

## RESEARCH PAPER

# Weight-adjusted waist index reflects fat and muscle mass in the opposite direction in older adults

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## Abstract

**Background** Age-related changes in body composition include decreased muscle mass and preserved or increased fat mass. There is no anthropometric index to assess both muscle and fat mass.

**Methods** Using a cross-sectional sample of 602 participants aged  $\geq 65$  years from the Ansan Geriatric study, we evaluated the association of weight-adjusted waist index (WWI) with muscle and fat mass and compared these with body mass index (BMI) and waist circumference (WC). WWI was calculated as WC (cm) divided by the square root of body weight (kg). Body composition was measured using bioelectrical impedance analysis, dual-energy X-ray absorptiometry and abdominal computed tomography.

**Results** WWI positively correlated with total abdominal fat area (TFA) ( $r = 0.421$ ,  $P < 0.001$ ), visceral fat area (VFA) ( $r = 0.264$ ,  $P < 0.001$ ), and percentage of total tissue fat ( $r = 0.465$ ,  $P < 0.001$ ), but negatively correlated with appendicular skeletal muscle mass (ASM) ( $r = -0.511$ ,  $P < 0.001$ ) and ASM/height<sup>2</sup> ( $r = -0.324$ ,  $P < 0.001$ ). Mean ASM was highest in the first quartile of WWI (17.85 kg/m<sup>2</sup>) and showed a decreasing trend, with the lowest value in the fourth WWI quartile (13.21 kg/m<sup>2</sup>,  $P$  for trend  $< 0.001$ ). In contrast, mean TFA was lowest in the first quartile and highest in the fourth WWI quartile ( $P$  for trend  $< 0.001$ ). The probability of combined low muscle mass and high fat mass was  $> 3\times$  higher in the fourth WWI quartile than in the lowest quartile (odds ratio 3.22, 95% confidence interval 1.32–7.83).

**Conclusions** WWI is an anthropometric index positively associated with fat mass and negatively associated with muscle mass in older adults.

**Keywords:** low muscle mass, central obesity, anthropometric index, older people

## Key Points

- There has been no anthropometric index to assess fat and muscle mass.
- A new anthropometric index—weight-adjusted waist index (WWI) is calculated as  $WC/\sqrt{\text{weight}}$ .
- WWI is positively associated with fat mass and negatively associated with muscle mass.
- WWI is associated with a high probability of combined low muscle mass and high fat mass.

## Introduction

Sarcopenia is characterised by reduced muscle mass and strength and is primarily associated with the ageing process [1,2]. Cumulative evidence has indicated that sarcopenia is common in older people, and it is associated with age-related loss of physical function and increased morbidity and mortality [3–5]. Along with sarcopenia, age-related changes in body composition often include a progressive gain in body fat content, especially visceral fat [6,7]. Sarcopenia combined with excess body fat is referred to as sarcopenic obesity, which is now considered a common problem in older people and a medical condition related to physical disability, metabolic disorders and even cardiovascular morbidity and mortality [8–12].

Therefore, a simple and accurate measurement of muscle and fat mass is important to assess physical function and health-related outcomes; however, specific methods of measurement are needed. Computed tomography (CT) and magnetic resonance imaging are highly accurate methods for measuring regional muscle and fat areas [13]. Dual-energy X-ray absorptiometry (DXA) and bioelectrical impedance analysis (BIA) are useful for the comprehensive measurement of body composition [14]. However, these methods are limited in clinical practice because of the following reasons: expensive, time-consuming with the added risk of radiation exposure and lack of sensitivity to patient conditions [15–17]. Moreover, specific devices are required for these measurements. Some anthropometric indices such as mid-upper arm circumference, calf circumference and skinfold thickness have been proposed as alternative methods, especially for determining muscle mass; however, these methods have not been universally adopted [13,18].

Recently, we proposed a new anthropometric index, a weight-adjusted waist index (WWI) by standardising waist circumference (WC) with bodyweight [19]. Previously, we have reported that WWI could overcome the limitation of body mass index (BMI) or WC, which often showed an inverse relationship with mortality. Unlike BMI and WC, WWI showed a positive linear association with both cardiometabolic morbidity and mortality. Further, we found that WWI was directly proportional to age indicating that it may reflect the changes in body composition with ageing.

