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Original Study

Prevalence and Associated Factors of Sarcopenia in Singaporean Adults—The Yishun Study

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A B S T R A C T

Objectives: To describe the normative values of sarcopenia among community-dwelling adults (≥21 years of age); compare the prevalence of sarcopenia using Asian Working Group for Sarcopenia criteria, 2014 (AWGS2014), Asian Working Group for Sarcopenia criteria, 2019 (AWGS2019), and European Working Group on Sarcopenia in Older People criteria, 2018 (EWGSOP2) guidelines; and identify factors associated with sarcopenia.
Design: Participants were recruited through random sampling. Sarcopenia assessments were performed using a dual-energy x-ray absorptiometry scan (muscle mass), handgrip test (muscle strength), and usual walking test (physical performance). Questionnaires were administered to evaluate lifestyle and cognition.
Setting and Participants: In total, 542 community-dwelling Singaporeans were recruited (21–90 years old, 57.9% women).
Methods: We assessed anthropometry, body composition, and questionnaire-based physical and cognitive factors, and estimated sarcopenia prevalence according to the AWGS2014, AWGS2019, and EWGSOP2 recommendations, and examined associations using logistic regression.
Results: According to AWGS2019, the Singapore population-adjusted sarcopenia prevalence was 13.6% (men 13.0%; women 14.2%) overall, and 32.2% (men 33.7%, women 30.9%) in those aged 60 years and above. The cut-offs derived from young adult reference group for low appendicular lean mass index were 5.28 kg/m2 for men and 3.69 kg/m2 for women (lower than AWGS recommended cut-off); for gait speed it was 0.82 m/s, (AWGS2019 recommended cut-off 1.0 m/s, AWGS2014 cut-off was 0.8 m/s); and for handgrip strength it was 27.9 kg/m2 for men and 16.7 kg/m2 for women (close to AWGS2019 recommendation). Age, sex, marital status, alcoholism, physical activity, body mass index, waist circumference, and global cognition were associated with sarcopenia ($P < .05$).
Conclusions and Implications: This is the first study to provide reference values of muscle mass, strength, and gait speed across the adult lifespan of Singaporeans. Using AWGS2019 criteria, sarcopenia is prominent in older age (32.2% in ≥60 years old), but it is already nontrivial (6.9%) among young and middle-age persons. Multidomain lifestyle modifications addressing muscle strength, cognition, and nutrition over the adult lifespan are important to delay the development of sarcopenia.

Sarcopenia is an age-associated muscle disease characterized by the progressive loss of muscle mass, strength, and function.[1] Given its associations with disability, falls, need for long-term care, and mortality,[1,2] rising sarcopenia prevalence because of longer life expectancy constitutes a public health concern. Since the recent upsurge in sarcopenia research (2000), studies have reported widely differing sarcopenia prevalence. To standardize its diagnosis and harmonize working definitions across studies, the European Working Group on

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Sarcopenia in Older People (EWGSOP) in 2010 published the first guidelines on sarcopenia classifications and diagnostic cut-offs.[3] In 2018, it revised its classification to recognize that low muscle strength constitutes "probable sarcopenia," low muscle mass confirms the diagnosis, and physical function determines the severity (European Working Group on Sarcopenia in Older People criteria, 2018, EWGSOP2).[1]

To address ethnic differences in body size and lifestyles, the Asian Working Group for Sarcopenia (AWGS) proposed its own diagnostic criteria for Asians in 2014 (Asian Working Group for Sarcopenia criteria, 2014, AWGS2014).[4] A 2016 review found widely differing prevalence in Asian populations, and concluded that further revisions to cut-offs are required, while calling for more data from Asia.[5] In 2019, the criteria was revised to recognize poor muscle strength and/or physical performance as "possible sarcopenia," and low muscle mass and poor muscle strength or physical performance as "sarcopenia," whereas the presence of all 3 constitutes "severe sarcopenia" (Asian Working Group for Sarcopenia criteria, 2019, AWGS2019).[6] The cut-offs for slow gait speed (GS) were raised from 0.8 to 1.0 m/s and low handgrip strength (HGS) for men from 26 to 28 kg. These changes are expected to inflate sarcopenia prevalence,[6] but to what extent is unknown.

In Singapore, a few small-sample studies have reported sarcopenia prevalence using different measurement instruments and sarcopenia domains on various population groups. Using the SARC-F, a questionnaire that assesses the 5 components of Strength, Assistance with walking, Rising from a chair, Climbing stairs, and Falls, a prevalence of 44.3% was reported for 115 outpatients (≥65 years of age) attending specialist clinics.[7] Among 186 community-dwelling older adults, 53.8% had low muscle mass [dual-energy x-ray absorptiometry (DXA)-appendicular lean mass (ALM)/ht^2] using EWGSOP cut-offs (Conference Abstract).[8] Amidst 387 type 2 diabetic older adults in primary care, 58% showed low muscle mass (bioimpedance estimated) and 28% had sarcopenia according to AWGS2014.[9] A fourth study, using AWGS2014 guidelines, reported a low muscle mass (bioimpedance estimated) prevalence of 20.6% among 400 community-dwelling adults (≥65 years of age).[10] These studies have several limitations. The SARC-F has low sensitivity in screening for sarcopenia.[11] Compared with the DXA, the bioimpedance estimate is also less reliable in measuring muscle mass because of its dependence on assessment conditions.[4] To date, there is no data on sarcopenia prevalence, muscle mass, and function based on gold standard measurements among Singaporeans in a representative community-dwelling sample that includes younger and older adults.

Studies suggest earlier onset and deterioration of muscle mass, strength, and function attributed to physiological and neuromuscular changes,[1] sedentary lifestyles,[12] inadequate nutrition,[13] obesity,[14] neurocognitive decline,[15] and more recently, the emerging role of gut microbiome in muscle health.[16] Studying the age-associated changes in muscle mass and function, development of sarcopenia across the lifespan, and its associated factors in the multi-ethnic population of Singapore contributes important data toward a better understanding and definition of sarcopenia among Asians.

