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Association of Sarcopenia and Sarcopenic Obesity With Mortality: A Comparison of the AWGS 2019 and 2025 Criteria

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Abstract

The Asian Working Group for Sarcopenia (AWGS) updated its diagnostic criteria in 2025, but their prognostic implications remain uncertain. We compared the associations of the AWGS 2019 and 2025 criteria with mortality and examined mortality across sarcopenia–obesity phenotypes. This prospective cohort study included 382 community-dwelling older adults from the Hallym Aging Study, followed through December 2023. Sarcopenia was defined using the AWGS 2019 and 2025 criteria, primarily using height-adjusted appendicular skeletal muscle mass, and obesity using sex-specific body fat percentage thresholds. During a median follow-up of 12.7 years, 128 participants (33.5%) died. Sarcopenia prevalence was lower with AWGS 2025 than AWGS 2019 (12.3% vs. 26.2%). After full adjustment, AWGS 2025-defined sarcopenia was associated with a but borderline-significant risk of all-cause mortality (HR 1.58, 95% CI 1.00–2.51; p = 0.052), whereas AWGS 2019-defined sarcopenia was not (HR 1.30, 95% CI 0.89–1.92). Significant associations were observed in women (HR 2.73, 95% CI 1.20–6.25) and participants without obesity (HR 1.75, 95% CI 1.02–3.00). Sarcopenia only was associated with higher mortality (HR 1.78, 95% CI 1.06–3.00), whereas obesity only and sarcopenic obesity were not. These findings highlight the impact of diagnostic criteria on sarcopenia prevalence and its association with mortality.

Introduction

Sarcopenia, the age-related loss of skeletal muscle mass and function, is recognized as a major determinant of adverse health outcomes in older adults, including falls, physical disability, hospitalization, and death [1–3]. A recent meta-analysis of 140 studies estimated its prevalence to be 16.5% (95% CI, 14.7–18.4) among community-dwelling older adults in Asia using the 2019 Asian Working Group for Sarcopenia (AWGS) criteria [4]. Reported estimates nevertheless vary widely, ranging from 9.9% to 40.4% across eight diagnostic definitions, reflecting differences in cutoff values for muscle mass, strength, and physical performance by ethnicity, age, and sex [5]. These considerations underscore the need to develop region-specific criteria for Asian populations.

AWGS published consensus definitions in 2014 [6] and 2019 [7] and presented a revised diagnostic framework in 2025 [8]. Situating sarcopenia within a life-course approach to muscle health, the 2025 update introduced substantive changes. First, it simplified the diagnostic definition to the presence of both low muscle mass and low muscle strength, repositioning physical performance as an outcome measure rather than a diagnostic criterion. Second, it extended the diagnostic criteria to include middle-aged adults (50–64 years) with dedicated cutoffs. Third, in addition to the existing height-adjusted muscle mass thresholds, the 2025 criteria introduced body mass index (BMI)-adjusted cutoffs and removed the severe sarcopenia category. However, the 2025 criteria were published only recently, and comparative data against the 2019 criteria and evidence on their prognostic validity remain scarce.

Interest in sarcopenic obesity has grown rapidly, with the condition defined as the coexistence of low muscle mass, impaired muscle function, and excess adiposity [9]. Obesity exacerbates sarcopenia through multiple mechanisms, including fat infiltration into skeletal muscle, adipokine-driven chronic inflammation, and insulin resistance, which impair muscle mass and function [10, 11]. Conversely, reduced muscle mass lowers resting energy expenditure and promotes further fat accumulation, creating a vicious cycle [12, 13]. In line with this, previous studies have reported higher all-cause and cardiovascular mortality in individuals with sarcopenic obesity than in healthy older adults [14, 15]. However, among older adults, higher BMI is paradoxically associated with lower mortality, a phenomenon known as the “obesity paradox” [16]. Although ESPEN and EASO proposed a consensus definition of sarcopenic obesity in 2022 [9], the AWGS 2025 framework did not adopt diagnostic

criteria for sarcopenic obesity but instead established a dedicated special interest group to develop region-specific diagnostic and management recommendations [8]. Nevertheless, evidence comparing the prognostic validity of sarcopenic obesity definitions in relation to mortality remains limited.

To address these gaps, we aimed to (1) compare the AWGS 2019 and AWGS 2025 criteria in their association with all-cause, cardiovascular, and respiratory mortality, (2) determine whether these associations differed by obesity status, and (3) examine the mortality risk associated with the sarcopenic obesity phenotype in a community-dwelling cohort of middle-aged and older Korean adults followed for a median of 12.7 years. To assess the robustness of the updated criteria, we further evaluated alternative indices of low muscle mass (height-adjusted, BMI-adjusted, and obesity-stratified hybrid) and three definitions of obesity (body fat percentage, BMI, and waist circumference).

Methods

Study design and participants

This study used data from the third wave (2010) of the Hallym Aging Study (HAS), a population-based prospective cohort of community-dwelling Korean adults. The HAS was launched in 2003 to examine health and quality of life among adults aged 45 years or older residing in Chuncheon, South Korea, and its detailed design has been described previously [17, 18]. In brief, a two-stage sampling design was used. All 1408 census districts in the city served as primary sampling units, of which 200 were selected at random. Within these districts, 1520 individuals (30% aged 45–64 years and 70% aged ≥ 65 years) were selected by systematic sampling, of whom 918 completed the baseline assessment in 2004 (first wave). Follow-up assessments were conducted in 2007 (second wave, n = 547) and 2010 (third wave, n = 382). Because dual-energy X-ray absorptiometry (DXA; Lunar, GE, Fairfield, CT, USA) was performed only in the third wave, the 2010 wave was used as the baseline for this analysis. All 382 participants who completed the third wave and had available DXA measurements and follow-up data were included in the analysis. All procedures were conducted in accordance with the relevant guidelines and regulations, including the ethical standards of the Declaration of Helsinki and its subsequent revisions. The study protocol was reviewed and approved by the Institutional Review Board of Hallym University (IRB approval number: 2024-09-001). Written informed consent was obtained from all participants before study enrollment.

Definition of sarcopenia

Sarcopenia was defined according to the AWGS 2019 [7] and 2025 [8] criteria. Appendicular skeletal muscle mass (ASM) was assessed by dual-energy X-ray absorptiometry (DXA; Lunar, GE, Fairfield, CT, USA) and muscle strength by handgrip dynamometry. The DXA-based muscle mass cutoffs specified by AWGS were applied. Because the AWGS 2019 criteria define low muscle mass only using ASM/height², we used ASM/height² with AWGS 2025 criteria for direct comparison, while evaluating ASM/BMI and a hybrid definition as alternatives.

AWGS 2019. Sarcopenia was defined as low muscle mass plus low muscle strength and/or low physical performance. Low muscle mass was defined as ASM/height² <7.0 kg/m² in men and < 5.4 kg/m² in women, low muscle strength as handgrip strength < 28 kg in men and < 18 kg in women, and low physical performance as a 6-m gait speed < 1.0 m/s or a five-times chair stand time ≥ 12 s.

AWGS 2025. Sarcopenia was defined as the presence of both low muscle mass and low muscle strength; physical performance was not included in the diagnostic criteria. Age- and sex-specific cutoffs were applied to ASM/height² and handgrip strength. For adults aged ≥ 65 years, the thresholds were 7.0 kg/m² and 28 kg in men and 5.4 kg/m² and 18 kg in women, respectively. For adults aged 50–64 years, the thresholds were 7.2 kg/m² and 34 kg in men and 5.5 kg/m² and 20 kg in women, respectively.