The aim of this study was to examine the relationship between WWI and body composition components including muscle and fat mass using a cross-sectional sample of a longitudinal population-based cohort of older people.

## Methods

### Study population

The Ansan Geriatric (AGE) study is a prospective, population-based cohort study of older people established in an urban area (Ansan City) in Korea. It was primarily designed to examine the health status, morbidity and related risk factors in older people aged  $\geq 60$  years. The first wave of

the study was accomplished with 1,391 participants (595 men and 796 women) between September 2004 and March 2006, and follow-up studies were conducted biannually. The second wave study included 841 subjects among those who participated in the first wave study. At second wave study, a random subset of 602 subjects (265 men and 338 women) underwent comprehensive body composition measurements including DXA, BIA and abdominal CT, which were analysed in the current study.

The demographic and medical information of the participants was obtained from an interviewer-administered questionnaire. Sociodemographic characteristics included age, sex, occupation, marital status and income. Lifestyle characteristics included smoking status (current, former and never), alcohol intake (current, former and never) and level of exercise (regular, less or never). The disease status of individuals including diabetes mellitus, hypertension, dyslipidemia, cardiovascular disease and mental disorders as well as the medication prescribed to the participants was noted. Details of the study protocol have been published previously [20].

### Anthropometric measurements

Anthropometric measurements were taken after an overnight fast. Height, body weight, BMI and WC of all participants were recorded. Height and body weight were measured to the nearest 0.1 cm and 0.1 kg, respectively. BMI was calculated as weight in kilograms divided by height in meters squared. WC was measured at the midpoint between the lower rib margin and the iliac crest in the standing position. WWI ( $\text{cm}/\sqrt{\text{kg}}$ ) was calculated as WC (cm) divided by the square root of weight (kg). WWI was developed from the derivation formula of WC standardised according to the body-weight [19]. Briefly, the formula was derived by standardising WC for body weight by the least squared regression of the logarithm-transformed WC on the logarithm-transformed body weight as given by  $\ln(\text{WC}) = \beta_0 + \beta_1 \ln(\text{weight}) + \varepsilon$ . Since the estimated  $\beta_1$  was 0.494 ( $\sim 0.5$ ), the final formula of WWI was  $\text{WC}/\sqrt{\text{weight}}$ . In this context, height was not involved in the formula formation of WWI, however, the correlation between height and WWI was  $-0.254$ , which was obtained by a previous study for half a million Korean people [19]. This implies that height is considered in WWI in an indirect way.

The institutional review board of the AGE Study approved this study protocol, and all participants provided written informed consent.

### Body composition measurements

Single-slice CT scanning (Brilliance 64; Philips, Cleveland, OH) was used to quantify the intra-abdominal fat area. The scans were conducted at 120 kV, with a slice thickness of 5 mm, at the level of the L4–5 vertebral interspace. The total intra-abdominal fat area (TFA) was delineated by manually tracing the muscle wall, and the visceral fat area (VFA) was defined as an area with an attenuation range between  $-190$

and –30 Hounsfield units. The subcutaneous fat area (SFA) was calculated as the TFA minus the VFA.

Total lean mass, total body fat mass, appendicular skeletal muscle mass (ASM) and percentage of total tissue fat were estimated using whole-body DXA (DPX-MD+; General Electric, Madison, WI). ASM was defined as the sum of fat-free soft tissue masses for the arms and legs. In addition, fat mass, skeletal muscle mass and percentage of body fat were obtained from BIA measurements.

Statistical analysis

All initial analyses were performed both in men and women, and subsequent analyses were performed separately in men and women. To identify the association between body composition measures and the three comparative anthropometric indices BMI, WC and WWI, correlation analyses were performed. Subsequently, the mean values of each muscle mass measurement (skeletal muscle mass by BIA, ASM and ASM/height<sup>2</sup> by DXA) and fat mass measurement (percentage of body fat by BIA, TFA, SFA and VFA by abdominal CT scan and percentage of total tissue fat by DXA) were compared across quartiles of WWI using one-way analysis of variance. Univariate and age-adjusted logistic regression analysis was conducted to identify the probability of combined low muscle mass and high fat mass according to WWI. In this analysis, low muscle mass was defined as ASM/height<sup>2</sup> < 6.49 kg/m<sup>2</sup> in men and < 5.39 kg/m<sup>2</sup> in women as referenced by the Korea Genome and Epidemiology study [21]. Obesity was defined based on two criteria: (i) VFA ≥ 100 cm<sup>2</sup> in both men and women or (ii) WC ≥ 90 cm and ≥80 cm in men and women, respectively, as referenced by the World Health Organization Asian standards. Statistical significance was considered as *P* < 0.05. All statistical analyses were performed using SPSS software version 20.0 (SPSS Inc., Chicago, IL).