The aims of the present study are (1) to describe the normative values of muscle mass, strength and function among community-dwelling adults in Singapore; (2) estimate sarcopenia prevalence using AWGS2014, AWGS2019, and EWGSOP2 guidelines; and (3) identify factors associated with AWGS2019 and EWGSOP2 sarcopenia.

Methods

Setting

Community-dwelling adults (≥21 years of age) were recruited from the large north-eastern residential town of Yishun in Singapore, residential population of 220,320 (50.6% female), with 12.2% older adults (≥65 years of age).[17] This is similar to the overall Singapore residential population of 4,026,210 (51.1% female), with 14.4% older adults (≥65 years of age).[17]

Participants

Random sampling was employed to obtain a representative sample of approximately 300 male and 300 female participants, filling quotas of 20 to 40 participants in each sex- and age-group (10-year age-groups between 21 and 60 years old; 5-year age-groups after 60 years old). Conventionally, the sample size of 30 or greater per age-group is sufficient for normative measures.[18] Between October 2017 and February 2019, using 2-stage random sampling, 50% of all housing blocks were selected, and 20% of the units were approached for participant recruitment. Between March and November 2019, 50% of all housing blocks were randomly selected and all units approached. Up to 3 eligible participants were recruited from each unit. Nonresponse units were recontacted a second time at a different time of day on a later date. Older adults (>75 years of age) were additionally recruited through community sources and from a list of registered participants in 4 senior activity centers. Exclusion criteria were individuals with disabilities, injuries, fractures or surgeries affecting function, neuromuscular, neurologic, and cognitive impairments, or more than 5 poorly controlled comorbidities. Pregnant women or those planning for pregnancy were also excluded. Overall response rate was 39.0%. Ethics approval was obtained from the National Healthcare Group DSRB (2017/00212). All respondents signed informed consent before participating in the study.

Questionnaires

Participants answered questionnaires pertaining to education level, housing type, living arrangement, marital status, smoking, and alcoholism; a health and medical questionnaire indicating medical conditions and comorbidities, a mini-nutritional assessment[19]; a global physical activity questionnaire (GPAQ)[20]; and the Longitudinal Aging Study Amsterdam physical activity questionnaire.[21]

Anthropometry

Body weight to the nearest 0.1 kg and height to nearest millimeter were measured using a digital balance and stadiometer (Seca, GmbH and Co. KG, Hamburg, Germany). Waist and hip circumferences were measured using a nonelastic, flexible measuring tape around the navel and widest part of the hips, respectively. Body mass index (BMI) was calculated as weight (kg) divided by height (m) squared.

Cognitive Assessment

Global cognition and cognitive domains including immediate and delayed memory, visuospatial, language, and attention were assessed using the Repeatable Battery for the Assessment of Neuropsychological Status.[22]

Body Composition

Bone mineral density and ALM were measured using DXA (Discovery WI, Hologic, Inc, Marlborough, MA). ALM index (ALMI) was calculated as ALM (kg) divided by height (m) squared, where ALM equals to the sum of lean mass in the upper and lower limbs.

HGS

HGS was assessed using the Jamar Plus+ Digital Hand Dynamometer (Patterson Medical, Cedarburg, WI). Seated with arms 90 degrees to the sides, 2 trials were taken per arm in an alternating fashion with 30 seconds of rest between trials. The highest reading was recorded.

GS

Usual GS was measured using the 6 m GAITRite Walkway (CIR Systems Inc, Sparta, NJ) with a 2 m lead in and out phase. Three trials were taken. The average GS was recorded.

Sarcopenia

Sarcopenia was assessed using the AWGS2014,[4] AWGS2019,[5] and EWGSOP2[1] criteria. Poor physical function was defined as GS < 1.0 m/s (AWGS2014 ≤0.8 m/s), low muscle mass as ALMI <7.0 and <5.4 kg/m^2, and muscle strength by HGS <28 kg (AWGS2014 <26 kg) and <18 kg for men and women, respectively. AWGS2014 categorizes low muscle mass and poor muscle strength and/or physical function as "sarcopenia."[4] AWGS2019 recognizes poor muscle strength and/or physical function as "probable sarcopenia," whereas low muscle mass and poor muscle strength or physical performance constitutes "sarcopenia confirmed."[5] EWGSOP2 recognizes low muscle strength as "probable sarcopenia," with low muscle mass confirming the diagnosis.[1] Presence of all 3 constitutes "severe sarcopenia" in both AWGS2019 and EWGSOP2.[1,5]

Statistical Analyses

SPSS v 22 (SPSS, Inc, Chicago, IL) was used for analysis. Continuous variables were reported as mean [standard deviation (SD)] and categorical variables as number (%). Sample estimates of sarcopenia were extrapolated to the general population weights by age groups. Univariate and multivariable logistic regressions using backward stepwise selection (removal threshold: $P = .05$) were performed to examine factors associated with sarcopenia, without correction for multiple significance testing. No sarcopenia and sarcopenia probable were grouped as "no sarcopenia," and "sarcopenia" was defined as sarcopenia confirmed and severe sarcopenia. Statistical significance was set at $P < .05$.

Results

A total of 542 participants (57.9% female) aged 21 to 90 years were recruited. Because of incomplete data from 6 participants, data from 536 participants were analyzed. Of these, 81.7% were Chinese, 8.6% Malays, 6.9% Indians, and 2.8% from other races. Mean age was 58.5 (18.8) years. The descriptive statistics are presented in Supplementary Table 1.