Alternative operationalizations of low muscle mass (AWGS 2025). In addition to ASM/height², the AWGS 2025 criteria provide BMI-adjusted cutoffs (ASM/BMI) as an alternative index of low muscle mass [8]. We therefore applied two additional operationalizations of AWGS 2025 sarcopenia. In each, low muscle strength was identified using the age- and sex-specific handgrip cutoffs specified by AWGS 2025 [8], and the definitions differed only in the index of low muscle mass. First, low muscle mass was defined by ASM/BMI alone, using the AWGS 2025 cutoffs of < 0.73 kg per kg/m² in men and < 0.52 kg per kg/m² in women at age ≥ 65 years, and < 0.80 and < 0.55 kg per kg/m², respectively, at age 50–64 years [8]. Second, because ASM/height² may underestimate low muscle mass in individuals with obesity whereas ASM/BMI may overestimate it in those without obesity, we constructed an obesity-stratified hybrid index that applied the AWGS 2025 ASM/height² cutoffs in participants without obesity and the AWGS 2025 ASM/BMI cutoffs in participants with obesity, with obesity classified by body fat percentage. Because results using the hybrid index may depend on the body fat threshold used to classify obesity, three cutoffs were evaluated: >29.7% in men and > 37.2% in women as the primary threshold, and > 25%/>35% and > 30%/>40% as additional thresholds.

Definition of obesity and sarcopenic obesity

Obesity was defined primarily using body fat percentage, with sex-specific thresholds of > 29.7% in men and > 37.2% in women [19]. Sarcopenic obesity was defined as the presence of both sarcopenia and obesity [9]. For the sarcopenia–obesity phenotype analysis, participants were classified into four groups: non-sarcopenic non-obese, obesity only, sarcopenia only, and sarcopenic obesity. To assess the robustness of findings across obesity definitions, two additional obesity indices were applied alongside body fat percentage: body mass index (BMI ≥ 25 kg/m²) and waist circumference (≥ 90 cm in men and ≥ 85 cm in women) [20].

Covariates

Sociodemographic and health behavior variables were collected through structured interviews. Variables included age, sex, smoking status, alcohol consumption and regular exercise. Current smoking was defined as having smoked 400 or more cigarettes in a lifetime and currently smoking, and ex-smoking as having smoked 400 or more cigarettes but not currently smoking. Alcohol drinking was defined as consuming alcohol at least once during the past year, and regular exercise as engaging in moderate-intensity exercise for at least 150 min per week. Comorbidities were classified as 0, 1, or ≥ 2 conditions or more based on self-reported hypertension, diabetes, dyslipidemia, cardiovascular disease (stroke or myocardial infarction), osteoporosis, arthritis, depression, and malignancy. Anthropometric measurements were obtained with participants in light clothing and without shoes. Height was measured to the nearest 0.1 cm and weight to the nearest 0.1 kg, and BMI was calculated as weight (kg) divided by height squared (m^2). Waist circumference was measured to the nearest 0.1 cm at the midpoint between the lowest rib and the iliac crest.

Assessment of mortality

Participants were followed from the date of the baseline examination in 2010 until death or 31 December 2023, whichever occurred first. Vital status and cause of death were ascertained through linkage with the Statistics Korea national death registry. Causes of death were classified according to the International Classification of Diseases, 10th revision (ICD-10), into cardiovascular disease (ICD-10 codes I00–I99), respiratory disease (ICD-10 codes J00–J99 and U07.1-U07.2, including COVID-19-related deaths), and other causes.

Statistical analysis

Descriptive statistics are presented as mean ± standard deviation or median [interquartile range] for continuous variables and frequency (percentage) for categorical variables. Between-group differences were assessed using the independent samples *t*-test or Mann–Whitney *U* test for continuous variables and the χ^2 test or Fisher's exact test for categorical variables. Kaplan–Meier curves were used to estimate survival probabilities across prespecified sarcopenia and sarcopenic obesity categories, and differences between curves were tested with the log-rank test. We used Cox proportional hazards models to estimate hazard ratios (HRs) and 95% confidence intervals (CIs) for all-cause mortality across three models: unadjusted (Model 1), adjusted for age and sex (Model 2), and additionally adjusted for smoking status, alcohol consumption, regular exercise, and comorbidity (Model 3). Analyses were repeated in sex-specific strata. For cause-specific events (cardiovascular and respiratory), deaths from competing causes were censored, and cause-specific Cox models were fitted. Participants were classified into four groups according to sarcopenia and obesity status (non-sarcopenic non-obese, obesity only, sarcopenia only, and sarcopenic obesity), with the non-sarcopenic non-obese group serving as the reference, and were compared using the same three models, with the non-sarcopenic non-obese group as the reference. Effect modification by obesity was assessed by adding a sarcopenia × obesity interaction term to Model 3, and stratified and interaction analyses were repeated for each of the three obesity definitions. The proportional hazards assumption was assessed using scaled Schoenfeld residuals. As a sensitivity analysis accounting for competing risks, Fine–Gray subdistribution hazard models were fitted for cardiovascular and respiratory mortality, treating deaths from other causes as competing events. Subdistribution hazard ratios and 95% CIs were estimated using the same three covariate adjustment models as the cause-specific Cox analyses. All analyses were performed using R version 4.2.0 (R Foundation for Statistical Computing, Vienna, Austria), with a two-sided $p < 0.05$ considered statistically significant.

Results

Characteristics of participants

This study analysed 382 community-dwelling adults aged 50 years or older who participated in the third wave (2010) of the Hallym Aging Study, with a median follow-up of 12.7 years. During follow-up, 128 participants (33.5%) died, including 28 cardiovascular deaths, 22 respiratory deaths, and 78 deaths from other causes. The diagnostic algorithms for sarcopenia and sarcopenic obesity according to the AWGS 2019 and 2025 criteria are presented in Fig. 1.

Using the AWGS 2019 criteria, sarcopenia and sarcopenic obesity were identified in 100 (26.2%) and 33 (8.6%) participants, respectively, and both prevalence estimates were lower using the AWGS 2025 criteria with ASM/height², at 47 (12.3%) and 13 (3.4%), respectively. Using the AWGS 2025 criteria with ASM/BMI, 67

participants (17.5%) had sarcopenia and 29 (7.6%) had sarcopenic obesity. The hybrid definitions applied ASM/height² to participants without obesity and ASM/BMI to those with obesity, with obesity classified by body fat percentage. Across body fat thresholds of 25%/35%, 29.7%/37.2% and 30%/40% (men/women), sarcopenia was identified in 67 (17.5%), 63 (16.5%), and 61 (16.0%) participants, respectively, and sarcopenic obesity in 47 (12.3%), 29 (7.6%), and 25 (6.5%), respectively. The baseline characteristics of the 382 participants (54.2% women; median age 74 years) according to AWGS 2025-defined sarcopenia status are presented in Table 1. Compared with those without sarcopenia, participants with sarcopenia were older ($p = 0.001$) and more likely to be ex-smokers (48.9% vs. 26.0%, $p = 0.004$). They also had a lower BMI ($p < 0.001$), waist circumference ($p = 0.018$), body fat mass ($p = 0.042$) and lean body mass ($p < 0.001$). Muscle mass and handgrip strength were lower, while gait speed was slower and chair stand performance was poorer in the sarcopenia group (all $p < 0.05$), whereas percentage body fat and the prevalence of obesity did not differ ($p = 0.372$ and $p = 0.701$, respectively). All-cause mortality was higher in the sarcopenia group ($p = 0.001$), whereas the distribution of causes of death did not differ between groups ($p = 0.372$).

Table 1
Baseline characteristics of participants according to sarcopenia status defined by the AWGS 2025 criteria

Age, years	**Total**	**No sarcopenia**	**Sarcopenia**	***p***
	(n = 382)	**(n = 335)**	**(n = 47)**	
	74.0 [68.0–77.0]	**73.0 [68.0–76.5]**	**76.0 [71.5–81.5]**	**0.001**
Sex, n (%)				0.062
Male	175 (45.8)	147 (43.9)	28 (59.6)	
Female	207 (54.2)	188 (56.1)	19 (40.4)	
Smoking status, n (%)				**0.004**
Never smoker	231 (60.5)	212 (63.3)	19 (40.4)	
Ex-smoker	110 (28.8)	87 (26.0)	23 (48.9)	
Current smoker	41 (10.7)	36 (10.7)	5 (10.6)	
Alcohol drinking, n (%)				0.709
No	265 (69.4)	234 (69.9)	31 (66.0)	
Yes	117 (30.6)	101 (30.1)	16 (34.0)	
Regular exercise, n (%)				0.265
No	279 (73.0)	241 (71.9)	38 (80.9)	
Yes	103 (27.0)	94 (28.1)	9 (19.1)	
Comorbidity, n (%)				0.486
0	76 (19.9)	69 (20.6)	7 (14.9)	
1	116 (30.4)	103 (30.7)	13 (27.7)	
≥2	190 (49.7)	163 (48.7)	27 (57.4)	
Body mass index, kg/m²	24.5 [22.6–26.7]	24.9 [22.8–26.9]	22.9 [20.1–24.9]	**< 0.001**
Waist circumference, cm	85.9 ± 9.0	86.3 ± 8.9	82.9 ± 9.5	**0.018**
Body fat mass, kg	18.1 ± 6.6	18.4 ± 6.6	16.3 ± 6.8	**0.042**
Lean body mass, kg	37.1 [33.1–45.1]	37.3 [33.4–45.5]	33.8 [29.6–40.7]	**< 0.001**
Body fat, %	30.4 [23.5–36.9]	30.6 [23.3–37.2]	28.9 [24.0–35.3]	0.372
Obesity, n (%)	119 (31.2)	106 (31.6)	13 (27.7)	0.701
ASM, kg	14.6 [12.5–18.0]	14.8 [12.7–18.4]	12.8 [10.6–15.8]	**< 0.001**

