, SFA; MTMA, Mid-thigh muscle area; VMR, VFA/MTMA ratio; ASM, Appendicular skeletal muscle.

Table 2. Prevalence (%) of Sarcopenia using ASM/height^2, SMI and residual methods

Indices of Sarcopenia	ASM/height^2 below 2 SD (Baumgartner et al.)	ASM/height^2 2 lower quintile (Zoico et al.)	Residual 20th percentile (Newman et al.)	SMI Below 2 SD (Janssen et al.)
Men				
40-59 (n=72)	2.8	23.6	19.4	1.4
≥ 60 (n=79)	6.3	54.4	15.4	5.1
Women				
40-59 (n=120)	2.5	39.5	15.1	4.2
≥ 60 (n=121)	4.1	40.5	22.3	14.2

ASM ; appendicular skeletal muscle, SMI ; skeletal muscle index, SD ; standard deviation

Table 3. Prevalence (%) of sarcopenic obesity using the different indices

Indices of SO	-2SD of ASM/height^2 plus Median of total body fat percentage (Baumgartner et al.)	2 lower quintile of ASM/height^2 plus 2 higher quintile of total body fat percentage (Zoico et al.)	-2SD of SMI plus 2 higher quintile of total body fat percentage (New index of the present study)
Men			
40-59 years (n=72)	2.8	9.7	1.4
≥ 60 years (n=79)	1.3	20.3	5.1
Women			
40-59 years (n=120)	0.8	11.8	3.3
≥ 60 years (n=121)	0.8	16.5	12.5

ASM ; appendicular skeletal muscle, SMI ; skeletal muscle index, SD ; standard deviation, SO ; sarcopenic obesity

Table 4. Clinical, anthropometric and metabolic characteristics of sarcopenic obesity defined using different indices in women participants

	2 lower quintile of ASM/height^2 plus 2 higher quintile of total body fat percentage		*p*	-2SD of SMI plus 2 higher quintile of total body fat percentage		*p*
	Normal (n=118)	SO (n=31)		Normal (n=128)	SO (n=19)	
Age (years)	58.1 ± 9.4	61.0 ± 10.4	0.165	57.7 ± 9.2	63.5 ± 6.3	0.003
Anthropometry						
Height (cm)	154.8 ± 4.7	155.2 ± 4.1	0.624	155.6 ± 5.6	153.2 ± 4.4	<0.001
Weight (kg)	56.6 ± 5.6	57.0 ± 4.8	0.698	54.8 ± 5.9	68.9 ± 12.0	0.001
BMI (kg/m^2)	23.6 ± 2.1	23.6 ± 1.7	0.942	22.7 ± 2.4	29.3 ± 4.5	<0.001
Waist circumference (cm)	80.5 ± 5.8	83.7 ± 5.1	0.004	79.3 ± 6.8	92.2 ± 8.9	<0.001
Metabolic parameters						
Systolic BP (mmHg)	123.2 ± 13.0	123.1 ± 11.2	0.969	120.8 ± 12.5	126.2 ± 12.4	0.090
Diastolic BP (mmHg)	79.0 ± 12.3	78.4 ± 8.1	0.758	78.5 ± 10.9	78.7 ± 6.0	0.902
Total cholesterol (mmol/L)	5.0 (4.5, 5.5)	5.3 (4.7, 5.6)	0.232	4.9 (4.3, 5.4)	5.2 (4.5, 5.6)	0.466
Triglyceride (mmol/L)	1.2 (0.9, 1.9)	1.5 (1.0, 1.7)	0.792	1.1 (0.8, 1.7)	1.4 (1.1, 1.7)	0.501
HDL cholesterol (mmol/L)	1.4 (1.3, 1.8)	1.4 (1.2, 1.7)	0.284	1.5 (1.3, 1.8)	1.3 (1.2, 1.6)	0.135
LDL cholesterol (mmol/L)	2.7 (2.3, 3.1)	3.1 (2.6, 3.5)	0.032	2.7 (2.3, 3.2)	3.0 (2.6, 3.5)	0.231
Fasting glucose (mmol/L)	5.4 ± 0.8	5.3 ± 1.1	0.837	5.3 ± 0.8	5.6 ± 1.3	0.315
Number of components of MetS	1.9 ± 1.4	2.0 ± 1.0	0.679	1.6 ± 1.3	2.5 ± 1.0	0.002
Prevalence of MetS (%)	30.9	34.3	0.829	23.4	52.6	0.012
Computed tomography (CT)						
VFA (cm^2)	104.5 ± 46.2	125.1 ± 42.2	0.025	98.1 ± 45.9	170.1 ± 60.4	<0.001
SFA (cm^2)	163.7 ± 55.8	199.2 ± 65.0	0.007	158.0 ± 53.9	287.0 ± 113.8	<0.001
MTMA (cm^2)	104.5 ± 11.0	90.7 ± 9.3	<0.001	99.6 ± 12.1	98.5 ± 18.1	0.811
VMR	1.0 ± 0.4	1.4 ± 0.4	<0.001	1.0 ± 0.4	1.7 ± 0.5	<0.001
Bioelectrical impedance analysis (BIA)						
Total body fat percentage (%)	27.0 ± 5.0	32.7 ± 3.5	<0.001	26.5 ± 5.1	38.1 ± 4.4	<0.001
Total body fat mass (kg)	15.8 ± 4.4	19.1 ± 3.0	<0.001	15.0 ± 4.1	27.0 ± 7.5	<0.001
Total lean body mass (kg)	39.6 ± 3.3	36.9 ± 2.4	<0.001	38.6 ± 3.4	40.4 ± 5.3	0.053
Dual Energy X-ray Absorptiometry (DXA)						
ASM (kg)	19.0 ± 1.7	16.4 ± 1.0	<0.001	18.1 ± 2.0	17.9 ± 2.6	0.611
ASM/height^2 (kg/m^2)	7.9 ± 0.5	6.8 ± 0.3	<0.001	7.5 ± 0.7	7.6 ± 1.0	0.542
SMI (%)	37.7 ± 2.6	32.1 ± 1.9	<0.001	37.2 ± 3.2	29.0 ± 0.9	<0.001