Results

The characteristics of participants are shown in Table 1. The study participants comprised of 265 men and 338 women. The mean age was 72.1 (65–89) years; mean (±standard deviation, SD) BMI and WC were 24.6 ± 3.1 kg/m<sup>2</sup> and 89.3 ± 8.1 cm, respectively; and 47.3% and 17.1% had hypertension and diabetes mellitus, respectively. The mean (±SD) WWI value was 11.5 ± 0.8 cm/√kg. WWI values were distributed normally in a bell-shaped curve between 9.42 and 14.07 cm/√kg (Appendix Figure S1). The mean WWI increased with age in both men and women, whereas BMI and WC did not (Appendix Table S1).

Correlations between the anthropometric index and body composition

Correlation analyses were performed for the association between anthropometric indices and body composition

Table 1. Baseline characteristics of the participants (n=603)

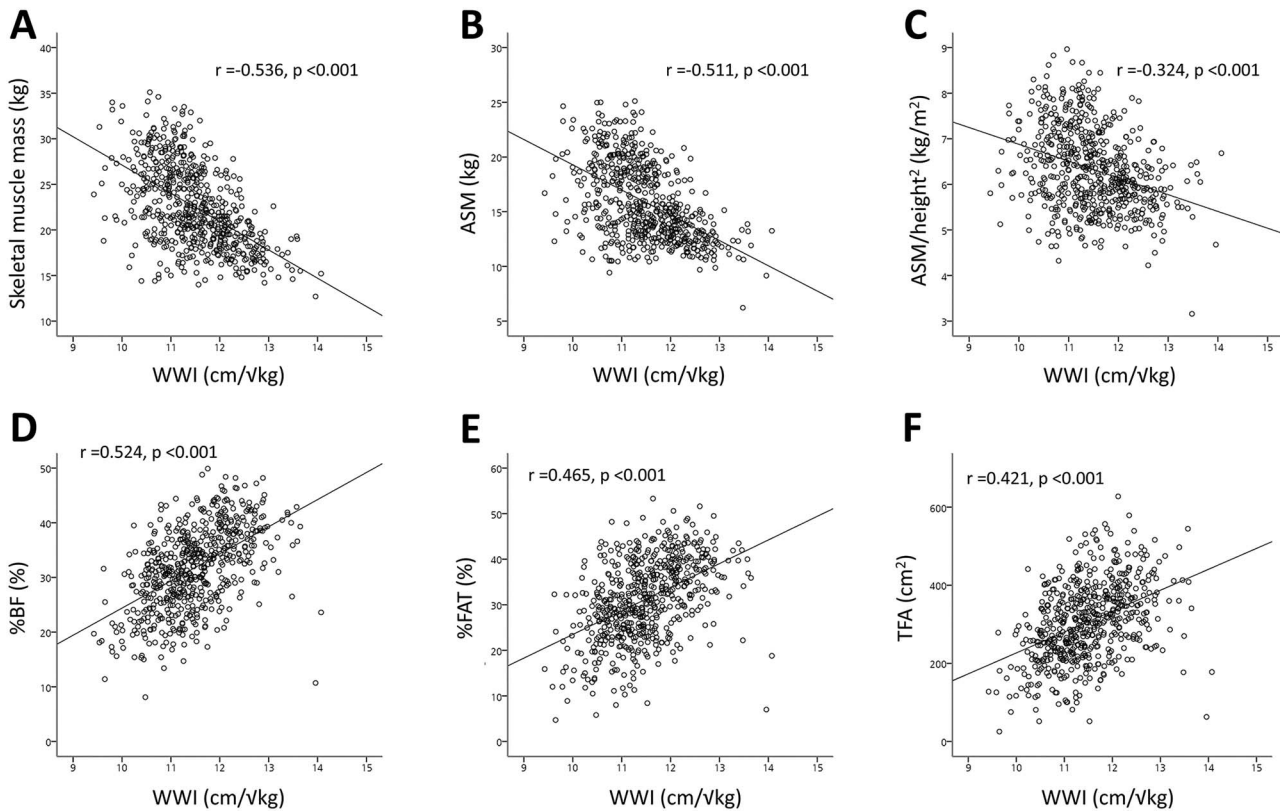
Variables	Data <sup>a</sup>
Age, y	72.1 (4.8)
Sex, n (%)	
Male	265 (43.9)
Female	338 (56.1)
Bodyweight, kg	61.1 (9.6)
Body mass index, kg/m <sup>2</sup>	24.6 (3.1)
Waist circumference, cm	89.3 (8.1)
Fasting glucose, mg/dl	102.2 (21.2)
Cholesterol, mg/dl	
Total	198.2 (36.6)
HDL	45.2 (10.6)
LDL	124.5 (33.0)
Triglyceride, mg/dl	142.6 (84.9)
Creatinine, mg/dl	0.96 (0.24)
Systolic blood pressure, mm Hg	132.3 (15.3)
Hypertension, n (%)	285 (47.3)
Diabetes mellitus, n (%)	103 (17.1)
Dyslipidemia, n (%)	57 (9.5)
Weight-adjusted waist index, cm/√kg	11.5 (0.8)
BIA measurements	
Fat mass, kg	19.5 (5.8)
Skeletal muscle mass, kg	22.5 (4.5)
Percent body fat	31.7 (7.4)
DXA measurements	
Percent of total tissue fat	31.2 (8.8)
ASM, kg	15.9 (3.6)
ASM/height <sup>2</sup> , kg/m <sup>2</sup>	6.3 (0.9)
CT measurements	
TFA, cm <sup>2</sup>	306.2 (98.9)
SFA, cm <sup>2</sup>	204.7 (70.5)
VFA, cm <sup>2</sup>	101.4 (44.2)