The prevalence of sarcopenic phenotypes according to age-groups are presented in Table 1, and comparisons among the 3 different criteria (ie, AWGS2014, AWGS2019, and EWGSOP2) shown in Figure 1. Participant characteristics and sarcopenia statuses are presented in Table 2. Overall population-adjusted prevalence of low muscle mass was 40.6%. Using AWGS2014 guidelines, the prevalence of low muscle strength was 7.3% and slow GS 4.1%. With AWGS2019, the prevalence of low muscle strength increased to 9.0% and slow GS to 24.0%, while prevalence of "probable sarcopenia" was 14.0%, "sarcopenia confirmed" 9.5%, and "severe sarcopenia" 4.1%, compared with EWGSOP2s 1.8% (probable), 3.1% (confirmed), and 4.1% (severe).

Overall sarcopenia prevalence according to AWGS2014 was 6.7% (male 6.9%; female 6.4%) compared with AWGS2019s 13.6% (male 13.0%; female 14.2%) and EWGSOP2s 7.1% (male 9.1%; female 5.3%; Supplementary Table 2).

Study Norms

The number of young adults sampled (21–40 years of age), mean age 30.5 (6.1) years, was $n = 121$ (55.4% female). Population-specific cut-offs, derived by subtracting 2 SD from the young reference mean,[1,3] for GS is 0.82 m/s (close to AWGS2014); for HGS, 27.9 and 16.7 kg (close to AWGS2019); and for ALMI, 5.28 and 3.69 kg/m2

Table 1
Prevalence of Sarcopenic Phenotypes According to Age Groups

Age Group (y)	21–30	31–40	41–50	51–60	61–65	66–70	71–75	76–80	≥81	Overall
AWGS2014 Sarcopenia										
Confirmed										
Male	0 (0)	0 (0)	0 (0)	1 (4.5)	3 (10.3)	4 (16.7)	7 (24.1)	8 (30.8)	13 (56.5)	36 (15.9)
Female	0 (0)	1 (2.9)	1 (2.6)	2 (5.4)	1 (3.2)	3 (8.6)	8 (27.6)	8 (23.5)	23 (62.2)	47 (15.2)
AWGS2019 Sarcopenia										
Probable										
Male	3 (10.7)	6 (23.1)	4 (20.0)	4 (18.2)	1 (3.4)	2 (8.3)	7 (24.1)	3 (11.5)	2 (8.7)	32 (14.1)
Female	2 (6.3)	4 (11.4)	4 (10.3)	5 (13.5)	2 (6.5)	7 (20.0)	5 (17.2)	13 (38.2)	8 (21.6)	50 (16.2)
Confirmed										
Male	0 (0)	0 (0)	0 (0)	2 (9.1)	5 (17.2)	5 (20.8)	5 (17.2)	7 (26.9)	7 (30.4)	31 (13.7)
Female	3 (9.4)	4 (11.4)	1 (2.6)	2 (5.4)	5 (16.1)	6 (17.1)	11 (37.9)	8 (23.5)	12 (32.4)	47 (15.2)
Severe										
Male	1 (3.6)	0 (0)	0 (0)	1 (4.5)	2 (6.9)	2 (8.3)	6 (20.7)	7 (26.9)	10 (43.5)	29 (12.8)
Female	0 (0)	0 (0)	0 (0)	1 (2.7)	1 (3.2)	1 (2.9)	2 (6.9)	5 (14.7)	15 (40.5)	25 (8.1)
EWGSOP2 Sarcopenia										
Probable										
Male	1 (3.6)	0 (0)	0 (0)	0 (0)	0 (0)	2 (8.3)	3 (10.3)	1 (3.8)	1 (4.3)	8 (3.5)
Female	0 (0)	0 (0)	0 (0)	1 (2.7)	1 (3.2)	2 (5.7)	0 (0)	5 (14.7)	3 (8.1)	12 (3.9)
Confirmed										
Male	0 (0)	0 (0)	0 (0)	1 (4.5)	2 (6.9)	2 (8.3)	2 (6.9)	3 (11.5)	3 (13.0)	13 (5.7)
Female	0 (0)	1 (2.9)	0 (0)	1 (2.7)	0 (0)	2 (5.7)	4 (13.8)	1 (2.9)	3 (8.1)	12 (3.9)
Severe										
Male	1 (3.6)	0 (0)	0 (0)	1 (4.5)	2 (6.9)	2 (8.3)	6 (20.7)	7 (26.9)	10 (43.5)	29 (12.8)
Female	0 (0)	0 (0)	0 (0)	1 (2.7)	1 (3.2)	1 (2.9)	2 (6.9)	5 (14.7)	15 (40.5)	25 (8.1)

Values are presented as number (%).