Age, years	Total (n = 382)	No sarcopenia (n = 335)	Sarcopenia (n = 47)	*p*
	74.0 [68.0–77.0]	**73.0 [68.0–76.5]**	**76.0 [71.5–81.5]**	**0.001**
ASM/height², kg/m²	6.17 [5.59–7.05]	6.32 [5.68–7.17]	5.33 [4.93–6.22]	**< 0.001**
ASM/BMI, kg per kg/m²	0.60 [0.51–0.74]	0.60 [0.51–0.75]	0.56 [0.47–0.69]	0.126
Low muscle mass, n (%)	147 (38.5)	100 (29.9)	47 (100.0)	**< 0.001**
Grip strength, kg	24.2 [19.4–33.1]	25.6 [20.2–33.6]	19.2 [16.5–24.5]	**< 0.001**
Dynapenia, n (%)	105 (27.5)	58 (17.3)	47 (100.0)	**< 0.001**
Gait speed, m/s	1.02 ± 0.26	1.03 ± 0.26	0.89 ± 0.27	**< 0.001**
Chair stand test, s	12.3 [10.1–15.5]	12.0 [9.9–15.4]	14.0 [12.2–16.9]	**0.002**
Low physical performance, n (%)	277 (72.5)	236 (70.4)	41 (87.2)	**0.025**
Death, n (%)	128 (33.5)	102 (30.4)	26 (55.3)	**0.001**
Cause of death, n (% of deaths)				0.372
Cardiovascular disease	28 (21.9)	20 (19.6)	8 (30.8)	
Respiratory disease	22 (17.2)	17 (16.7)	5 (19.2)	
Other	78 (60.9)	65 (63.7)	13 (50.0)	

Abbreviations: ASM, appendicular skeletal muscle mass; AWGS, Asian Working Group for Sarcopenia; BMI, body mass index.

Values are mean ± SD, median [IQR], or n (%). *p* values are from the *t*-test or Mann–Whitney *U* test for continuous variables and the χ^2 test for categorical variables, except Fisher's exact test for cause of death. Percentages for cause of death are of decedents within each group.

Sarcopenia was defined according to the AWGS 2025 as the concurrent presence of low muscle mass (ASM/height²) and low handgrip strength. Dynapenia was defined as low handgrip strength irrespective of muscle mass. Obesity was defined as body fat percentage > 29.7% in males and > 37.2% in females. Participants unable to complete handgrip strength (n = 2), the five-time chair stand (n = 12) or gait speed (n = 5) were classified as having low muscle strength or low physical performance and excluded only from continuous analyses. Waist circumference was missing for 2 participants.

p values < 0.05 are presented in bold.

Associations of sarcopenia with all-cause and cause-specific mortality

The associations between sarcopenia and mortality according to the AWGS 2019 and 2025 criteria are presented in Table 2. The hazard of all-cause mortality was higher in participants with sarcopenia across all definitions, and sarcopenia was significantly associated with all-cause mortality in unadjusted analyses (all $p < 0.05$). After full

adjustment, the association was no longer significant by the AWGS 2019 criteria (HR 1.30, 95% CI 0.89–1.92, p = 0.178), whereas sarcopenia by the AWGS 2025 height-adjusted criteria showed a borderline association (HR 1.58, 95% CI 1.00–2.51, p = 0.052). Among the alternative AWGS 2025 definitions, the hybrid definition using body fat > 30%/>40% was significantly associated with all-cause mortality (HR 1.57, 95% CI 1.03–2.41, p = 0.038), while the BMI-adjusted definition showed the weakest association (HR 1.14, 95% CI 0.73–1.79). Sarcopenia was significantly associated with all-cause mortality after full adjustment in women by the AWGS 2025 height-adjusted definition (HR 2.73, 95% CI 1.20–6.25, p = 0.017) and by all three hybrid definitions (HR range 2.29–2.92, all p < 0.05), whereas the AWGS 2019 and AWGS 2025 BMI-adjusted definitions showed no significant association in either sex. For cardiovascular mortality, none of the sarcopenia definitions was significantly associated with mortality after full adjustment, although hazard ratios were consistently elevated. For respiratory mortality, sarcopenia defined by the AWGS 2019 criteria, the AWGS 2025 height-adjusted criteria, and all three hybrid definitions was significantly associated with mortality after full adjustment (HR 3.06, 3.32 and 3.48–3.95, respectively; all p < 0.05), whereas no significant association was observed for the BMI-adjusted definition. In sensitivity analyses using Fine–Gray competing-risk models across all six operationalizations, cardiovascular mortality associations were attenuated after adjustment, and no significant associations with respiratory mortality were observed (Additional file 1: Table S3).

Table 2
Associations of sarcopenia with all-cause and cause-specific mortality across six AWGS operationalizations.

	Deaths / N		Hazard ratio (95% confidence interval)					
	No sarcopenia	Sarcopenia	Model 1[a]	*p*	Model 2[b]	*p*	Model 3[c]	*p*
All-cause mortality								
AWGS 2019 (ASM/height²)								
All participants	77/282	51/100	2.19 (1.54–3.13)	**< 0.001**	1.47 (1.02–2.11)	**0.041**	1.30 (0.89–1.92)	0.178
Males	46/116	39/59	2.02 (1.31–3.09)	**0.001**	1.38 (0.89–2.14)	0.151	1.09 (0.68–1.75)	0.715
Females	31/166	12/41	1.67 (0.86–3.25)	0.133	1.74 (0.89–3.39)	0.107	1.73 (0.86–3.48)	0.127
AWGS 2025 (ASM/height²)								
All participants	102/335	26/47	2.36 (1.53–3.63)	**< 0.001**	1.74 (1.12–2.71)	**0.014**	1.58 (1.00–2.51)	0.052
Males	67/147	18/28	1.84 (1.09–3.09)	**0.022**	1.41 (0.82–2.42)	0.212	1.19 (0.68–2.10)	0.539
Females	35/188	8/19	2.78 (1.29–5.99)	**0.009**	3.01 (1.39–6.54)	**0.005**	2.73 (1.20–6.25)	**0.017**
AWGS 2025, BMI-adjusted (ASM/BMI)								
All participants	99/315	29/67	1.55 (1.02–2.34)	**0.039**	1.23 (0.80–1.88)	0.345	1.14 (0.73–1.79)	0.556
Males	70/149	15/26	1.42 (0.81–2.48)	0.222	0.88 (0.49–1.59)	0.676	0.72 (0.38–1.35)	0.309
Females	29/166	14/41	2.24 (1.18–4.24)	**0.013**	1.96 (1.04–3.72)	**0.039**	1.80 (0.92–3.53)	0.086
AWGS 2025, hybrid (body fat > 29.7%/>37.2%)								
All participants	96/319	32/63	2.04 (1.36–3.04)	**< 0.001**	1.64 (1.09–2.47)	**0.018**	1.51 (0.99–2.32)	0.058
Males	67/146	18/29	1.72 (1.02–2.89)	**0.042**	1.24 (0.72–2.13)	0.433	1.02 (0.57–1.81)	0.959
Females	29/173	14/34	2.90 (1.53–	**0.001**	2.61 (1.37–	**0.003**	2.55 (1.30–	**0.007**

