Journal of Asian Health

RESEARCH ARTICLE

Prevalence and Risk Factors for Presarcopenia among Young and Middle-aged Asian Americans: A Cross-Sectional Study using NHANES data

Zachary Rezler[1,2#], Vishal Shankar[1#], Ranjana Vittal[1], Krithi Pachipala[1], Shahmir H. Ali PhD[1,3], Robert J. Huang MD,[1,4] Malathi S. Srinivasan MD[1,5], Latha Palaniappan MD[1,6], Jin Long PhD[*1,7] and Ngan F. Huang PhD[*1,8,9,10,11]

OBJECTIVES: To examine the prevalence of and risk factors for presarcopenia (low muscle mass with normal function) among Asian Americans (AAs), compared with non-Hispanic Whites (NHWs); and to assess the relationship between appendicular lean mass index (ALMI) and handgrip strength by race.

DESIGN: A cross-sectional analysis of the National Health and Nutrition Examination Survey (2011–2014) was conducted, using ALMI (assessed via dual-energy X-ray absorptiometry) and handgrip strength data from adults aged 18–59 years.

RESULTS: Of the 3,116 participants (2,293 NHW, 823 AA), presarcopenia prevalence was 10% among NHWs and 27% among AAs. In multivariable regression, AA race (odds ratio [OR]: 4.2, 95% confidence interval [CI]: 2.6–6.6) and female sex (OR: 1.6, 95% CI: 1.3–2.0) were associated with presarcopenia. Conversely, holding a college degree (OR: 0.52, 95% CI: 0.30–0.92), high physical activity (OR: 0.59, 95% CI: 0.43–0.80), being overweight (OR: 0.06, 95% CI: 0.04–0.08) and obesity (OR: 0.00, 95% CI: 0.00–0.02) status were inversely associated. Both AAs and NHWs exhibited higher prevalences of low muscle mass with reduced handgrip strength.

CONCLUSION: Young and middle-aged AAs are at an increased risk of presarcopenia, relative to NHWs. This vulnerable demographic group may benefit from targeted public health interventions to reduce progression toward sarcopenia later in life.

Key Words: presarcopenia ▪ sarcopenia ▪ disease prevention ▪ Asian American health ▪ predictors

Characterized by both low muscle mass and function,[1] age-related sarcopenia affects more than 18 million adults over 60 years of age in the United States (US)[2] and up to 200 million individuals globally.[3] In the preclinical stage known as presarcopenia, individuals have low muscle mass but adequate muscle function.[4] Both sarcopenia and presarcopenia have been associated with functional disability,[5,6] lower quality of life,[7,8] and all-cause mortality.[9,10] Among older adults living in community settings, those with low muscle mass alone (i.e. presarcopenia) have demonstrated a significantly greater deterioration of body mass index (BMI), grip and back muscle strength, bone mineral density, and osteoporosis at 5-year follow-up compared to controls.[11]

In the US, the prevalence of sarcopenia and presarcopenia vary by race and ethnicity, with Asian Americans (AAs) having the highest rates of sarcopenia and Black Americans having the lowest.[12] There is limited evidence on why AAs are particularly at risk. However, some studies have found that Asian populations, including AAs and South Asians, have lower skeletal muscle mass and strength in relation to their Black, White, and Hispanic counterparts.[13,14] It has been hypothesized that these findings are due to anthropometric (e.g. smaller body size and higher adiposity) and cultural/lifestyle differences (e.g. physical activity level and diet).[15] Presarcopenia prevalence estimates using appendicular lean mass scores adjusted for BMI are similarly highest among AA (22%) and Hispanic Americans (28%) and lowest among non-Hispanic White (NHW) (15%) and Black Americans (4%).[16] Experts agree that in order to prevent or delay sarcopenia, maximizing muscle mass and strength in

# Contributed equally
Correspondence to: Dr. Ngan F. Huang, PhD. Email: ngantina@stanford.edu; Dr. Jin Long, PhD. Email: jinlong@stanford.edu.
For Sources of Funding, see page 10.

Journal of Asian Health is available at https://journalofasianhealth.org

POPULAR SCIENTIFIC SUMMARY

- Presarcopenia is at increased prevalence among Asian Americans, compared to non-Hispanic Whites.
- Asian American race and female sex is associated with presarcopenia, but obesity and high physical activity are inversely associated with presarcopenia.

youth and young adulthood, with a focus on maintenance later in life, is crucial (Fig. 1).[1,17] Therefore, identifying the individuals and groups most at risk of presarcopenia can enable early intervention and could significantly curb future sarcopenia-related disability.