HDL, high-density lipoprotein; LDL, low-density lipoprotein; y, years; n (%), number (percentage). <sup>a</sup>Data are expressed as mean (SD) unless otherwise specified.

(Appendix Table S2). BMI and WC were positively correlated with all fat and muscle measurements. However, the association of WWI with fat and muscle measurements was different. All fat measurements including percentage of body fat (*r* = 0.524) by BIA, percentage of total tissue fat (*r* = 0.465) by DXA, and TFA (*r* = 0.421), SFA (*r* = 0.425) and VFA (*r* = 0.264) by CT scan were positively correlated with WWI, although the correlation coefficients were smaller than those for BMI and WC. Meanwhile, all muscle mass measurements including skeletal muscle mass (*r* = –0.536) by BIA and ASM (*r* = –0.511) by DXA were negatively associated with WWI (Figure 1). Although the analyses were performed separately for men and women, the associations were similar (Appendix Table S3).

Association between WWI and body composition

The mean values of body composition measurements according to quartiles of WWI are shown in Table 2. Muscle mass measurements tended to decrease whereas fat measurements tended to increase with higher quintiles of WWI. For example, the mean (±SD) ASM was 17.82 (±3.72) kg, 17.20 (±3.51) kg, 15.27 (±2.73) kg, and 13.21 (±2.05) kg



**Figure 1.** Correlation between weight-adjusted waist index and body composition measurements. (A: skeletal muscle mass; B: ASM; C: ASM/height<sup>2</sup>; D: % BF; E: % FAT; F: TFA.) % BF, percentage of body fat; % FAT, percentage of total tissue fat.

and the mean ( $\pm$ SD) TFA was 249.4 ( $\pm$ 87.2) cm<sup>2</sup>, 288.8 ( $\pm$ 87.5) cm<sup>2</sup>, 323.6 ( $\pm$ 96.1) cm<sup>2</sup>, and 361.4 ( $\pm$ 9.5) cm<sup>2</sup> from the lowest quartile to the highest quartile of WWI, respectively ( $P < 0.001$ ). Moreover, these associations were maintained in the different categories of BMI, indicating that WWI was independently associated with fat and muscle mass (Figure 2 and Appendix Table S4). Further, the analyses were performed separately in men and women, and we obtained similar results (Appendix Table S5).