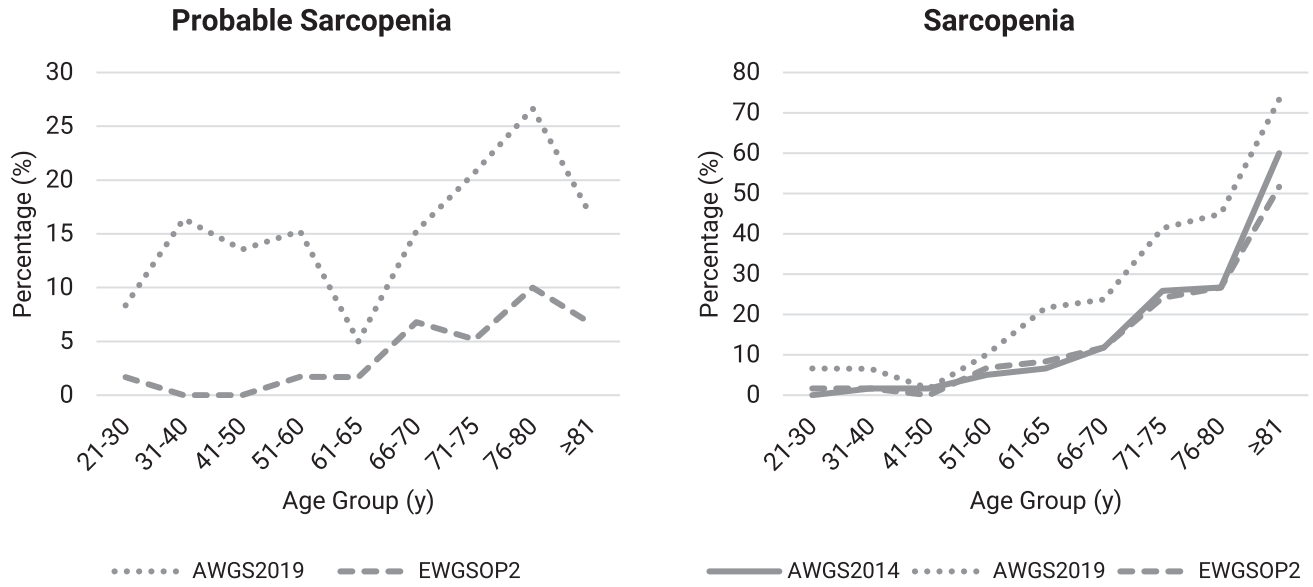

Fig. 1. Comparisons among the diagnostic criteria; AWGS2014, AWGS2019, and EWGSOP2.

(lower than AGWS) for men and women, respectively. Using these cut-offs, the prevalence of low muscle strength is 7.2% (overall) and 18.9% (≥60 years of age), muscle mass 0.3% (overall) and 1.1% (≥60 of age), and physical performance 4.9% (overall) and 11.9% (≥60 of age).

Factors associated with sarcopenia

Table 3 shows the results of significant variables associated with sarcopenia in a regression model from backward stepwise selection. Across age, AWGS2019 sarcopenia prevalence was 6.9% (21–59 years of age), 32.2% (≥60 years of age), 39.1% (≥65 years of age), and 53.4% (≥75 years of age).

With AWGS2019, age, ethnicity, education level, housing type, living arrangement, and marital status were associated with sarcopenia in univariate analysis ($P < .05$). Age and marital status remained significant after multivariable analyses ($P < .01$). With EWGSOP2, age, sex, and marital status were associated with sarcopenia after multivariable analyses ($P < .05$).

Health and Medical Conditions

Diabetes, hypertension, high cholesterol, and number of medical conditions were associated with sarcopenia in univariate analyses ($P < .01$). Alcoholism was associated with AWGS2019 sarcopenia after multivariable analyses ($P < .01$).

Nutrition and Physical Activity

Mini-nutritional assessment and GPAQ were associated with sarcopenia in univariate analyses ($P < .05$). GPAQ remained significant after multivariable analyses in both AWGS2019 ($P < .01$) and EWGSOP2 ($P < .05$).

Anthropometry and Body Composition

With univariate analysis, BMI and hip circumference were associated with sarcopenia ($P < .001$). Bone mineral density was associated with AWGS2019 sarcopenia ($P < .01$). After multivariable analyses, BMI remained significant ($P < .001$), while waist circumference was associated with AWGS2019 sarcopenia ($P < .05$).

Cognitive Performance

Global cognition was associated with sarcopenia in univariate analyses ($P < .001$) and remained significant after multivariable analyses ($P < .05$).

Discussion

Our study contributes to a growing Asian database for sarcopenia. It is the first population-based study to present reference values for muscle mass, strength, GS, and sarcopenia prevalence across the age groups of community-dwelling Singaporean adults. Sarcopenia prevalence vary widely across studies.[5] Our estimated AWGS2014 prevalence was 18.0% (≥60 years of age) and 24.1% (≥65 years of age), at the upper range (5.5%–25.7%) of those surveyed in the recent AWGS update.[4] Other East Asian studies have reported similar prevalence of 27.8% (Korea)[23] and 29.7% (China),[24] as well as much lower ones of 8.6% (Japan)[25] and 6.8% (Taiwan).[26]

Despite similarities in ethnicities and body size, the wide-ranging prevalences reported across Asian studies are attributable to the different assessment methods. Muscle mass assessed through bioimpedance analysis[23,24] is less consistent and reliable than DXA because of its dependence on hydration status, humidity, and other assessment conditions.[4] There are yet insufficient studies to validate the use of bioimpedance analysis for specific Asian populations.[1,4] The Lunar DXA machine[26] may also give differing results from the Hologic machine used in this study.[27] Interinstrumental DXA measurements have low reliability and significant intermanufacturer differences.[27] Furthermore, HGS assessed with the Smedley dynamometer[25,26] has low agreement with the Jamar dynamometer used in this study.[28] Recommended by the American Society of Hand Therapists, the Jamar is the most widely used and tested, has higher inter- and intra-individual reliability, and is considered the "gold standard."[28]

Sociodemographic differences among study populations (ie, rural-dwellers,[23] suburban-dwellers,[25] working farmers,[26] and city community-dwellers[24]) could have further contributed to the heterogeneity of sarcopenia prevalence in Asian studies. In addition, only 44.8% of Yuki et al's[25] participants were aged ≥75 years, compared with 54.8% in this study. Huang et al[26] further