Muscle mass can be approximated by calculating appendicular lean mass index (ALMI) scores, which use bone density limb scores from dual-energy X-ray absorptiometry (DXA) that are corrected for body composition.[18] However, current classification ALMI cut-offs from the European Working Group on Sarcopenia in Older People (EWGSOP) are derived mainly from White European cohorts[1,4] and fail to represent anthropometric differences across populations. In response, the Asian Working Group for Sarcopenia (AWGS) formulated more appropriate cut-offs for Asian cohorts.[19] After applying Asian-specific cut-offs (accounting for potential over/underestimation), women in non-Asian countries demonstrate a higher sarcopenia prevalence than those in Asian countries (20% vs. 11%, respectively); the opposite is observed with men (6% vs. 9%).[20] However, there exist few data comparing EWGSOP and AWGS criteria in either Asian or AA populations.

To date, presarcopenia has not been well studied in AAs, the fastest growing racial or ethnic minority in the United States,[21] especially with Asian-specific ALMI cut-offs. In addition, biometric data needed to classify sarcopenia/presarcopenia status (e.g. DXA and handgrip strength data) is only available in a limited timeframe within the National Health and Nutrition Examination Survey (NHANES), a national dataset of US households.[22] Due to this scarcity of data regarding presarcopenia in AAs, we examined the prevalence of and risk factors for presarcopenia among AA and NHW (reference group) adults aged 18–59 using 2011–2014 NHANES data containing both DXA and handgrip strength data. In the AA cohort, we compared the relative performance of EWGSOP and AWGS criteria in evaluating presarcopenia prevalence. Finally, we evaluated the relationship between muscle mass and handgrip strength by race.

METHODS

Study design and participants

The NHANES is an annually conducted, cross-sectional, and nationally representative survey that collects

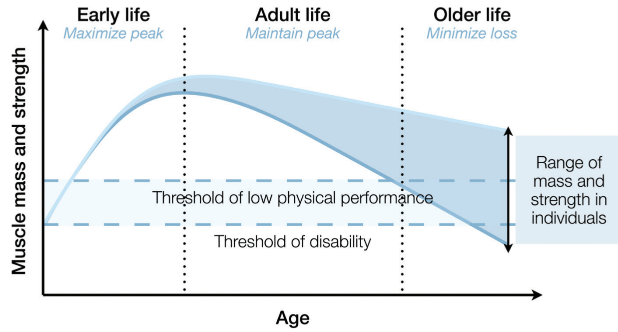

Fig. 1. Muscle mass and strength across the lifespan. 'To prevent or delay sarcopenia development, maximize muscle in youth and young adulthood, maintain muscle in middle age, and minimize loss in older age'. Adapted from the 2018 European Working Group on Sarcopenia in Older People (EWGSOP2) consensus paper.[1]

nutrition and health information from nearly 5,000 non-institutionalized civilians in the US through a complex, multistage probability sampling design.[22] In this analysis, 2011–2014 NHANES data were combined, during which AAs were oversampled[23] and DXA and handgrip dynamometer data were available. Participants older than 59 years of age were not administered DXA whole body scans and were thus excluded from the analysis.

Body composition and muscle strength measurements

The NHANES involves physical examinations in mobile examination centers[24]: weight in kilograms and height in centimeters are measured using standardized techniques and equipment; BMI is calculated as weight in kilograms, divided by the square of the height in meters; and whole body and regional measures of lean mass (excluding bone mineral content) are measured with DXA. By summing the lean mass values for the right arm, right leg, left arm, and left leg, the appendicular lean mass (ALM) in grams was calculated and converted to kilograms. The ALM index (ALMI) was then calculated by dividing the ALM in kilograms by the square of the height in meters. Muscle strength was measured using a handgrip dynamometer, in which able participants were asked to squeeze the device with each hand, three times in an alternating fashion. The combined grip strength variable (the sum of the largest reading from each hand, expressed in kilograms) was divided by two to calculate an average handgrip strength score for each participant.

Presarcopenia definitions and outcome variables

Two outcome variables were constructed to classify participants as presarcopenic (low ALMI with normal handgrip strength): one using EWGSOP2 cut-offs (for both NHWs and AAs), and another using EWGSOP2 cut-offs for NHWs and AWGS cut-offs for AAs. In the EWGSOP criteria, low ALMI was defined as <7.0 kg/m^2 for men and <5.5 kg/m^2 for women and low handgrip strength as <27 kg for men and <16 kg for women.[1] In the AWGS criteria, low ALMI was defined as <7.0 kg/m^2 for men and <5.4 kg/m^2 for women and low handgrip strength as <28 kg for men and <18 kg for women.[19]