	Deaths / N		Hazard ratio (95% confidence interval)					
	No sarcopenia	Sarcopenia	Model 1[a]	*p*	Model 2[b]	*p*	Model 3[c]	*p*
All-cause mortality								
			5.50)		4.95)		5.00)	
AWGS 2025, hybrid (body fat > 25%/>35%)								
All participants	95/315	33/67	1.95 (1.31–2.89)	**0.001**	1.62 (1.08–2.43)	**0.019**	1.49 (0.98–2.27)	0.065
Males	66/144	19/31	1.68 (1.01–2.79)	**0.048**	1.29 (0.76–2.18)	0.347	1.06 (0.60–1.87)	0.835
Females	29/171	14/36	2.66 (1.41–5.04)	**0.003**	2.39 (1.26–4.52)	**0.008**	2.29 (1.16–4.51)	**0.016**
AWGS 2025, hybrid (body fat > 30%/>40%)								
All participants	96/321	32/61	2.15 (1.44–3.21)	**< 0.001**	1.70 (1.13–2.57)	**0.011**	1.57 (1.03–2.41)	**0.038**
Males	67/146	18/29	1.72 (1.02–2.89)	**0.042**	1.24 (0.72–2.13)	0.433	1.02 (0.57–1.81)	0.959
Females	29/175	14/32	3.18 (1.68–6.03)	**< 0.001**	2.94 (1.55–5.58)	**< 0.001**	2.92 (1.48–5.74)	**0.002**
Cause-specific mortality								
AWGS 2019 (ASM/height²)								
Cardiovascular	15/282	13/100	2.81 (1.34–5.92)	**0.006**	1.92 (0.87–4.23)	0.104	1.60 (0.70–3.68)	0.266
Respiratory	12/282	10/100	2.97 (1.28–6.89)	**0.011**	2.17 (0.92–5.16)	0.078	3.06 (1.21–7.75)	**0.018**
AWGS 2025 (ASM/height²)								
Cardiovascular	20/335	8/47	3.62 (1.59–8.23)	**0.002**	2.47 (1.03–5.96)	**0.043**	2.06 (0.79–5.36)	0.140
Respiratory	17/335	5/47	2.94 (1.08–7.98)	**0.034**	2.55 (0.92–7.08)	0.072	3.32 (1.11–9.98)	**0.032**
AWGS 2025, BMI-adjusted (ASM/BMI)								

	Deaths / N		Hazard ratio (95% confidence interval)					
	No sarcopenia	Sarcopenia	Model 1[a]	*p*	Model 2[b]	*p*	Model 3[c]	*p*
All-cause mortality								
Cardiovascular	19/315	9/67	2.46 (1.11–5.44)	**0.026**	1.54 (0.67–3.52)	0.308	1.23 (0.51–3.01)	0.645
Respiratory	17/315	5/67	1.63 (0.60–4.43)	0.335	1.33 (0.48–3.69)	0.584	1.98 (0.64–6.14)	0.239
AWGS 2025, hybrid (body fat > 29.7%/>37.2%)								
Cardiovascular	19/319	9/63	2.83 (1.28–6.26)	**0.010**	1.91 (0.84–4.35)	0.122	1.63 (0.68–3.90)	0.273
Respiratory	15/319	7/63	3.04 (1.24–7.46)	**0.015**	2.71 (1.09–6.71)	**0.031**	3.66 (1.35–9.92)	**0.011**
AWGS 2025, hybrid (body fat > 25%/>35%)								
Cardiovascular	18/315	10/67	3.05 (1.41–6.61)	**0.005**	2.18 (0.98–4.83)	0.056	1.85 (0.79–4.32)	0.155
Respiratory	15/315	7/67	2.78 (1.13–6.83)	**0.025**	2.57 (1.04–6.36)	**0.041**	3.48 (1.29–9.41)	**0.014**
AWGS 2025, hybrid (body fat > 30%/>40%)								
Cardiovascular	19/321	9/61	2.98 (1.35–6.59)	**0.007**	2.00 (0.87–4.55)	0.101	1.70 (0.71–4.07)	0.236
Respiratory	15/321	7/61	3.23 (1.31–7.92)	**0.011**	2.84 (1.15–7.04)	**0.024**	3.95 (1.45–10.8)	**0.007**

Abbreviations: ASM, appendicular skeletal muscle mass; AWGS, Asian Working Group for Sarcopenia; BMI, body mass index.

AWGS 2019 (ASM/height²): low muscle mass plus low muscle strength and/or low physical performance. AWGS 2025 (ASM/height²): low muscle mass plus low muscle strength, using age-specific cutoffs (50–64 and ≥ 65 years). AWGS 2025 (ASM/BMI): AWGS 2025 criteria with low muscle mass defined by ASM/BMI. AWGS 2025 (hybrid): AWGS 2025 criteria with low muscle mass defined by ASM/height² in participants without obesity and by ASM/BMI in participants with obesity, with obesity defined by the body fat cutoff shown.

[a] Model 1: unadjusted.

[b] Model 2: adjusted for age and sex (sex omitted in sex-specific strata).

[c] Model 3: adjusted for age, sex (sex omitted in sex-specific strata), smoking status, alcohol consumption, regular exercise and comorbidity.

p values < 0.05 are presented in bold.

Survival by sarcopenia status within obesity strata

Kaplan–Meier survival curves stratified by obesity status are presented in Fig. 2. Across all three obesity definitions, participants with sarcopenia in the non-obese group had lower survival probabilities than those without sarcopenia (log-rank $p < 0.001$ for all three definitions), whereas survival did not differ by sarcopenia status in the obese group.

Associations of sarcopenia with all-cause mortality by obesity status

Sarcopenia was significantly associated with all-cause mortality in participants without obesity after full adjustment when obesity was defined using body fat percentage (HR 1.75, 95% CI 1.02–3.00, $p = 0.041$) and BMI (HR 2.14, 95% CI 1.24–3.69, $p = 0.006$), but not using waist circumference (HR 1.62, 95% CI 0.91–2.87, $p = 0.101$). No significant associations were observed in participants with obesity across the three definitions (Table 3). The sarcopenia × obesity interaction was statistically significant only when obesity was defined using BMI (p for interaction = 0.049). A similar pattern was observed across the alternative sarcopenia definitions. When obesity was defined using BMI, sarcopenia was associated with all-cause mortality only in participants without obesity under the AWGS 2019, AWGS 2025 height-adjusted and all three hybrid definitions (p for interaction 0.017–0.055), but not under the BMI-adjusted definition (p for interaction = 0.580) (Table 3).

Table 3

Associations of sarcopenia with all-cause mortality by obesity status across six AWGS operationalizations.

Obesity strata	Deaths / N		Hazard ratio (95% confidence interval)						*p* for interaction[d]
	No sarcopenia	Sarcopenia	Model 1[a]	*p*	Model 2[b]	*p*	Model 3[c]	*p*	
Obesity defined by body fat percentage									
AWGS 2019 (ASM/height²)									
Without obesity	54/196	39/67	2.64 (1.74–3.98)	**< 0.001**	1.68 (1.09–2.59)	**0.018**	1.45 (0.92–2.29)	0.112	0.303
With obesity	23/86	12/33	1.46 (0.73–2.95)	0.284	1.05 (0.51–2.16)	0.893	0.89 (0.39–2.01)	0.770	
AWGS 2025 (ASM/height²)									
Without obesity	72/229	21/34	2.80 (1.72–4.56)	**< 0.001**	1.97 (1.18–3.28)	**0.009**	1.75 (1.02–3.00)	**0.041**	0.378
With obesity	30/106	5/13	1.46 (0.57–3.77)	0.433	1.22 (0.46–3.24)	0.684	1.07 (0.35–3.22)	0.906	
AWGS 2025, BMI-adjusted (ASM/BMI)									
Without obesity	75/225	18/38	1.73 (1.03–2.89)	**0.038**	1.24 (0.72–2.14)	0.430	1.15 (0.65–2.04)	0.626	0.921
With obesity	24/90	11/29	1.50 (0.74–3.07)	0.263	1.14 (0.55–2.37)	0.718	1.05 (0.48–2.27)	0.904	
AWGS 2025, hybrid (body fat > 29.7%/>37.2%)									
Without obesity	72/229	21/34	2.80 (1.72–4.56)	**< 0.001**	1.97 (1.18–3.28)	**0.009**	1.75 (1.02–3.00)	**0.041**	0.303
With obesity	24/90	11/29	1.50 (0.74–3.07)	0.263	1.14 (0.55–2.37)	0.718	1.05 (0.48–2.27)	0.904	
AWGS 2025, hybrid (body fat > 25%/>35%)									
Without obesity	50/164	14/20	3.56 (1.96–6.46)	**< 0.001**	2.67 (1.45–4.91)	**0.002**	2.20 (1.13–4.25)	**0.020**	0.050
With obesity	45/151	19/47	1.49 (0.87–2.55)	0.144	1.20 (0.69–2.09)	0.515	1.06 (0.59–1.90)	0.853	
AWGS 2025, hybrid (body fat > 30%/>40%)									