### Prevalence and odds ratio of combined low muscle mass and high fat mass according to quartiles of anthropometric indices

The prevalence of combined low muscle mass and high fat mass was high in those with a high WWI (Table 3). When combined low muscle mass and high fat mass was defined as ASM/height<sup>2</sup> and VFA, the prevalence was 5.0% in the lowest quartile of WWI and 14.4% in the highest quartile of WWI. The odds ratios (ORs) of combined low muscle mass and high fat mass were significantly higher in the third and fourth quartiles of WWI than in the first quartile (OR 3.02, 95% CI 1.23–7.37 in the third quartile; OR 3.22, 95% CI 1.32–7.83 in the fourth quartile group). On the contrary, when the same analyses were performed with BMI and WC, no significant association with combined low muscle mass and high fat mass was observed. When it was defined by

ASM/height<sup>2</sup> and WC, similar results were obtained. Those with high WWI had a high probability of combined low muscle mass and high fat mass. Although, a high WC was associated with increased ORs of combined low muscle mass and high fat mass, the trend was not linear. Further, the analyses were performed separately in men and women, and we obtained similar results; however, the significance was slightly diminished (Appendix Table S6).

### Discussion

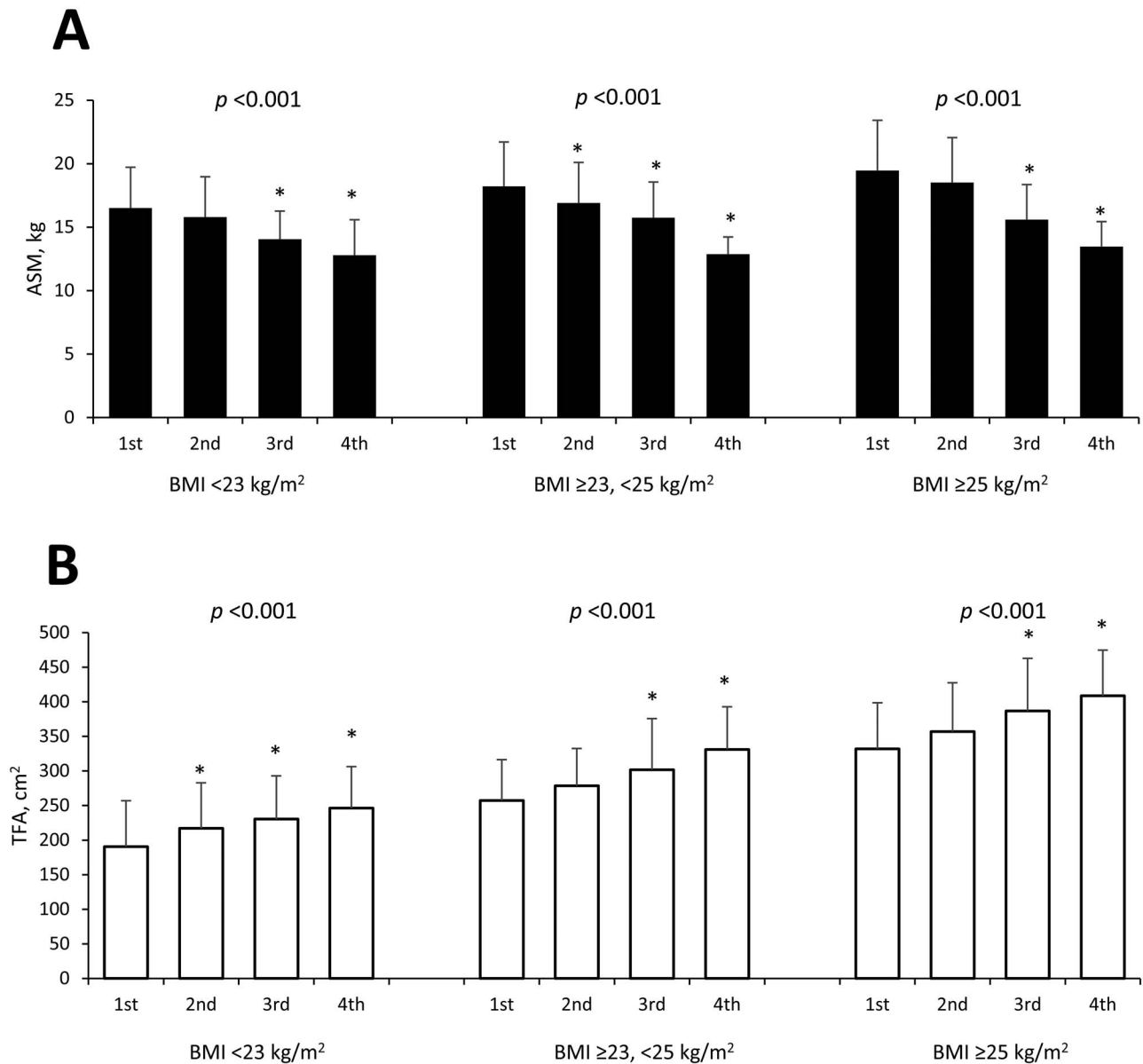
In this study, we showed that a new anthropometric index, WWI, could be considered as a marker that can assess high fat mass and low muscle mass simultaneously. WWI was positively associated with fat mass and negatively associated with muscle mass measured by various methods. Moreover, WWI was associated with a high probability of combined low muscle mass and high fat mass.