Covariates

Each participant's age, sex, race, education level, income, physical activity level, and self-reported health measures for general health and dietary health were collected by household interviews. The demographic variables considered in this study were sex (male and female), age (18–39 and 40–59 years), and self-identified race/ethnicity (NHW and non-Hispanic Asian [Asian American]). Socioeconomic covariates included education level (<high school, high school graduate/General Equivalency Diploma (GED), some college, or ≥college graduate) and family income to poverty ratio (IPR). Family IPR was defined as the ratio of family income to the year-specific federal poverty threshold[22] and categorized as <130%, 130–349% and ≥350%. Self-reported general health and dietary health were regrouped into three levels: excellent/very good, good, and fair/poor. Physical activity level was regrouped into three categories: low, medium, and high (<150, 150–300, and >300 min of moderate intensity equivalent activity per week, respectively). Following recommendation from the World Health Organization to adjust for cardiometabolic disease risk among Asian populations,[25] BMI was grouped into the following race-specific categories: normal or below (BMI <25 for NHWs; BMI <23 for Asians); overweight (BMI ≥25 and <30 for NHWs; BMI ≥23 and <27 for Asians); and obese (BMI ≥30 for NHWs; BMI ≥27 for Asians). BMI cut-offs for NHWs were derived from the standard definition given by the US Centers for Disease Control and Prevention (CDC).[26]

Statistical methods

Participants' characteristics, including age, sex, education level, family IPR self-reported general health and dietary health, and physical activity level, were represented as unweighted frequencies and weighted percentages with 95% confidence intervals (CIs) by race. Weighted mean and corresponding 95% CIs of ALMI and handgrip strength were also calculated for each group. Missing values were not excluded from the sample. Instead, a 'missing' category was included for each variable. The prevalence of presarcopenia, along with 95% CIs, was calculated for each group and stratified according to the aforementioned demographic, socioeconomic, and health variables. *P*-values for comparisons of the prevalence between NHWs and AAs were obtained with chi-squared tests.

The first multivariable analysis involved identifying potential predictors of presarcopenia in the entire sample. Variables that were statistically significant (i.e. $P < 0.05$) in bivariate logistic regression were included as covariates in the final adjusted model. Additionally, regardless of initial significance, age and sex were included in the final models as these are established risk factors for sarcopenia and likely predictors of presarcopenia.[1,19,27,28] Unadjusted and adjusted odds ratios (ORs and aORs) were calculated to estimate the associations between the variables of interest and presarcopenia status. The variance inflation factor for each covariate was calculated to evaluate the collinearity between variables in the multivariate regressions. However, no evidence of significant multicollinearity was found.

To assess how well low muscle mass (i.e. low ALMI) distributes across low to high muscle function between groups, handgrip strength deciles were constructed for the NHW and AA samples, separately. The percentage of participants in each handgrip strength decile with low ALMI was then calculated. EWGSOP2 cut-offs for low ALMI were used initially, followed by a supplementary analysis using AWGS cut-offs for AAs. Bar graphs were created to visualize and examine the relationship between low ALMI and handgrip strength by race/ethnicity.

NHANES Mobile Examination Center (MEC) 2-year sample weights[24] were applied to all analyses to account for unequal probabilities of population selection and non-responses, thereby providing estimates representative of the non-institutionalized civilian US population (year 2000 population weights). The Taylor Series Linearization variance approximation procedure was used to account for the complex sample design of NHANES in the variance estimation. Statistical significance was set at $P < 0.05$. All analyses were conducted in RStudio Desktop version 1.4.1717 (R Foundation for Statistical Computing).

RESULTS

The final sample included 3,116 participants aged 18–59 years with complete DXA and handgrip dynamometer data: 2,293 NHWs and 823 AAs. Sex, family IPR, and self-reported general health status were similarly distributed across both groups (Table 1). The AA cohort was slightly younger than their NHW counterparts (56% vs. 48% aged 18–39 years, respectively). Additional disparities were observed within variables, including highest level of education, self-reported dietary health, and physical activity level, with AAs being more highly educated and reporting better diets but less physical activity than NHWs. AAs were also less obese than NHWs by BMI status (26% vs. 32%, respectively).

Table 1. Characteristics of adults (ages 18–59) with dual-energy X-ray absorptiometry (DXA) and handgrip dynamometer data from the United States National Health and Nutrition Examination Survey (NHANES), 2011–2014.

	Cohort characteristics by race, % (95% CI)	
	Non-Hispanic White (*n* = 2,293)	Non-Hispanic Asian (*n* = 823)
Demographic measures		
Sex		
Female	48.2 (46.2–50.1)	49.1 (46.6–51.6)
Male	51.8 (49.9–53.8)	50.9 (48.4–53.4)
Age		
18–39	47.7 (43.8–51.6))	56.1 (51.1–61.1)
40–59	52.3 (48.4–56.2)	43.9 (38.9–48.9)
Socioeconomic measures		
Highest level of education		
<High school	8.8 (6.1–11.5)	7.2 (4.9–9.6)
High school graduate/GED	19.4 (16.2–22.6)	12.3 (8.7–15.9)
Some college	32.4 (29.4–35.3)	22.4 (18.0–26.7)
≥College graduate	34.8 (30.5–39.0)	54.4 (47.9–60.9)
Family income to poverty ratio		
<130%	19.5 (15.2–23.8)	16.7 (12.9–20.4)
130–349%	30.1 (26.3–33.9)	28.3 (23.1–33.7)
>350%	46.4 (40.7–52.0)	48.7 (41.6–55.8)
Self-reported health measures		
General health status		
Fair/poor	11.2 (9.4–12.9)	6.9 (5.5–8.3)
Good	37.0 (33.8–40.3)	38.3 (34.8–41.9)
Excellent/very good	48.5 (44.4–52.5)	45.6 (41.9–49.3)
Dietary health		
Fair/poor	24.9 (22.5–27.1)	14.4 (11.8–17.0)
Good	44.7 (42.2–47.3)	43.4 (40.1–46.7)
Excellent/very good	30.4 (28.5–32.4)	42.3 (38.1–46.4)
Physical activity level		
Low	40.2 (38.1–42.3)	53.9 (50.6–57.3)
Medium	17.9 (16.2–19.6)	19.9 (17.0–22.7)
High	41.8 (39.0–44.7)	26.2 (22.8–29.6)
BMI		
Normal or below	33.7 (30.7–36.8)	40.0 (35.8–44.3)
Overweight	34.0 (31.5–36.5)	34.3 (30.9–37.8)
Obese	32.2 (29.1–35.3)	25.6 (22.6–28.5)