Obesity strata	Deaths / N		Hazard ratio (95% confidence interval)						*p* for interaction[d]
	No sarcopenia	Sarcopenia	Model 1[a]	*p*	Model 2[b]	*p*	Model 3[c]	*p*	
Obesity defined by body fat percentage									
Without obesity	76/255	23/36	3.15 (1.97–5.04)	**< 0.001**	2.16 (1.32–3.52)	**0.002**	1.97 (1.18–3.30)	**0.010**	0.242
With obesity	20/66	9/25	1.20 (0.55–2.64)	0.646	1.00 (0.44–2.27)	0.991	0.93 (0.39–2.21)	0.873	
Obesity defined by body mass index (≥ 25 kg/m²)									
AWGS 2019 (ASM/height²)									
Without obesity	34/135	39/73	2.63 (1.66–4.18)	**< 0.001**	2.07 (1.30–3.31)	**0.002**	1.86 (1.12–3.09)	**0.016**	**0.017**
With obesity	43/147	12/27	1.61 (0.85–3.05)	0.146	0.81 (0.41–1.61)	0.550	0.56 (0.26–1.22)	0.142	
AWGS 2025 (ASM/height²)									
Without obesity	52/172	21/36	2.63 (1.58–4.38)	**< 0.001**	2.45 (1.46–4.13)	**< 0.001**	2.14 (1.24–3.69)	**0.006**	**0.049**
With obesity	50/163	5/11	1.70 (0.68–4.26)	0.260	0.79 (0.30–2.05)	0.622	0.63 (0.23–1.74)	0.370	
AWGS 2025, BMI-adjusted (ASM/BMI)									
Without obesity	59/177	14/31	1.58 (0.88–2.83)	0.124	1.34 (0.73–2.45)	0.339	1.23 (0.65–2.32)	0.527	0.580
With obesity	40/138	15/36	1.57 (0.87–2.85)	0.135	1.04 (0.56–1.94)	0.904	0.95 (0.49–1.84)	0.876	
AWGS 2025, hybrid (body fat > 29.7%/>37.2%)									
Without obesity	52/172	21/36	2.63 (1.58–4.38)	**< 0.001**	2.45 (1.46–4.13)	**< 0.001**	2.14 (1.24–3.69)	**0.006**	**0.036**
With obesity	44/147	11/27	1.42 (0.73–2.76)	0.296	0.88 (0.44–1.75)	0.713	0.81 (0.39–1.67)	0.567	
AWGS 2025, hybrid (body fat > 25%/>35%)									
Without obesity	52/172	21/36	2.63 (1.58–4.38)	**< 0.001**	2.45 (1.46–4.13)	**< 0.001**	2.14 (1.24–3.69)	**0.006**	**0.031**

Obesity strata	Deaths / N		Hazard ratio (95% confidence interval)						*p* for interaction[d]
	No sarcopenia	Sarcopenia	Model 1[a]	*p*	Model 2[b]	*p*	Model 3[c]	*p*	
Obesity defined by body fat percentage									
With obesity	43/143	12/31	1.34 (0.71–2.54)	0.373	0.89 (0.46–1.72)	0.730	0.81 (0.40–1.62)	0.549	
AWGS 2025, hybrid (body fat > 30%/>40%)									
Without obesity	52/172	21/36	2.63 (1.58–4.38)	**< 0.001**	2.45 (1.46–4.13)	**< 0.001**	2.14 (1.24–3.69)	**0.006**	0.055
With obesity	44/149	11/25	1.59 (0.82–3.08)	0.170	0.95 (0.48–1.89)	0.883	0.88 (0.43–1.83)	0.738	
Obesity defined by waist circumference (males ≥ 90 cm, females ≥ 85 cm)									
AWGS 2019 (ASM/height²)									
Without obesity	42/138	34/67	1.99 (1.27–3.13)	**0.003**	1.47 (0.93–2.34)	0.100	1.20 (0.74–1.97)	0.460	0.866
With obesity	35/143	16/32	2.27 (1.25–4.10)	**0.007**	1.39 (0.75–2.60)	0.297	1.30 (0.65–2.60)	0.466	
AWGS 2025 (ASM/height²)									
Without obesity	57/172	19/33	2.47 (1.47–4.16)	**< 0.001**	2.09 (1.22–3.59)	**0.007**	1.62 (0.91–2.87)	0.101	0.696
With obesity	45/162	6/13	1.77 (0.75–4.15)	0.189	1.11 (0.47–2.65)	0.814	1.09 (0.42–2.87)	0.856	
AWGS 2025, BMI-adjusted (ASM/BMI)									
Without obesity	61/173	15/32	1.63 (0.93–2.88)	0.089	1.36 (0.75–2.47)	0.306	1.11 (0.59–2.10)	0.746	0.983
With obesity	38/141	13/34	1.49 (0.79–2.80)	0.215	1.03 (0.54–1.95)	0.939	0.99 (0.50–1.95)	0.967	
AWGS 2025, hybrid (body fat > 29.7%/>37.2%)									
Without obesity	57/171	19/34	2.33 (1.39–3.93)	**0.001**	2.08 (1.21–3.56)	**0.008**	1.61 (0.91–2.86)	0.104	0.594
With obesity	39/147	12/28	1.70 (0.89–3.24)	0.110	1.14 (0.59–2.19)	0.704	1.14 (0.56–2.30)	0.722	

Obesity strata	Deaths / N		Hazard ratio (95% confidence interval)						*p* for interaction[d]
	No sarcopenia	Sarcopenia	Model 1[a]	*p*	Model 2[b]	*p*	Model 3[c]	*p*	
Obesity defined by body fat percentage									
AWGS 2025, hybrid (body fat > 25%/>35%)									
Without obesity	56/170	20/35	2.44 (1.46–4.07)	**< 0.001**	2.17 (1.28–3.68)	**0.004**	1.69 (0.96–2.97)	0.071	0.400
With obesity	39/144	12/31	1.47 (0.77–2.81)	0.245	1.05 (0.55–2.03)	0.873	1.04 (0.52–2.09)	0.910	
AWGS 2025, hybrid (body fat > 30%/>40%)									
Without obesity	57/171	19/34	2.33 (1.39–3.93)	**0.001**	2.08 (1.21–3.56)	**0.008**	1.61 (0.91–2.86)	0.104	0.735
With obesity	39/149	12/26	1.89 (0.99–3.60)	0.055	1.22 (0.63–2.37)	0.548	1.25 (0.61–2.53)	0.540	

Abbreviations: ASM, appendicular skeletal muscle mass; AWGS, Asian Working Group for Sarcopenia; BMI, body mass index.

AWGS 2019 (ASM/height²): low muscle mass plus low muscle strength and/or low physical performance. AWGS 2025 (ASM/height²): low muscle mass plus low muscle strength, using age-specific cutoffs (50–64 and ≥ 65 years). AWGS 2025 (ASM/BMI): AWGS 2025 criteria with low muscle mass defined by ASM/BMI. AWGS 2025 (hybrid): AWGS 2025 criteria with low muscle mass defined by ASM/height² in participants without obesity and by ASM/BMI in participants with obesity, with obesity defined by the body fat cutoff shown.

Two participants with missing waist circumference were excluded from the waist circumference analysis (n = 380).

[a] Model 1: unadjusted.

[b] Model 2: adjusted for age and sex.