Body mass index = BMI; Total fat area = TFA; Visceral fat area = VFA; Subcutaneous fat area = SFA; Mid-thigh muscle area = MTMA; VFA/MTMA ratio = VMR; Appendicular skeletal muscle = ASM; SO = Sarcopenic obesity; MetS = metabolic syndrome.

Table 5. Odds ratio from logistic regression models predicting metabolic syndrome, based on total body fat percentage quintile, ASM/height^2 quintile, SMI quintile and sarcopenia/obesity grouping using two different indices
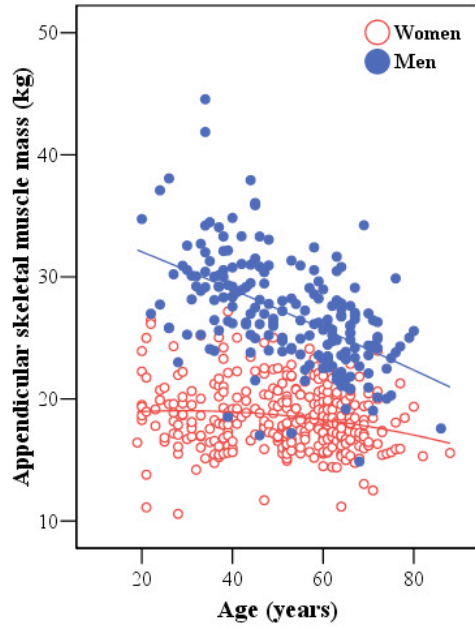
Characteristics (n = 392)		OR (95% CI)[a]
ASM/height^2 quintile		
Women	Men	
I (< 6.86 kg/m^2)	(< 8.37 kg/m^2)	0.20 (0.09-0.42)
II (6.87-7.36 kg/m^2)	(8.38-8.81 kg/m^2)	0.18 (0.09-0.39)
III (7.37-7.72 kg/m^2)	(8.82-9.37 kg/m^2)	0.43 (0.22-0.85)
IV (7.73-8.30 kg/m^2)	(9.38-10.06 kg/m^2)	0.68 (0.36-1.31)
V (> 8.31 kg/m^2)	(> 10.07 kg/m^2)	1.00
Sarcopenia/obesity group (by Zoico's method using ASM/height^2 index)		
Normal body fat and muscle mass		1.00
High body fat only		1.84 (1.08-3.15)
Low muscle mass only		0.27 (0.14-0.54)
SO		0.60 (0.30-1.21)
SMI quintile		
Women	Men	
I (< 32.40%)	(< 39.84%)	3.44 (1.60-7.38)
II (32.41-34.06%)	(39.85-41.47%)	2.50 (1.16-5.37)
III (34.07-35.78%)	(41.48-43.10%)	2.53 (1.18-5.41)
IV (35.79-37.87%)	(43.11-45.29%)	1.83 (0.84-3.99)
V (> 37.88%)	(> 45.30%)	1.00
Sarcopenia/obesity group (by New method using SMI index)		
Normal body fat and muscle mass		1.00
High body fat only		1.89 (1.18-3.02)
Low muscle mass only		6.05 (0.52-70.37)
SO		3.03 (1.26-7.26)

[a]Adjusted age and gender.

CI = confidence interval.

Fig. 1. Relationship between age and appendicular skeletal muscle mass (A; men: *r*= -0.529, *P* <0.001, women: *r*= -0.165, *P* = 0.003) or visceral fat area (B; men: *r*= 0.128, *P* = 0.077, women: *r*= 0.558, *P* <0.001) in the study subjects.
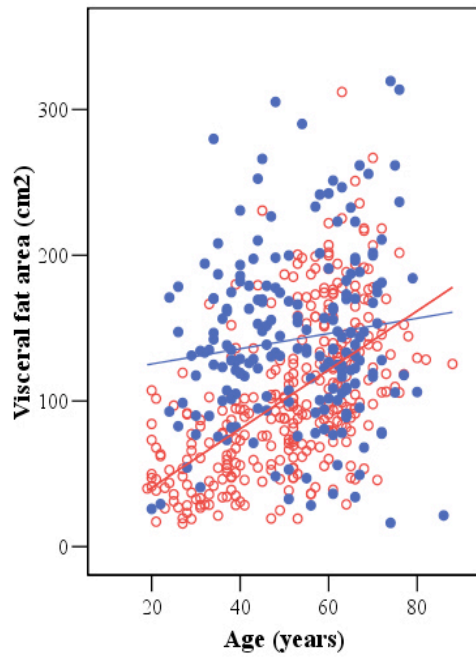
A.

B.

Fig. 2. The difference of prevalence of the metabolic syndrome between subjects with sarcopenic obesity and normal subjects classified using two different definitions of sarcopenic obesity