Note: Percentages do not add up to 100 when there are missing values. BMI cut-offs followed the recommendations of the World Health Organization.

Prevalence of presarcopenia

Presarcopenia prevalence estimates according to EWGSOP2 and AWGS cut-offs by race and covariates are depicted in Table 2.

Using EWGSOP2 cut-offs, the overall prevalence of presarcopenia was significantly higher among AAs (27%; 95% CI: 23–31%) compared with NHWs (10%; 95% CI: 8–12%). The prevalence of presarcopenia among AAs was only slightly lower using the AWGS cut-offs (25%, 95% CI: 21–29%). For both AAs and NHWs, more females than males were presarcopenic (13% [NHW] and 36% [AA] vs. 7% [NHW] and 19% [AA], respectively; $P < 0.001$). In addition, individuals aged 40–59 had a significantly lower prevalence than those aged 18–39 (8% [NHW] and 23% [AA] vs. 12% [NHW] and 30% [AA], respectively). Very similar results were obtained while applying AWGS cut-offs for AAs.

Among NHWs, higher education ($P < 0.001$) and income ($P = 0.01$) were associated with a lower prevalence of presarcopenia. NHWs who completed at least some college had a slightly lower prevalence of presarcopenia

Table 2. **Prevalence of presarcopenia in adults (age 18–59 years) with dual-energy X-ray absorptiometry (DXA) and handgrip dynamometer data from the United States National Health and Nutrition Examination Survey (NHANES), 2011–2014.**

	Prevalence of Presarcopenia, % (95% CI)		
	Non-Hispanic White (*n* = 2,293)	Non-Hispanic Asian (*n* = 823)	
	EWGSOP2	EWGSOP2	AWGS
Overall	9.8 (7.7–11.9)	27.1 (22.9–31.3)	25.2 (21.3–29.1)
Demographic Measures			
Sex			
Female	12.8 (10.0–15.6)	35.8 (29.6–42.0)	31.9 (26.4–37.4)
Male	6.9 (5.2–8.6)	18.7 (14.7–22.7)	18.7 (14.7–22.7)
P	<0.001*	<0.001*	<0.001*
Age			
18–39	11.9 (9.1–14.6)	30.1 (24.7–35.5)	28.2 (23.3–33.2)
40–59	7.9 (5.5–10.3)	23.2 (18.3–28.2)	21.3 (17.3–25.3)
P	0.01*	0.04*	0.01*
Socioeconomic measures			
Highest level of education			
<High school	14.0 (9.5–18.6)	17.7 (7.5–27.9)	17.7 (7.5–27.9)
High school graduate/GED	10.3 (7.0–13.5)	29.2 (19.2–39.2)	27.3 (18.1–36.4)
Some college	8.0 (5.3–10.6)	31.7 (24.9–38.5)	29.4 (23.8–35.1)
≥College graduate	8.5 (6.2–10.8)	25.8 (20.2–31.3)	23.6 (18.5–28.8)
P	<0.001*	0.22	0.23
Family income to poverty ratio			
<130%	14.8 (9.1–20.5)	31.3 (22.2–40.3)	29.8 (21.2–38.4)
130–349%	8.7 (6.0–11.4)	28.6 (20.9–36.3)	27.1 (19.5–34.8)
>350%	8.1 (5.8–10.4)	24.9 (20.2–29.7)	22.6 (18.3–26.8)
P	0.01*	0.46	0.31
Self-reported health measures			
General health status			
Fair/poor	12.6 (7.0–18.2)	12.5 (4.2–20.8)	10.9 (3.7–18.2)
Good	8.7 (6.1–11.2)	30.2 (24.2–36.2)	28.3 (22.6–34.1)
Excellent/very good	9.7 (7.2–12.2)	25.6 (20.7–30.4)	23.2 (18.7–27.3)
P	0.32	0.02*	0.01*
Dietary health			
Fair/poor	8.4 (6.1–10.6)	32.3 (22.6–42.0)	31.6 (21.8–41.4)
Good	10.6 (7.3–13.8)	25.9 (20.8–31.1)	23.4 (18.5–28.3)
Excellent/very good	9.8 (6.6–12.9)	26.5 (21.3–31.7)	24.9 (19.6–30.1)
P	0.51	0.37	0.23
Physical activity level			
Low	11.4 (8.0–14.8)	33.5 (28.0–39.0)	31.1 (26.0–36.2)
Medium	10.6 (6.9–14.3)	19.6 (12.2–27.0)	18.1 (11.2–25.0)
High	7.9 (5.7–10.1)	19.6 (14.0–25.1)	18.4 (13.4–23.4)
P	0.09	<0.001*	<0.001*
BMI			
Normal or below	27.4 (22.4–32.3)	56.7 (50.4–63.1)	52.8 (46.7–58.9)
Overweight	1.5 (0.0–2.5)	12.4 (7.1–17.8)	11.5 (6.7–16.3)
Obese	0.0 (0.0–0.0)	0.0 (0.0–1.4)	0.5 (0.–1.4)
P	<0.001*	<0.001*	<0.001*