[c] Model 3: adjusted for age, sex, smoking status, alcohol consumption, regular exercise and comorbidity.

[d] *p* for interaction is from a sarcopenia × obesity product term in Model 3. It is a property of each definition rather than of an obesity stratum and is therefore reported once per definition.

p values < 0.05 are presented in bold.

All-cause and cause-specific mortality across sarcopenia–obesity phenotypes

All-cause mortality across the four sarcopenia–obesity phenotypes and the corresponding Kaplan–Meier survival curves are presented in Figs. 3 and 4, respectively. Under both the AWGS 2019 and 2025 criteria, participants with sarcopenia only had the lowest survival throughout follow-up (log-rank $p < 0.001$ for both criteria). Compared with the non-sarcopenic non-obese group, sarcopenia only was significantly associated with all-cause mortality under the AWGS 2025 criteria (HR 1.78, 95% CI 1.06–3.00, $p = 0.030$) but not the AWGS 2019 criteria (HR 1.47, 95% CI

0.94–2.29, $p = 0.092$). Neither obesity only nor sarcopenic obesity was significantly associated with mortality using either criterion (Fig. 3).

The association between sarcopenia only phenotype and all-cause mortality was consistent across all hybrid definitions (HR range 1.79–2.57, all $p < 0.05$) but not the BMI-adjusted definition (HR 1.16, 95% CI 0.66–2.01, $p = 0.610$) (Additional file 1: Table S1). In cause-specific analyses (Additional file 1: Table S2), sarcopenia only phenotype was significantly associated with cardiovascular mortality using the AWGS 2025 height-adjusted criteria (HR 3.24, 95% CI 1.16–9.03, $p = 0.024$) and all three hybrid definitions (HR range 2.97–5.47, all $p < 0.05$). For respiratory mortality, sarcopenia only phenotype was significantly associated with mortality using the AWGS 2019 criteria (HR 5.37, 95% CI 1.85–15.60, $p = 0.002$), the AWGS 2025 height-adjusted criteria (HR 4.01, 95% CI 1.28–12.50, $p = 0.017$) and all three hybrid definitions (HR range 4.18–7.37, all $p < 0.05$), but not the BMI-adjusted definition. No significant associations were observed for obesity only or sarcopenic obesity phenotypes across any definition.

Discussion

In this community-dwelling cohort, the AWGS 2025 criteria identified fewer participants with sarcopenia than the AWGS 2019 criteria. Sarcopenia defined by the AWGS 2025 height-adjusted criteria showed an elevated but borderline statistically significant association with all-cause mortality after full adjustment, whereas the corresponding association under AWGS 2019 was not statistically significant. Associations also varied by sex, obesity status, and the muscle mass index used. Sarcopenic obesity was not significantly associated with mortality, although the small size of this subgroup limits the precision of these estimates. Overall, our findings highlight the importance of diagnostic operationalization when examining the prognostic relevance of sarcopenia.

The choice of criteria substantially affected the prevalence of both sarcopenia and sarcopenic obesity. The more than two-fold difference between the criteria likely reflects differences in their diagnostic structures, with the 2019 criteria including low physical performance as a diagnostic component whereas the 2025 criteria reposition it as an outcome [7, 8]. This is consistent with a systematic review of community-dwelling older adults, in which definitions combining muscle mass with strength or physical performance showed lower prevalence estimates (9.9 to 18.6%) than definitions based on muscle mass alone (24.2 to 40.4%) [5]. This difference between the criteria may partly explain why the 2025 definition showed a stronger association with mortality. Physical performance can be impaired by conditions not primarily attributable to sarcopenia, such as osteoarthritis, musculoskeletal pain and neurological limitations [21–23]. Thus, the 2019 criteria may identify some individuals with impaired physical performance despite relatively less pronounced abnormalities in muscle mass or strength, whereas the emphasis of the 2025 criteria on muscle mass and strength might identify a smaller subgroup at higher mortality risk. The 2025 criteria also introduced a BMI-adjusted index for muscle mass. In our cohort, this index raised the prevalence of sarcopenia from 12.3% to 17.5% but attenuated the association with mortality. This is consistent with other cohort studies, in which the BMI-adjusted index classified a larger proportion of individuals with obesity as sarcopenic than the height-adjusted index [24, 25]. In contrast, the obesity-stratified hybrid definitions (ASM/height² in participants without obesity and ASM/BMI in participants with obesity) yielded relatively stable prevalence estimates across the three obesity cutoffs and showed a stronger association with mortality.

The association between sarcopenia and mortality was statistically significant in women but not in men, although evidence regarding sex differences remains inconsistent. Previous studies have reported associations in men but

not women [26, 27], a greater risk in women [28, 29] or significant associations in both sexes [30]. Potential mechanisms underlying sex differences in the association between sarcopenia and mortality include estrogen-related metabolic and inflammatory changes and greater arterial stiffness in women with sarcopenia [28, 30]. In cause-specific analyses, sarcopenia was associated with both cardiovascular and respiratory mortality, consistent with previous cohorts [31, 32]. Respiratory mortality showed particularly strong associations across the AWGS 2019, AWGS 2025 height-adjusted and hybrid definitions. This may reflect the age-related muscle loss of respiratory muscle and function, which can impair lung capacity and respiratory efficiency, and reduce peak expiratory flow has been shown to mediate part of the excess mortality associated with sarcopenia [33]. However, these associations were attenuated in Fine–Gray analyses accounting for competing risks, and the respiratory mortality associations observed in the cause-specific Cox models were no longer statistically significant. This difference between the cause-specific Cox and Fine–Gray results may reflect differences in how the two approaches account for competing events, and should be interpreted cautiously given the small number of cause-specific events.

Sarcopenia was significantly associated with all-cause mortality among participants without obesity, and the interaction between sarcopenia and obesity reached statistical significance when obesity was defined by BMI. Participants with sarcopenia alone had lower survival than the other phenotype groups, whereas sarcopenic obesity was not significantly associated with mortality relative to the non-sarcopenic non-obese group. Previous studies have reported heterogeneous findings: some found no modification by obesity, while meta-analytic evidence has associated sarcopenic obesity with elevated mortality compared with healthy older adults. Conversely, a recent meta-analysis reported lower mortality for sarcopenic obesity than for sarcopenia alone in community-dwelling older adults. In our cohort, the point estimate for sarcopenic obesity was also lower than that for sarcopenia alone. However, this pattern should be interpreted cautiously because the sarcopenic-obesity subgroup was small (n = 13), and our study was not designed to establish a protective effect of adiposity. The relatively low prevalence of severe obesity in this cohort and residual confounding may also have contributed to the observed findings.

The attenuated association with the BMI-adjusted index may reflect the paradoxical relationship between adiposity and mortality in older adults. BMI adjustment is recognized as more sensitive than height adjustment for identifying sarcopenia in individuals with obesity [36], and in our cohort, it classified a higher proportion of participants with obesity as having sarcopenia than the height-adjusted index. However, because excess adiposity was not associated with increased mortality risk in this cohort, the additional participants classified under BMI adjustment attenuated the association with mortality. Hybrid definitions may offer the advantage of applying each index according to obesity status, thereby avoiding under- or overestimation of sarcopenia in either group. In our cohort, the hybrid definitions yielded stable prevalence estimates and consistently strong associations with mortality, although studies applying this approach remain limited [37], and further investigation is warranted.

Several mechanisms may account for the obesity paradox observed in this cohort. The direction of the association between adiposity and mortality varies with age, and excess adiposity is associated with higher mortality risk in younger adults but with lower risk in older populations. Given the median age of 74 years in our cohort, the association between adiposity and survival may therefore have differed from that observed in younger populations. With advancing age, fat mass may accumulate before substantial muscle loss occurs, whereas fat mass may decline at later stages of ageing. Thus, sarcopenic obesity may precede sarcopenia without obesity in some individuals. Preserved adiposity in later life may therefore be associated with a relatively less advanced

stage of ageing, such that individuals with sarcopenia and higher fat mass may represent a biologically earlier stage of ageing than those with sarcopenia and lower fat mass [35].