Since WWI was derived by standardising WC according to body weight, we expect that this index would primarily reflect pure central obesity without effects of body weight. However, unlike BMI or WC, the high correlation of WWI with age suggested that this index might be associated with age-related changes in body composition [19]. Moreover, this study shows that a positive linear association exists between WWI and age (Appendix Table S1). Interestingly,

**Table 2.** Mean values of muscle and fat parameters according to WWI quartiles

	Quartiles of WWI				<i>P</i>
	1st ( <i>n</i> = 149)	2nd ( <i>n</i> = 151)	3rd ( <i>n</i> = 151)	4th ( <i>n</i> = 150)	
Muscle mass parameters					
Skeletal muscle mass, kg	25.17 (4.66)	24.18 (4.40)	21.77 (3.46)	19.04 (2.76)	<0.001
ASM, kg	17.82 (3.72)	17.20 (3.51)	15.27 (2.73)	13.21 (2.05)	<0.001
ASM/height <sup>2</sup> , kg/m <sup>2</sup>	6.62 (0.95)	6.60 (0.96)	6.22 (0.77)	5.89 (0.66)	<0.001
Fat mass parameters					
% BF, %	26.76 (6.80)	29.95 (5.93)	33.06 (6.78)	37.09 (6.07)	<0.001
TFA, cm <sup>2</sup>	249.4 (87.2)	288.8 (87.5)	323.6 (96.1)	361.4 (89.5)	<0.001
SFA, cm <sup>2</sup>	166.8 (59.3)	188.2 (62.2)	214.5 (69.1)	248.5 (64.1)	<0.001
VFA, cm <sup>2</sup>	82.5 (39.6)	100.6 (40.8)	109.1 (47.8)	112.9 (42.4)	<0.001
% FAT, %	25.87 (8.41)	29.37 (7.87)	32.59 (7.84)	36.75 (7.04)	<0.001

% BF, percentage of body fat; % FAT, percentage of total tissue fat. Data are expressed as mean (SD) unless otherwise specified.



**Figure 2.** Mean ASM (A), and TFA (B) by weight-adjusted waist index quartiles according to BMI category. \**P* < 0.05 with respect to the first quartile of WWI in each group.