Note: Presarcopenia for non-Hispanic Whites was defined using the EWGSOP consensus paper criteria definition[4] of low muscle mass (i.e. ALMI) with normal muscle function (i.e. handgrip strength), with EWGSOP2 cut-offs: low ALMI as <7.0 kg/m² for men and <5.5 kg/m² for women; and low handgrip strength as <27 kg for men and <16 kg for women.[1] For non-Hispanic Asians, EWGSOP cut-offs were compared with AWGS[19] cut-offs: low ALMI as <7.0 kg/m² for men and <5.4 kg/m² for women; and low handgrip strength as <28 kg for men and <18 kg for women.

P-values for the differences among categories of the variable for each group were obtained by the chi-squared test.

**P* < 0.05 is considered significant.

than those who had no college education (8–9% vs. 10–14%, respectively). Across family IPR categories (<130%, 130–349%, and ≥350%), the prevalence of presarcopenia among NHWs was lower in the latter two categories (15, 9, and 8%, respectively). Among AAs, there was no statistically significant difference between levels of education and family IPRs with respect to presarcopenia prevalence, using either EWGSOP2 or AWGS cut-offs. For self-reported general health status, only AAs had a statistically significant difference in prevalence among categories, with individuals in the good and excellent/very good category demonstrating a higher prevalence than the fair/poor group (30% and 26% vs. 13%, respectively; $P = 0.02$). Contrarily, NHWs reporting a healthier diet had a lower prevalence of presarcopenia. Furthermore, both NHWs and AAs had a lower presarcopenia prevalence among those reporting a greater level of physical activity. However, the differences were only significant among AAs ($P < 0.001$). About one-third (34%) of AAs with a low level of physical activity were presarcopenic, compared to 20% of those reporting a medium or high level of physical activity. In both AAs and NHWs, overweight and obesity status were strongly, inversely associated with presarcopenia prevalence ($P < 0.001$). These effects remained significant while applying AWGS cut-offs.

Predictors of presarcopenia by logistic regression

Multivariable analysis of the entire cohort (inclusive of both AA and NHWs) are depicted in Table 3. Univariable analysis demonstrated significant results and trends for sex, age, race, education level, family IPR, physical activity level, and BMI. These were included as covariates in the final multivariable model. Sex, race, education, physical activity, and BMI yielded statistically significant aORs. Female participants had higher odds of being presarcopenic when compared with male participants (aOR = 1.6; 95% CI: 1.3–2.0). After adjusting for key covariates, AAs had higher odds of being presarcopenic compared with NHWs (aOR = 4.2; 95% CI: 2.6–6.6). Furthermore, those who had graduated from college had significantly lower odds of being presarcopenic compared with those who did not complete high school, yielding an aOR of 0.5 (95% CI: 0.3–0.9). Those in the 130–349% and >350% categories for family IPR also had a reduced presarcopenia risk. However, this association disappeared after adjustment. A negative trend was observed with physical activity level in the sense that those reporting high levels of physical activity had an aOR of 0.4 (95% CI: 0.3–0.6). Finally, those who were overweight or obese according to BMI also had lower odds of being presarcopenic, with aORs of 0.1 (95% CI: 0.0–0.1) and 0.0 (95% CI: 0.00–0.00), respectively, in relation to those with BMIs that were normal or below. The given results remained consistent regardless of use of EWGSOP2 or AWGS cut-offs for AAs.