To our knowledge, this is one of the first studies to compare the AWGS 2019 and 2025 criteria for all-cause, cardiovascular and respiratory mortality across multiple muscle mass and obesity definitions. Our study included DXA-derived body composition data and a median follow-up of 12.7 years in middle-aged and older adults. However, this study has several limitations. First, although our study included adults aged 50 years or older, the number of middle-aged participants aged 50–64 years was small (*n* = 62), limiting our ability to evaluate the middle-aged diagnostic criteria newly introduced in the AWGS 2025 framework. Second, the relatively small sample size resulted in a limited number of cause-specific events (28 cardiovascular and 22 respiratory deaths) and the sarcopenic-obesity subgroup (*n* = 13), which may have reduced the statistical power to detect associations. Third, despite adjustment for age, sex, lifestyle factors and comorbidity, residual confounding cannot be excluded. Future studies in larger and age-diverse cohorts are needed to compare alternative diagnostic definitions, identify the optimal muscle mass and obesity indices, and validate the prognostic utility of the AWGS 2025 framework.

In conclusion, this prospective cohort of community-dwelling Korean adults, the AWGS 2025 criteria identified fewer individuals with sarcopenia than the AWGS 2019 criteria. The association between sarcopenia and all-cause mortality varied according to the diagnostic criteria and muscle mass index, while sarcopenic obesity was not significantly associated with mortality. These findings suggest that the operational definition of sarcopenia may influence its observed prognostic associations. Larger studies are needed to establish the prognostic implications of the AWGS 2025 criteria and to clarify the relationship between sarcopenia, adiposity, and mortality.

Declarations

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Authors' contributions: YJK and HMN conceptualized and designed the study. DHK and JYJ curated the data, and YJK performed the statistical analyses. YJK and HMN drafted the manuscript. HJS, DHK, JYJ, and KHP critically reviewed and revised the manuscript. All authors read and approved the final manuscript.

Data availability statement: The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare no competing interests.

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Figures

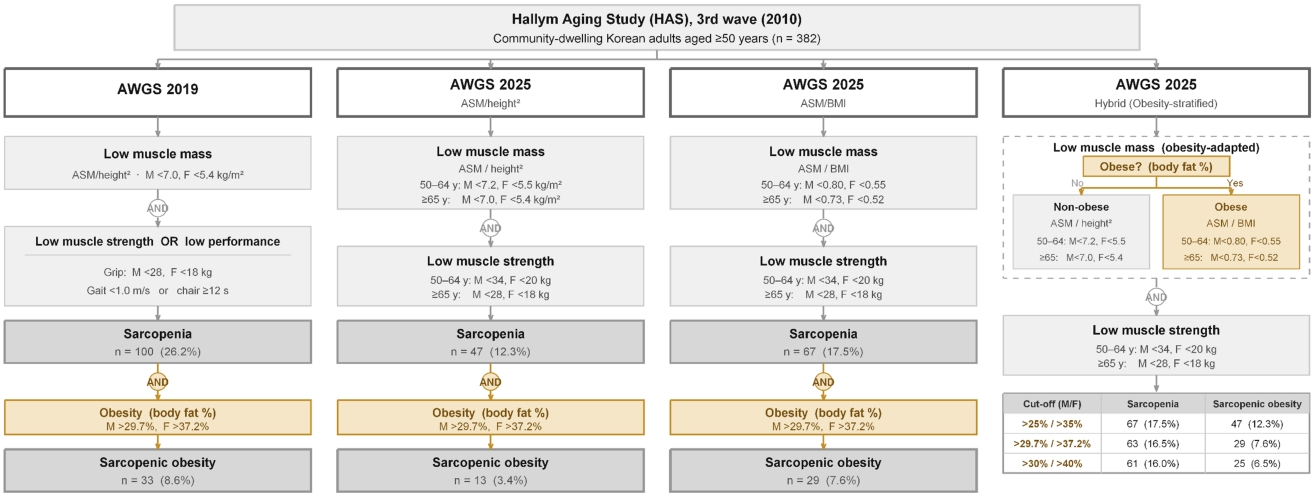


Figure 1

Diagnostic algorithms for sarcopenia and sarcopenic obesity using AWGS 2019 and AWGS 2025 criteria.

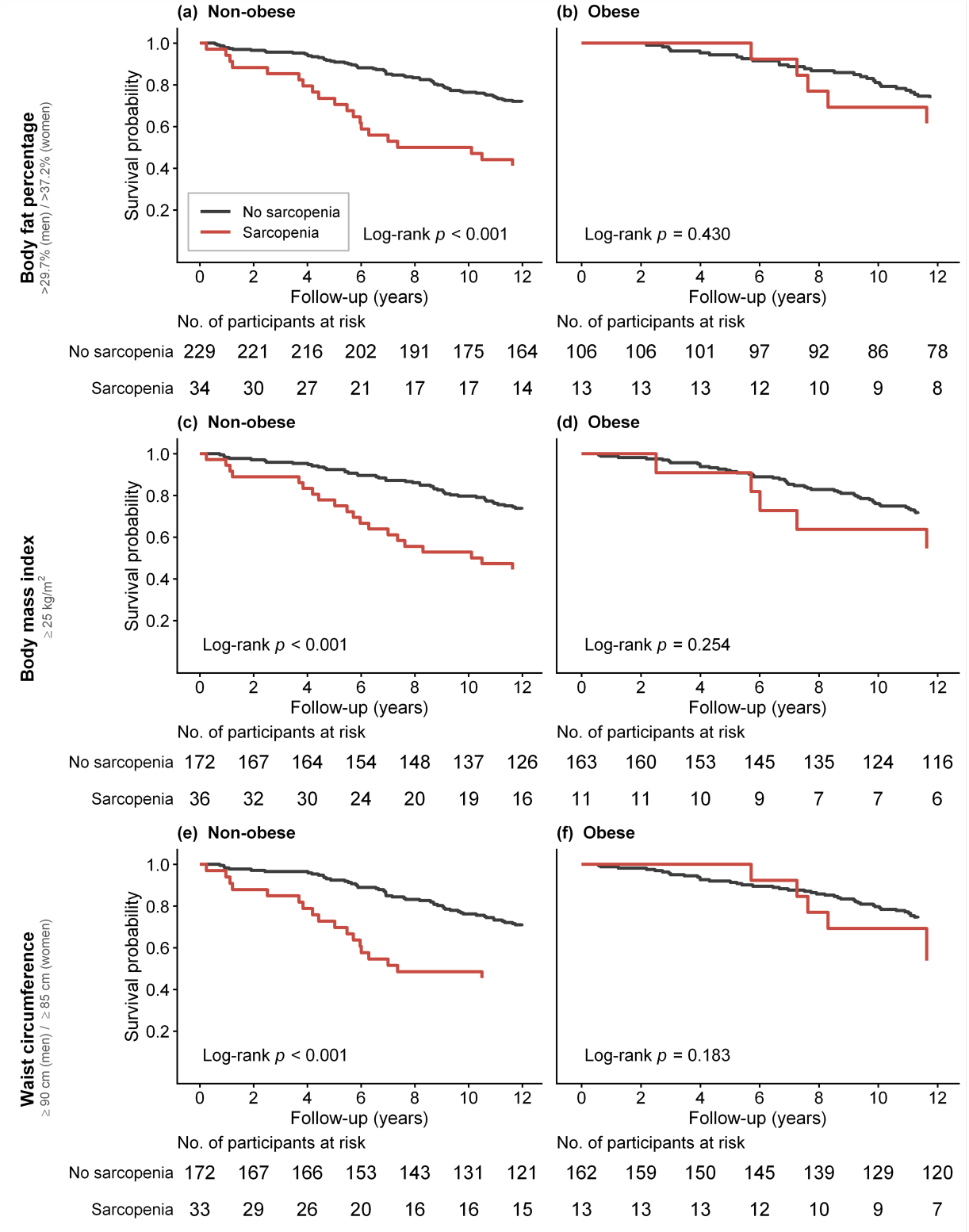


Figure 2

Survival by sarcopenia status within obesity strata according to three obesity definitions. Kaplan–Meier curves compare participants with sarcopenia (red) and those without sarcopenia (black) in the non-obese (left) and obese (right) groups. Sarcopenia was defined according to the AWGS 2025 criteria using ASM/height². Obesity was defined by body fat percentage (a, b), body mass index (c, d), and waist circumference (e, f). Numbers at risk are shown below each panel. After full adjustment, HRs for all-cause mortality were estimated using participants without sarcopenia as the reference: (a) HR 1.75 (95% CI 1.02–3.00, p = 0.041); (b) HR 1.07 (95% CI 0.35–3.22, p =

0.906); (c) HR 2.14 (95% CI 1.24–3.69, *p* = 0.006); (d) HR 0.63 (95% CI 0.23–1.74, *p* = 0.370); (e) HR 1.62 (95% CI 0.91–2.87, *p* = 0.101); and (f) HR 1.09 (95% CI 0.42–2.87, *p* = 0.856). The total number of events in each panel was as follows: (a) 93 (72 without sarcopenia and 21 with sarcopenia); (b) 35 (30 and 5); (c) 73 (52 and 21); (d) 55 (50 and 5); (e) 76 (57 and 19); and (f) 51 (45 and 6).