Table 2
Participant Characteristics and Sarcopenia Status According to AWGS2019

Characteristics	Total n = 536	No Sarcopenia n = 317	Probable n = 82	Confirmed n = 83	Severe n = 54
Age (y)	58.5 (18.8)	51.5 (17.2)	62.4 (18.6)	69.6 (14.5)	76.7 (10.3)
21–40	121 (22.6)	98 (30.9)	15 (18.3)	7 (8.4)	1 (1.9)
41–60	118 (22.0)	94 (29.7)	17 (20.7)	5 (6.0)	2 (3.7)
61–80	237 (44.2)	119 (37.5)	40 (48.8)	52 (62.7)	26 (48.1)
≥81	60 (11.2)	6 (1.9)	10 (12.2)	19 (22.9)	25 (46.3)
Sex					
Male	227 (42.4)	135 (42.6)	32 (39.0)	31 (37.3)	29 (53.7)
Female	309 (57.6)	182 (57.4)	50 (61.0)	52 (62.7)	25 (46.3)
Ethnicity					
Chinese	438 (81.7)	259 (81.7)	57 (69.5)	76 (91.6)	46 (85.2)
Malay	46 (8.6)	33 (10.4)	11 (13.4)	1 (1.2)	1 (1.9)
Indian	37 (6.9)	18 (5.7)	9 (11.0)	5 (6.0)	5 (9.3)
Others	15 (2.8)	7 (2.2)	5 (6.1)	1 (1.2)	2 (3.7)
Highest qualification					
≤Primary	173 (32.3)	62 (19.6)	39 (47.6)	42 (50.6)	30 (55.6)
Secondary	165 (30.8)	110 (34.7)	16 (19.5)	26 (31.3)	13 (24.1)
Tertiary	115 (21.5)	84 (26.5)	15 (18.3)	11 (13.3)	5 (9.3)
≥Degree	83 (15.5)	61 (19.2)	12 (14.6)	4 (4.8)	6 (11.1)
Years of education (y)					
≤6	169 (31.5)	59 (18.6)	38 (46.3)	42 (50.6)	30 (55.6)
7–12	201 (37.5)	134 (42.3)	23 (28.0)	27 (32.5)	17 (31.5)
≥13	166 (31.0)	124 (39.1)	21 (25.6)	14 (16.9)	7 (13.0)
Housing type					
1–2 rooms	63 (11.8)	21 (6.6)	11 (13.4)	15 (18.1)	16 (29.6)
3 rooms	111 (20.7)	64 (20.2)	12 (14.6)	26 (31.3)	9 (16.7)
4–5 rooms	316 (59.0)	201 (63.4)	53 (64.6)	37 (44.6)	25 (46.3)
High-end Public/private	46 (8.6)	31 (9.8)	6 (7.3)	5 (6.0)	4 (7.4)
Living arrangement (n = 487)					
Alone	42 (8.6)	19 (6.8)	4 (5.3)	11 (13.9)	8 (15.1)
Not alone	445 (91.4)	261 (93.2)	71 (94.7)	68 (86.1)	45 (84.9)
Marital status (n = 509)					
Married	348 (68.4)	215 (71.9)	53 (67.9)	49 (62.0)	31 (58.5)
Single	75 (14.7)	61 (20.4)	6 (7.7)	6 (7.6)	2 (3.8)
Divorced/separated	17 (3.3)	8 (2.7)	2 (2.6)	5 (6.3)	2 (3.8)
Widowed	69 (13.6)	15 (5.0)	17 (21.8)	19 (24.1)	18 (34.0)
Medical conditions					
No known conditions	236 (44.0)	174 (54.9)	28 (34.1)	24 (28.9)	10 (18.5)
Diabetes	80 (14.9)	28 (8.8)	16 (19.5)	17 (20.5)	19 (35.2)
Hypertension	196 (36.6)	80 (25.2)	38 (46.3)	44 (53.0)	34 (63.0)
High cholesterol	202 (37.7)	85 (26.8)	46 (56.1)	41 (49.4)	30 (55.6)
Others	33 (6.2)	18 (5.7)	4 (4.9)	6 (7.2)	5 (9.3)
1–3	258 (48.1)	132 (41.6)	45 (54.9)	48 (57.8)	33 (61.1)
≥4	42 (7.8)	11 (3.5)	9 (11.0)	11 (13.3)	11 (20.4)
Smoking and drinking					
Smokers/ex-smokers	115 (21.5)	66 (20.8)	18 (22.0)	16 (19.2)	15 (27.8)
Alcoholics/ex-alcoholics	46 (8.6)	25 (7.9)	4 (4.9)	10 (12.0)	7 (13.0)
Smoke and drink	25 (4.7)	12 (3.8)	3 (3.7)	4 (4.8)	6 (11.1)

Values are presented as mean (SD) or number (%).

acknowledged that their participants, mostly working farmers, had remarkable physical activity levels that probably protected them from sarcopenia.

AWGS2019 Cut-Offs

Our study sheds light on the ramifications of the AWGS guidelines that are promulgated and revised with the intent to reduce heterogeneity of prevalence and to standardize sarcopenia diagnosis. Sarcopenia prevalence in this study increased from 6.7% (AWGS2014) to 13.6% (AWGS2019) because of the revisions in diagnostic criteria. The proportions of our sample with low HGS increased from 7.3% to 9.0%, and slow GS from 4.1% to 24.0%, the latter being most responsible for inflating sarcopenia prevalence. At the very least, this calls for caution when interpreting data according to the AWGS2014 and the current AWGS2019 criteria. To better refine diagnostic criteria, more normative data of HGS, GS, and especially DXA-muscle mass based on young reference adult Asian populations are needed. Our population-derived cut-offs for HGS for men (27.9 kg) is identical to AWGS2019 (28 kg), and for women (16.7 kg) just a little lower than AWGS2019 (18 kg). For GS, our cut-off (0.82 m/s) is lower than the revised AWGS2019 (1.0 m/s), but close to the original AWGS2014 (0.8 m/s). For DXA-ALMI, our cut-offs for men and women (5.28 and 3.69 kg/m^2) are considerably lower than AWGS2019 (7.0 and 5.4 kg/m^2). The latter cut-off values are placed at about the mean of this reference population for women, and roughly 1 SD below the mean for men, not 2 SD below the mean, which has the effect of inflating low muscle mass prevalence.