We next performed analysis among AAs only (Table 4). The regressions conducted for presarcopenia status using only AA data reflected many of the trends observed in the broader sample, aside from education. Univariable regressions demonstrated statistically significant results for sex, age, general health status, physical activity level, and BMI. These were included as covariates in the final multivariable regression model. Sex, physical activity, and BMI yielded statistically significant aORs. General health status was a newly statistically significant covariate in univariable regression, with greater odds in those reporting healthier diets (i.e. good and excellent/very good): ORs of 3.0 (1.3–6.8) and 2.4 (1.1–5.3), respectively. However, these findings were no longer significant after adjustment. While applying AWGS cut-offs for AAs, results remained relatively mostly unchanged. Yet, sex was no longer a statistically significant predictor after adjustment among AAs.

Race-specific handgrip strength deciles were created for NHWs and AAs, and the proportion of individuals with low ALMI using EWGSOP2 and AWGS cut-offs was calculated for each decile and plotted by race (Fig. 2). In both groups, prevalence of low ALMI decreased with increasing handgrip strength decile (P for trend: 0.001 for NHWs and 0.0003 for AAs). About 16–23% of NHWs in the first three deciles were classified as having low ALMI, compared with 2–6% in the final three deciles. In comparison, 42–58% of AAs in the first three deciles had low ALMI, compared with 1–25% in the final three deciles. In every decile, excluding the last decile, there was a greater proportion of AAs with low ALMI compared with NHWs. However, there was still a significant proportion of AAs with low ALMI in the latter half of deciles, such as the eighth decile: 25% (95% CI: 15–35). Using AWGS cut-offs, these observations and trends remained. However, due to the slightly lower ALMI cut-off in the AWGS definition, the prevalence of low ALMI in AAs was somewhat lower across deciles.

DISCUSSION

In this population-based, cross-sectional analysis of young and middle-aged Americans, the prevalence of presarcopenia among AAs was almost three times that of NHWs. Female sex, greater education level, and higher levels of physical activity were presarcopenia risk factors agnostic of race, whereas an overweight/obese BMI status was found to be strongly protective. The same was true when examining AAs alone, with the exception of education. These observations were true

Table 3. **Univariable and multivariable associations between variables of interest and presarcopenia status for entire cohort (N = 3,116).**

Univariable and multivariable predictors of presarcopenia for entire cohort (*N* = 3,116), OR (95% CI)				
	EWGSOP2-only model		EWGSOP2 / AWGS model	
	Univariable	Multivariable	Univariable	Multivariable
Demographic measures				
Sex				
Male	Ref.	Ref.	Ref.	Ref.
Female	2.03* (1.73–2.37)	1.60* (1.26–2.02)	1.98* (1.69–2.31)	1.54* (1.22–1.94)
Age				
18–39	Ref.	Ref.	Ref.	Ref.
40–59	0.63* (0.47–0.83)	1.09 (0.76–1.54)	0.62* (0.47–0.83)	1.08 (0.76–1.55)
Race				
Non-Hispanic White	Ref.	Ref.	Ref.	Ref.
Non-Hispanic Asian	3.43* (2.46–4.78)	4.16* (2.61–6.62)	3.11* (2.24–4.31)	3.51* (2.24–5.48)
Socioeconomic measures				
Highest level of education				
<High school	Ref.	Ref.	Ref.	Ref.
High school graduate/GED	0.76 (0.50–1.16)	0.88 (0.50–1.55)	0.75 (0.49–1.16)	0.87 (0.49–1.55)
Some college	0.61* (0.39–0.95)	0.67 (0.33–1.38)	0.60* (0.39–0.94)	0.67 (0.33–1.36)
≥College graduate	0.71 (0.50–1.00)	0.52* (0.30–0.92)	0.69* (0.48–0.98)	0.52* (0.30–0.91)
Family income to poverty ratio				
<130%	Ref.	Ref.	Ref.	Ref.
130–349%	0.60* (0.39–0.91)	0.75 (0.45–1.24)	0.60* (0.39–0.91)	0.75 (0.45–1.24)
>350%	0.55* (0.33–0.92)	0.67 (0.35–1.29)	0.54* (0.33–0.91)	0.67 (0.35–1.28)
Self-reported health measures				
General health status				
Fair/poor	Ref.	-	Ref.	-
Good	0.81 (0.50–1.30)	-	0.80 (0.50–1.29)	-
Excellent/very good	0.84 (0.50–1.42)	-	0.83 (0.49–1.41)	-
Dietary health				
Fair/poor	Ref.	-	Ref.	-
Good	1.27 (0.87–1.84)	-	1.25 (0.86–1.82)	-
Excellent/very good	1.25 (0.82–1.89)	-	1.23 (0.81–1.87)	-
Physical activity Level				
Low	Ref.	Ref.	Ref.	Ref.
Medium	0.81 (0.54–1.22)	0.67 (0.420–1.05)	0.82 (0.55–1.22)	0.68 (0.43–1.06)
High	0.59* (0.43–0.80)	0.43* (0.28–0.64)	0.59* (0.43–0.82)	0.43* (0.28–0.64)
BMI				
Normal or below	Ref.	Ref.	Ref.	Ref.
Overweight	0.06* (0.04–0.08)	0.05* (0.03–0.08)	0.05* (0.04–0.08)	0.05* (0.03–0.08)
Obese	0.00* (0.00–0.02)	0.00* (0.00–0.02)	0.00* (0.00–0.02)	0.00* (0.00–0.02)

In EWGSOP2-only model, presarcopenia for both non-Hispanic Whites and Asians are defined by EWGSOP2 cut-offs. In EWGSOP2/AWGS model, EWGSOP2 cut-offs used for non-Hispanic Whites and AWGS cut-offs used for Asians.