**Table 3.** Prevalence and odds ratios of combined low muscle mass and high fat mass by quartiles WWI, BMI and WC

Combined low muscle mass and high fat mass (%), defined by ASM/height <sup>2</sup> and WC <sup>a</sup>	Prevalence (%)	OR (95% CI)	Age-adjusted OR (95% CI)
Quartiles of WWI			
1st	3.4	Ref.	Ref.
2nd	8.8	2.74 (0.95–7.88)	2.74 (0.95–7.91)
3rd	17.3	5.96 (2.22–15.98)	5.86 (2.18–15.75)
4th	20.3	7.22 (2.72–19.20)	7.06 (2.64–18.84)
Quartiles of BMI			
First	9.6	Ref.	Ref.
Second	15.5	1.74 (0.86–3.52)	1.82 (0.89–3.72)
Third	14.0	1.54 (0.75–3.15)	1.58 (0.77–3.25)
Fourth	10.7	1.13 (0.53–2.42)	1.22 (0.57–2.63)
Quartiles of WC			
First	9.6	Ref.	Ref.
Second	8.7	0.90 (0.41–1.99)	0.89 (0.40–1.98)
Third	17.7	2.03 (1.02–4.03)	2.05 (1.03–4.07)
Fourth	13.6	1.48 (0.71–3.08)	1.46 (0.70–3.05)
Combined low muscle mass and high fat mass (%), defined by ASM/height <sup>2</sup> and VFA <sup>b</sup>	Prevalence (%)	OR (95% CI)	Age-adjusted OR (95% CI)
Quartiles of WWI			
First	5.0	Ref.	Ref.
Second	9.5	2.02 (0.79–5.15)	2.08 (0.81–5.34)
Third	13.6	3.02 (1.23–7.37)	2.74 (1.11–6.75)
Fourth	14.4	3.22 (1.32–7.83)	2.89 (1.18–7.07)
Quartiles of BMI			
First	7.0	Ref.	Ref.
Second	12.4	1.89 (0.84–4.24)	2.19 (0.96–5.01)
Third	14.9	2.32 (1.06–5.10)	2.57 (1.16–5.72)
Fourth	8.2	1.19 (0.50–2.85)	1.46 (0.60–3.57)
Quartiles of WC			
First	4.9	Ref.	Ref.
Second	13.6	3.06 (1.25–7.48)	3.06 (1.24–7.52)
Third	12.3	2.73 (1.11–6.72)	2.83 (1.14–6.99)
Fourth	11.7	2.57 (1.02–6.46)	2.54 (1.00–6.42)

CI, confidence interval. <sup>a</sup>Cut-off points for ASM/height<sup>2</sup> were 6.49 kg/m<sup>2</sup> in men and 5.39 kg/m<sup>2</sup> in women and the cut-off points for WC were 90 cm in men and 80 cm in women. <sup>b</sup>Cut-off points for ASM/height<sup>2</sup> were 6.49 kg/m<sup>2</sup> in men and 5.39 kg/m<sup>2</sup> in women, and the cut-off point for VFA was 100 cm<sup>2</sup>.

in this cross-sectional analysis, we found that WWI was associated with both fat and muscle mass components. Further research is necessary to elucidate how this indicator is inversely proportional to muscle mass as well as directly proportional to fat mass.

The European Working Group on Sarcopenia in Older People proposed a diagnostic criterion of sarcopenia which includes three components: low muscle strength, low physical performance and low muscle mass [13]. We were unable to evaluate the association of WWI with muscle strength or sarcopenia-associated health problems due to lack of relevant data. Therefore, even if WWI was shown to be directly associated with low muscle mass, we cannot confirm whether it is a true marker for sarcopenia without relevant information. Further validation of this association is needed.

Previously, we reported that WWI was a unique anthropometric index with a positive linear association with both cardiometabolic morbidity and mortality in a longitudinal population-based study [19]. Specifically, the 'obesity paradox' phenomenon observed in the case of the relation between BMI or WC and mortality was not apparent for WWI. The present findings imply that the obesity paradox

may not truly exist, but originates from the limitation of BMI, which does not differentiate between muscle mass and fat mass [22,23]. Given that WWI is an index reflecting both muscle mass and fat mass, it should be applied in future studies to evaluate the association of obesity with morbidity and mortality.

Some other anthropometric measurements have been proposed as possible indicators of low muscle mass. Calf circumference was positively but weakly correlated with ASM, and the cut-off point for sarcopenia had low sensitivity [24]. Recently, a simple screening model to estimate the probability of sarcopenia using age, grip strength and calf circumference was proposed, but this needs to be evaluated further in various population settings [25]. In addition, mid-upper arm circumference is a potential indicator of muscle mass, but there have been few validation studies, especially in older populations [13]. Unfortunately, we were not able to compare these indices with WWI for the effectiveness of assessing sarcopenia, especially in the setting of low muscle mass, due to lack of relevant data. However, the strength of WWI is that it reflects both fat and muscle mass, regardless of the BMI category.

This study has several limitations. First, this study is limited by the relatively small number of participants included in the analyses. Further studies in larger scale would be needed to support the results of the current study. Second, our study samples did not include the younger population. Thus, we referred to other studies for the cut-off points for combined low muscle mass and high fat mass. Third, this study included only Koreans, and therefore, further studies in different ethnic groups are required. Fourth, the association between WWI and muscle strength or physical performance, which are other components of sarcopenia, was not determined.

In conclusion, the WWI is an anthropometric index reflecting both high fat mass and low muscle mass in Koreans. It is simple to calculate, making it applicable in clinical practice.

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**Declaration of Conflicts of Interest:** None.

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