Factors Associated with Sarcopenia

Multivariable logistic regression using backward stepwise selection procedures revealed that age, sex, marital status, alcoholism, physical activity, BMI, waist circumference, and global cognition were associated with sarcopenia. In sensitivity analyses, we also used forward selection which led to identical findings as backward selection for AWGS2019 analyses, but for EWGSOP2, it identified the same but 2 fewer risk factors. The full saturated models identified the same but 1 fewer risk factor for AWGS2019, and the same but 3

Table 3
Factors Associated with Sarcopenia Using Logistic Regression

Characteristics	Univariate		Multivariable	
	AWGS2019	EWGSOP2	AWGS2019	EWGSOP2
	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Age, y	1.08 (1.06–1.10)***	1.10 (1.08–1.13)***	1.07 (1.04–1.09)***	1.08 (1.04–1.12)***
Sex				
Female	1	1	–	1
Male	1.08 (0.73–1.60)	1.67 (1.03–2.70)*	–	2.20 (1.15–4.19)*
Ethnicity				
Non-Chinese	1	1	–	–
Chinese	2.14 (1.19–3.85)*	1.88 (0.91–3.91)	–	–
Education level				
Tertiary and above	1	1	–	–
Secondary and below	3.24 (2.02–5.18)***	3.13 (1.71–5.74)***	–	–
Housing type				
4-Room and above	1	1	–	–
3-Room and below	2.51 (1.68–3.74)***	1.82 (1.12–2.96)*	–	–
Living arrangement				
Not alone	1	1	–	–
Alone	2.43 (1.28–4.62)**	1.76 (0.83–3.76)	–	–
Marital status				
Not married	1	1	1	1
Married	0.63 (0.41–0.95)*	0.64 (0.39–1.05)	0.41 (0.23–0.73)**	0.48 (0.25–0.94)*
Diabetes				
No	1	1	–	–
Yes	2.88 (1.76–4.71)***	3.13 (1.79–5.44)***	–	–
Hypertension				
No	1	1	–	–
Yes	3.15 (2.11–4.70)***	3.23 (1.98–5.29)***	–	–
High cholesterol				
No	1	1	–	–
Yes	2.20 (1.48–3.27)***	1.98 (1.23–3.21)**	–	–
No. of medical conditions	1.56 (1.36–1.80)***	1.45 (1.24–1.70)***	–	–
Smoker/ex-smoker				
No	1	1	–	–
Yes	1.10 (0.69–1.75)	1.19 (0.68–2.09)	–	–
Alcoholic/ex-alcoholic				
No	1	1	1	–
Yes	1.81 (0.96–3.40)	1.24 (0.56–2.77)	4.04 (1.59–10.22)**	–
Self-rated health	1.05 (0.82–1.35)	1.32 (0.98–1.79)	–	–
MNA score	0.76 (0.67–0.87)***	0.80 (0.68–0.92)**	–	–
Physical Activity				
GPAQ, MET h/wk	0.99 (0.99–1.00)***	0.99 (0.99–1.00)**	0.99 (0.99–1.00)**	0.99 (0.99–1.00)*
LAPAQ, MET h/wk	1.00 (0.99–1.00)	1.00 (0.99–1.00)	–	–
BMI, kg/m^2	0.82 (0.77–0.87)***	0.83 (0.77–0.90)***	0.66 (0.58–0.77)***	0.78 (0.71–0.86)***
Waist circumference, cm	0.98 (0.97–1.00)	0.99 (0.97–1.01)	1.05 (1.00–1.11)*	–
Hip circumference, cm	0.92 (0.89–0.95)***	0.92 (0.88–0.95)***	–	–
RBANS total score	0.98 (0.97–0.98)***	0.98 (0.97–0.98)***	0.99 (0.98–1.00)*	0.99 (0.98–1.00)*
BMD (w/o head), g/cm^2	0.06 (0.01–0.33)**	0.34 (0.05–2.35)	–	–

BMD, bone mineral density; CI, confidence interval; LAPAQ, Longitudinal Aging Study Amsterdam Physical Activity Questionnaire; MET: Metabolic Equivalent of Task; MNA, Mini Nutritional Assessment; OR, odds ratio; RBANS, Repeatable Battery for the Assessment of Neuropsychological Status.
*$P < .05$; **$P < .01$; ***$P < .001$.

fewer risk factors for EWGSOP2. Forward selection has the drawback of suppressor effects, whereas leaving a large number of clearly insignificant factors in the model reduces the effects of potentially significant factors.

Older men were more likely to develop sarcopenia[25,26,29,30] as age-related hormonal changes affect men more than women.[30] Although age-associated decrease in sex hormones is a major contributor to loss of lean mass and increase in fat mass for both sexes, fat promotes the conversion of androgens to estrogens, a process that exhibits anabolic effects only in women,[31] thereby attenuating the loss of lean mass and strength in women but not in men.

Higher BMI lowered the risk of sarcopenia.[10,32] Overweight and obese individuals are better-nourished with diets higher in calories, proteins, and nutrients, translating to better health outcomes than the underweight and malnourished.[13,32] However, a larger waist circumference increased sarcopenia risk. Excess body fat exacerbates fat infiltration into muscle, decreasing muscle quality and physical performance.[1,32] Increased abdominal and visceral fat stimulates the production of proinflammatory cytokines that perpetuate chronic and muscle inflammation, further contributing to muscle loss.[30] Moreover, obese individuals are often less physically active, resulting in a gradual decrease in muscle mass and strength.[32] Given the contrasting evidence, it is important to assess adiposity in addition to BMI.

Poorer global cognition increased sarcopenia risk. Gait and function require input from the executive functional, attentional, visuospatial and memory resources.[33] Declining cognitive functions and brain structures affect gait and balance,[34] and corroboratively, lower IQ, smaller brain volume, and cortical thinning were associated with slower GS, suggesting that gait was influenced by brain health and neurocognition.[15] Indeed, a recent study reported the association between lower, but not upper, extremity muscle mass and cognitive impairment in persons with type 2 diabetes.[35] More

studies can elucidate the relationship between specific cognitive domains and gait. Taken together, lower-extremity strength and cognition, both domains of intrinsic capacity,[36] are important factors in sarcopenia prevention.

Low physical activity levels were associated with sarcopenia. Physical activity, although inconsistent in maintaining muscle mass and strength, lowers sarcopenia risk possibly, through its effects on preserving physical function.[12]

Interestingly, alcoholism was associated with AWGS2019 but not EWGSOP2 sarcopenia. This could be attributed to the different diagnostic criteria; poor physical function is confirmative of AWGS2019 sarcopenia, but merely indicative of severity in EWGSOP2. Excessive alcohol intake propagates systemic inflammation, leading to mobility limitations and decreased physical performance.[37] More specific measures of alcohol consumption could clarify our understanding of its effects on sarcopenia.