*$P < 0.05$ is considered significant.

regardless of use of EWGSOP2 or AWGS biometric criteria. In the handgrip strength decile analysis, there was a greater proportion of AAs with low ALMI in the lower deciles compared with NHWs, indicating a potentially stronger correlation between muscle mass and strength among AAs.

Previous analyses have similarly shown significant disparities in prevalence of sarcopenia and presarcopenia among AAs and Asian populations when compared with non-Asian groups.[12,20,29] However, data are limited for young and middle-aged adults, a critical group where targeted efforts may delay or attenuate future muscle

Table 4. **Univariable and multivariable associations between variables of interest and presarcopenia status for non-Hispanic Asians only (N = 823).**

Univariable and multivariable predictors of presarcopenia for Asians (N = 823), OR (95% CI)				
	EWGSOP2 model		AWGS model	
	Univariable	Multivariable	Univariable	Multivariable
Demographic measures				
Sex				
Male	Ref.	Ref.	Ref.	Ref.
Female	2.42* (1.81–3.25)	1.61* (1.16–2.22)	2.03* (1.52–2.71)	1.24 (0.89–1.74)
Age				
18–39	Ref.	Ref.	Ref.	Ref.
40–59	0.70* (0.49–1.00)	1.26 (0.79–2.01)	0.69* (0.51–0.92)	1.17 (0.77–1.78)
Socioeconomic measures				
Highest level of education				
<High school	Ref.	-	Ref.	-
High school graduate/GED	1.91 (0.97–3.77)	-	1.74 (0.84–3.58)	-
Some college	2.16 (0.95–4.90)	-	1.94 (0.88–4.29)	-
≥College graduate	1.61 (0.76–3.41)	-	1.44 (0.69–3.00)	-
Family income to poverty ratio				
<130%	Ref.	-	Ref.	-
130–349%	0.88 (0.49–1.59)	-	0.88 (0.48–1.59)	-
>350%	0.73 (0.44–1.21)	-	0.69 (0.42–1.13)	-
Self-reported health measures				
General health status				
Fair/poor	Ref.	Ref.	Ref.	Ref.
Good	3.02* (1.34–6.83)	2.64 (0.96–7.28)	3.22* (1.48–7.00)	2.78 (0.96–8.01)
Excellent/very good	2.40* (1.09–5.31)	1.46 (0.58–3.70)	2.46* (1.12–5.39)	1.49 (0.58–3.85)
Dietary health				
Fair/poor	Ref.	-	Ref.	-
Good	0.73 (0.44–1.22)	-	0.66 (0.39–1.13)	-
Excellent/very good	0.76 (0.46–1.25)	-	0.72 (0.43–1.20)	-
Physical activity Level				
Low	Ref.	Ref.	Ref.	Ref.
Medium	0.48* (0.32–0.74)	0.36* (0.21–0.61)	0.49* (0.32–0.75)	0.37* (0.23–0.62)
High	0.48* (0.30–0.77)	0.53* (0.31–0.89)	0.50* (0.33–0.77)	0.56* (0.33–0.94)
BMI				
Normal or below	Ref.	Ref.	Ref.	Ref.
Overweight	0.11* (0.06–0.10)	0.10* (0.05–0.17)	0.12* (0.07–0.19)	0.10* (0.06–0.17)
Obese	0.00* (0.00–0.03)	0.00* (0.00–0.02)	0.00* (0.00–0.03)	0.00* (0.00–0.03)

In EWGSOP2 model, presarcopenia defined by EWGSOP2 cut-offs. In AWGS model, presarcopenia defined by AWGS cut-offs.

*$P < 0.05$ is considered significant.

loss. Our study significantly expands upon the body of literature around Asian age-related muscle loss. Previous analyses of US and Japanese cohorts found that the prevalence of presarcopenia was higher among women.[11,29] Conversely, the Louisiana Osteoporosis Study[12] observed a higher prevalence of low ALMI among men in both their NHW and AA samples. The finding that education level is associated with a lower prevalence of sarcopenia and presarcopenia has been observed.[12,29] Individuals with greater education tend to exhibit better health behaviors[30–32] with respect to diet and exercise and disproportionately live in communities (e.g. green spaces) that encourage physical activity.[33] Together, these factors are believed to optimize overall health and minimize muscle loss in the long term. Increasing physical activity also appears protective against muscle loss.[29,34] A lower level of physical activity is associated with muscle loss over time, whereas higher levels correspond with