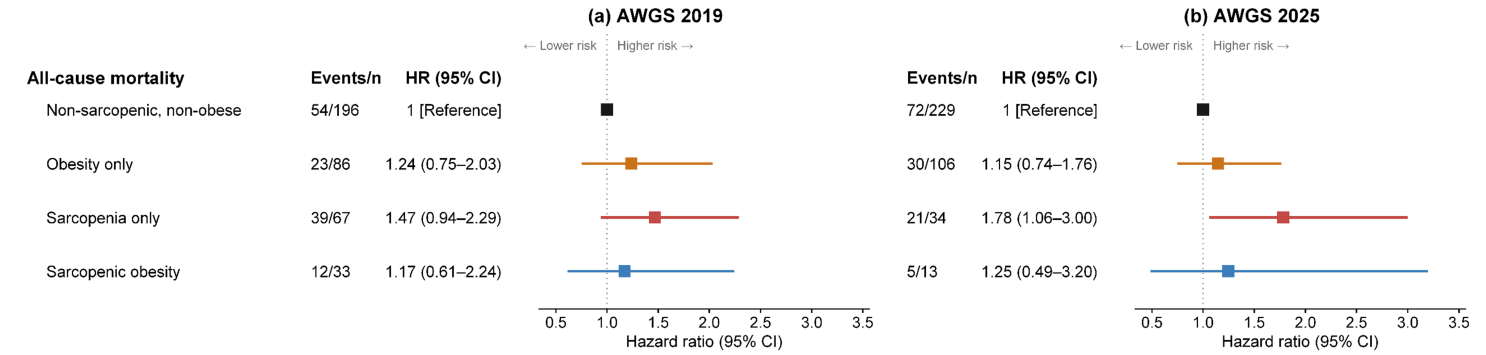


Figure 3

All-cause mortality across sarcopenia–obesity phenotypes using AWGS 2019 and AWGS 2025 criteria. Squares represent hazard ratios, and horizontal lines represent 95% confidence intervals, estimated from fully adjusted Cox proportional hazards models (Model 3: age, sex, smoking status, alcohol consumption, regular exercise, and comorbidity), with the non-sarcopenic, non-obese group as the reference. Obesity was defined by body fat percentage (>29.7% in men and >37.2% in women).

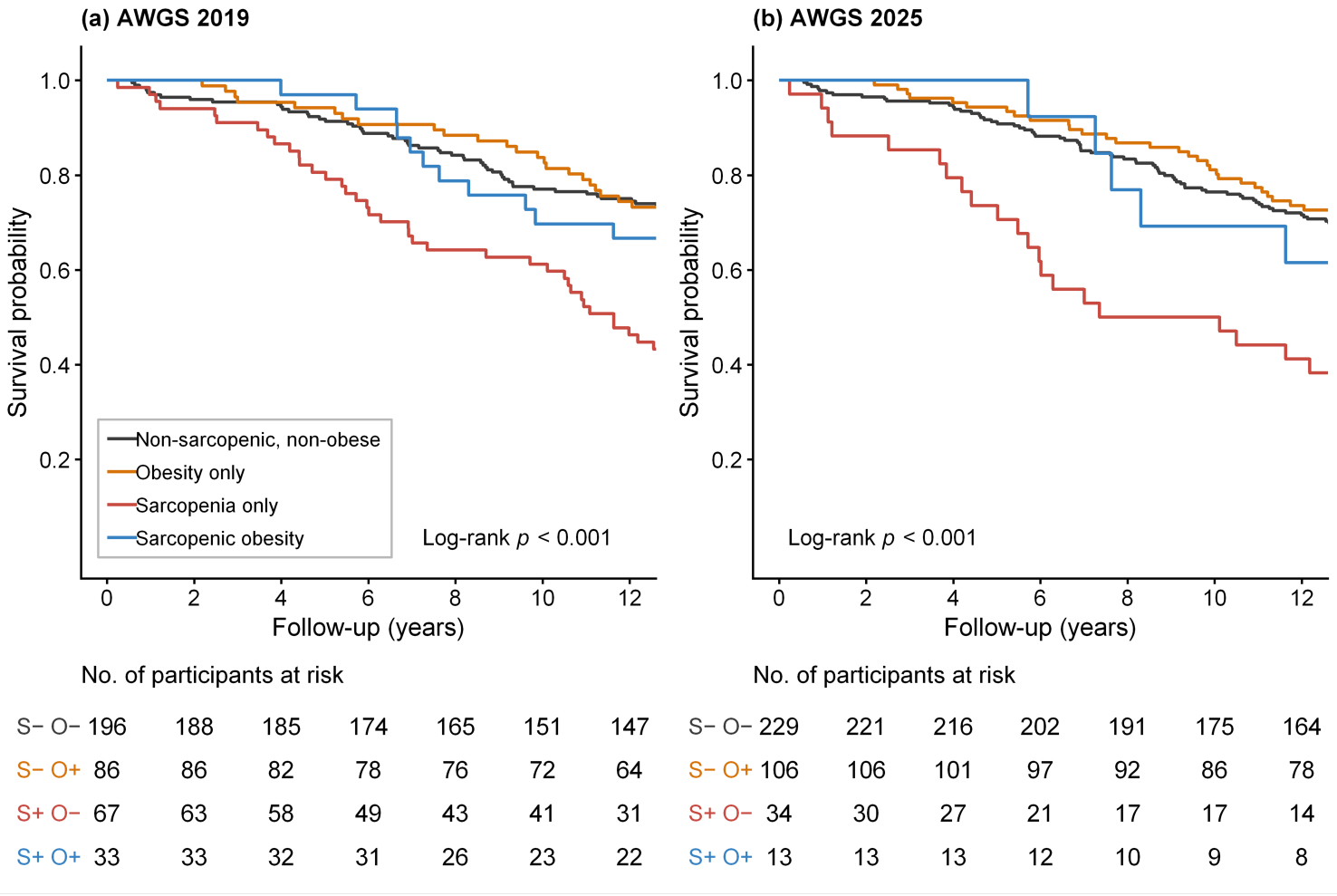


Figure 4

Kaplan–Meier curves for all-cause mortality across sarcopenia–obesity phenotypes. Obesity was defined by body fat percentage. The four phenotypes were non-sarcopenic and non-obese (S−O−), obesity only (S−O+), sarcopenia only (S+O−), and sarcopenic obesity (S+O+). Numbers at risk are shown below each panel. After full adjustment, HRs for all-cause mortality were estimated using S−O− as the reference: AWGS 2019, S−O+ HR 1.24 (95% CI 0.75–2.03, p = 0.404), S+O− HR 1.47 (95% CI 0.94–2.29, p = 0.092), and S+O+ HR 1.17 (95% CI 0.61–2.24, p = 0.631); AWGS 2025, S−O+ HR 1.15 (95% CI 0.74–1.76, p = 0.534), S+O− HR 1.78 (95% CI 1.06–3.00, p = 0.030), and S+O+ HR 1.25 (95% CI 0.49–3.20, p = 0.646). The total number of events was 128 in each analysis: AWGS 2019, S−O− = 54, S−O+ = 23, S+O− = 39, and S+O+ = 12; AWGS 2025, S−O− = 72, S−O+ = 30, S+O− = 21, and S+O+ = 5.

Supplementary Files

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