Notably, married adults had lower sarcopenia risk. Marital status is critical, especially in mid- to later-life, in regards to its protective effects on health and mortality through mutual care provision and reception.[38]

Sarcopenia in Younger Adults

Among younger and middle-age adults (21–59 years), 32.4% have low muscle mass and 14.1% have probable sarcopenia, whereas 6.9% have sarcopenia, suggesting that sarcopenia was not exclusive to the older adults. Interventions to improve and maintain intrinsic capacity are needed well before old age so as to delay functional disability. Consistent with previous reports, our data showed that muscle mass and strength peak in early adulthood (31–40 years) before declining thereafter.[39] Indeed, sarcopenia can develop from a multitude of factors secondary to aging,[1] of which, physical inactivity, poor nutrition, and obesity have been discussed previously.[12–14] Identifying and implementing multidomain lifestyle modifications over the adult lifespan and across life-stage transitions may be important to effectively prevent or delay the development of sarcopenia. Such multidomain lifestyle interventions have been shown to reverse sarcopenia in community-dwelling older adults.[40]

This study has several limitations. It presents cross-sectional data on the muscular health and function of Singaporeans and is subject to cohort effects. This may actually mean the younger generation of Singaporeans are at increased risk of sarcopenia. Age-related changes may not fully reflect the temporal changes across the lifetime, as well as the longitudinal trajectories of muscle mass and function, and the causal relationships between sarcopenia and the associated parameters. The participants were also relatively healthy, community-dwelling adults; therefore, the findings may not be generalizable to the institutionalized or disabled individuals.

Conclusions and Implications

This study presents new and much-needed reference data for appendicular lean mass index, HGS, GS, and sarcopenia prevalence across age groups of community-dwelling adults in Singapore. Age, sex, marital status, alcoholism, physical activity, BMI, waist circumference, and global cognition are associated with sarcopenia. Moreover, some younger adults are already at risk of sarcopenia. These findings add to Asian data on sarcopenia definition and suggest the important role of multidomain lifestyle interventions to strengthen or maintain intrinsic capacity in younger and middle-age adults to reduce sarcopenia so as to delay functional disability in old age.

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Supplementary Table 1
Descriptive Statistics by Sex and Age Groups

Age Group (y)	21–30	31–40	41–50	51–60	61–65	66–70	71–75	76–80	≥81	Overall
Sample Size (n)										
Male	28	26	20	22	29	24	29	26	23	227
Female	32	35	39	37	31	35	29	34	37	309
Age (y)										
Male	25.1 (2.8)	35.9 (2.9)	45.8 (2.5)	57.0 (2.5)	63.1 (1.4)	68.3 (1.4)	72.9 (1.7)	77.9 (1.3)	83.7 (2.3)	58.8 (19.1)
Female	25.1 (2.8)	35.9 (2.9)	45.6 (3.0)	55.1 (3.0)	63.1 (1.4)	67.8 (1.5)	72.5 (1.6)	77.9 (1.5)	83.1 (2.1)	58.4 (18.6)
Height (m)										
Male	1.73 (0.07)	1.70 (0.05)	1.68 (0.06)	1.69 (0.07)	1.66 (0.06)	1.65 (0.05)	1.65 (0.06)	1.62 (0.07)	1.62 (0.07)	1.67 (0.07)
Female	1.60 (0.05)	1.59 (0.05)	1.57 (0.07)	1.57 (0.06)	1.55 (0.05)	1.54 (0.05)	1.53 (0.05)	1.52 (0.05)	1.48 (0.04)	1.55 (0.06)
Weight (kg)										
Male	80.4 (22.4)	81.2 (20.0)	76.8 (13.4)	73.5 (10.9)	66.2 (8.0)	65.9 (10.9)	65.4 (8.5)	63.0 (10.3)	61.6 (11.4)	70.3 (15.4)
Female	57.7 (11.7)	61.6 (12.3)	63.4 (11.7)	63.1 (14.1)	58.8 (8.7)	59.3 (7.6)	53.8 (8.4)	57.5 (8.2)	52.8 (8.6)	58.8 (10.9)
BMI (kg/m^2)										
Male	27.1 (8.2)	28.0 (6.7)	27.2 (3.8)	25.7 (3.2)	24.0 (2.9)	24.0 (3.4)	24.2 (3.2)	23.7 (3.0)	23.5 (4.1)	25.2 (4.9)
Female	22.5 (4.5)	24.5 (4.7)	25.7 (4.3)	25.6 (5.5)	24.4 (3.6)	25.0 (3.0)	22.9 (3.7)	25.0 (3.5)	24.2 (4.0)	24.5 (4.2)
WC (cm)										
Male	91.3 (18.6)	94.2 (17.4)	94.3 (8.3)	91.7 (8.8)	89.7 (8.0)	89.8 (9.1)	91.9 (9.4)	90.1 (9.4)	90.6 (9.9)	91.4 (11.7)
Female	77.1 (11.8)	83.1 (11.4)	84.9 (11.0)	86.9 (12.4)	87.4 (9.3)	89.6 (6.9)	86.0 (10.4)	89.7 (8.9)	89.4 (8.9)	86.1 (10.8)
HC (cm)										
Male	102.6 (13.9)	103.0 (12.6)	99.1 (7.6)	98.9 (6.6)	95.3 (4.8)	96.1 (6.7)	96.8 (5.9)	95.5 (6.7)	96.1 (7.1)	98.1 (8.9)
Female	96.0 (8.5)	99.0 (10.0)	100.7 (9.2)	101.7 (11.1)	98.9 (7.8)	100.1 (6.8)	95.9 (6.7)	99.2 (6.7)	97.9 (8.3)	98.9 (8.6)
HGS (kg)										
Male	42.3 (8.1)	44.6 (7.4)	42.1 (6.5)	40.0 (6.7)	35.5 (5.9)	32.9 (5.9)	29.0 (7.0)	28.3 (4.8)	24.4 (7.4)	35.3 (9.4)
Female	25.7 (4.7)	26.2 (4.6)	27.7 (5.3)	23.7 (4.1)	23.1 (3.7)	22.8 (4.5)	21.1 (4.2)	19.6 (4.1)	17.9 (3.4)	23.1 (5.3)
ALMI (kg/m^2)										
Male	7.86 (1.44)	8.16 (1.29)	7.72 (1.07)	7.66 (1.11)	6.73 (0.70)	6.63 (0.74)	6.48 (0.71)	6.37 (0.71)	6.19 (0.97)	7.07 (1.21)
Female	5.36 (0.90)	5.76 (0.95)	6.01 (1.03)	5.96 (1.31)	5.47 (0.70)	5.58 (0.65)	5.20 (0.74)	5.42 (0.73)	5.16 (0.69)	5.56 (0.93)
GS (m/s)										
Male	1.14 (0.15)	1.12 (0.19)	1.14 (0.16)	1.14 (0.17)	1.12 (0.19)	1.11 (0.17)	0.99 (0.15)	0.95 (0.21)	0.83 (0.21)	1.06 (0.20)
Female	1.14 (0.18)	1.14 (0.13)	1.18 (0.20)	1.14 (0.16)	1.09 (0.14)	1.05 (0.18)	1.02 (0.14)	0.90 (0.17)	0.83 (0.16)	1.05 (0.20)
Low HGS										
Male	2 (7.1)	0 (0)	0 (0)	2 (9.1)	4 (13.8)	6 (25.0)	11 (37.9)	11 (42.3)	14 (60.9)	50 (22.0)
Female	0 (0)	1 (2.9)	0 (0)	3 (8.1)	2 (6.5)	5 (14.3)	6 (20.7)	11 (32.4)	21 (56.8)	49 (15.9)
Low ALMI										
Male	7 (25.0)	4 (15.4)	5 (25.0)	8 (36.4)	20 (65.5)	16 (69.0)	21 (72.4)	23 (88.5)	19 (82.6)	123 (54.2)
Female	20 (62.5)	12 (34.3)	8 (20.5)	15 (40.5)	17 (54.8)	15 (42.9)	22 (75.9)	16 (47.1)	28 (75.7)	153 (49.5)
Slow GS										
Male	3 (10.7)	6 (23.1)	4 (20.0)	6 (27.3)	6 (20.7)	6 (25.0)	15 (51.7)	14 (53.8)	16 (69.6)	76 (33.5)
Female	5 (15.6)	7 (20.0)	5 (12.8)	7 (18.9)	8 (25.8)	11 (31.4)	14 (48.3)	24 (70.6)	32 (86.5)	113 (36.6)

HC, hip circumference; WC, waist circumference; WHR, waist–hip ratio.
Values are presented as mean (SD) or number (%).

Supplementary Table 2
Prevalence Estimates in Study Sample and Adjusted to the Singapore General Population Age Groups Weights

	Sample Estimates					Population-Adjusted Estimates				
	Overall	21–59 y	≥60 y	≥65 y	≥75 y	Overall	21–59 y	≥60 y	≥65 y	≥75 y
AWGS2014										
Low HGS	16.0	2.6	26.4	31.0	41.2	7.3	3.2	18.6	25.1	39.9
Low ALMI	51.5	33.0	65.7	66.9	71.3	40.6	32.4	63.4	65.1	69.3
Slow GS	10.4	1.7	17.2	20.6	31.6	4.1	1.6	11.0	15.6	31.2
Confirmed	15.5	2.1	25.7	30.2	41.2	6.7	2.6	18.0	24.1	38.0
AWGS2019										
Low HGS	18.5	3.4	30.0	35.5	45.6	9.0	4.2	22.3	30.6	44.5
Low ALMI	51.5	33.0	65.7	66.9	71.3	40.6	32.4	63.4	65.1	69.3
Slow GS	35.3	18.0	48.5	54.0	69.9	24.0	18.7	38.8	46.1	69.4
Probable	15.3	13.3	16.8	19.4	22.8	14.0	14.1	13.7	17.6	24.6
Confirmed	15.5	5.2	23.4	25.8	27.9	9.5	5.5	20.7	24.5	26.1
Severe	10.1	1.3	16.8	19.4	28.7	4.1	1.4	11.6	14.6	27.3
EWGSOP2										
Low HGS	18.5	3.4	30.0	35.5	45.6	9.0	4.2	22.3	30.6	44.5
Low ALMI	51.5	33.0	65.7	66.9	71.3	40.6	32.4	63.4	65.1	69.3
Slow GS	35.3	18.0	48.5	54.0	69.9	24.0	18.7	38.8	46.1	69.4
Probable	3.7	0.9	5.9	7.3	8.8	1.8	0.8	4.6	6.9	10.0
Confirmed	4.7	1.3	7.3	8.9	8.1	3.1	1.9	6.1	9.1	7.2
Severe	10.1	1.3	16.8	19.4	28.7	4.1	1.4	11.6	14.6	27.3
Study Norm										
Low HGS	15.1	2.1	25.1	29.4	37.5	7.2	3.0	18.9	25.6	36.0
Low ALMI	0.7	0.0	1.3	1.6	2.2	0.3	0.0	1.1	1.7	2.3
Slow GS	11.6	2.6	18.5	22.2	33.8	4.9	2.4	11.9	16.9	33.6
Probable	20.9	4.7	33.3	39.5	50.7	10.4	5.3	24.6	34.0	49.1
Confirmed	0.6	0.0	1.0	1.2	1.5	0.2	0.0	0.9	1.4	1.4
Severe	0.2	0.0	0.3	0.4	0.7	0.1	0.0	0.2	0.3	0.9

Values are presented as percentages (%).