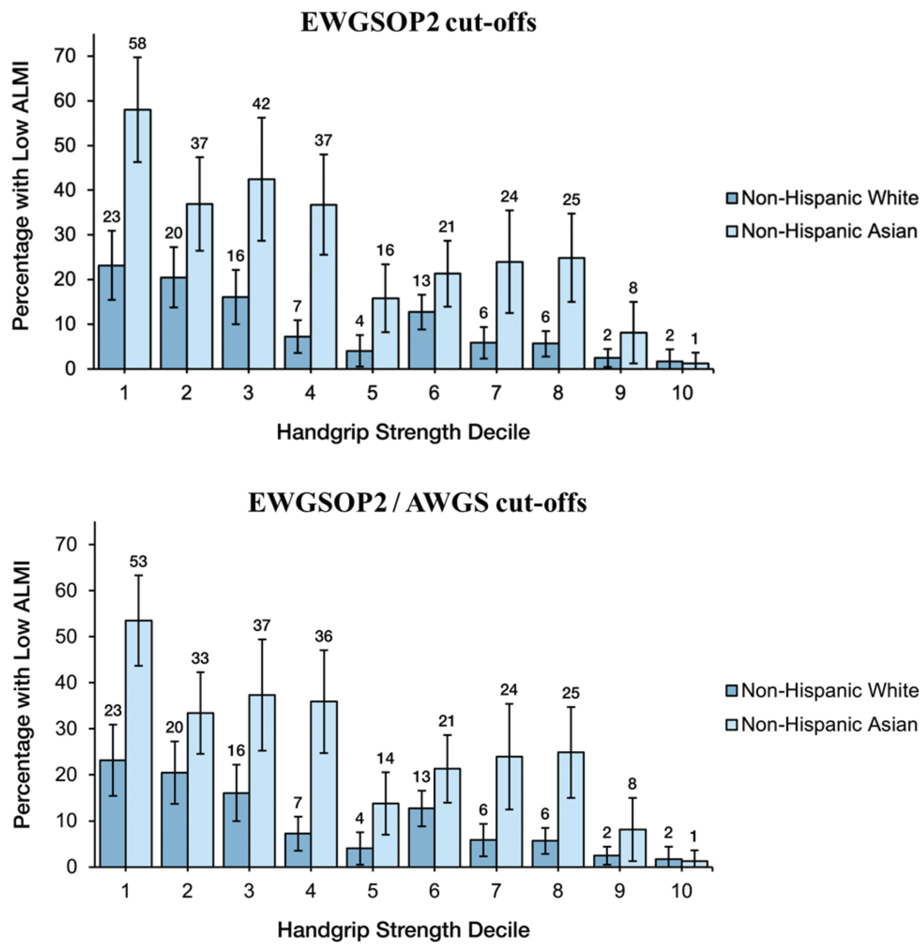

Fig. 2. Percentage of participants with a low appendicular lean mass index (ALMI) score across handgrip strength deciles, by race. In top panel, ALMI and handgrip strength defined for all individuals using EWGSOP2 cut-offs. In bottom panel, ALMI and handgrip strength defined for non-Hispanic Whites by EWGSOP2 cut-offs, and for non-Hispanic Asians by AWGS cut-offs.

increased muscle mass and strength.[35–37] Interestingly, overweight and obesity status were strongly and inversely associated with presarcopenia. Obese individuals of all ages tend to have greater proportional muscle strength due to the increased, sustained overload on antigravity muscles that enhances muscle mass.[38] This phenomenon directly counters the loss of lean muscle mass that would lead individuals to be classified as presarcopenic. Morgan et al. (2020) observe that this 'paradoxical' relationship complicates interventional studies, because even though obesity may play a protective role in preserving muscle mass at older ages, it is associated with its own, significant health complications (e.g. diabetes and cardiovascular disease).[39]

Currently, individuals are classified as sarcopenic or non-sarcopenic according to individual sarcopenia definitions proposed by expert consensus groups, including the EWGSOP,[4] EWGSOP2,[1] AWGS,[19] International Working Group on Sarcopenia (IWGS),[40] US Sarcopenia Definitions and Outcomes Consortium (SDOC),[41,42] and other researchers.[43–46] Nine out of these 10 guidelines used ALMI cut-offs as a component of their sarcopenia definition. Accordingly, our decile analysis aimed to evaluate two current cut-offs for low ALMI (EWGSOP2 and AWGS cut-offs) across racial groups. Our data suggest that in this AA cohort, the choice of cut-off did not significantly impact major outcome parameters, namely presarcopenia prevalence, presarcopenia risk factors, or the association between handgrip strength and ALMI. There may exist significant differences in anthropometric parameters, exercise patterns, and dietary patterns between AA and Asians, perhaps limiting the generalizability of Asian-specific criteria to AAs. These results would require further validation in independent AA cohorts.

Sarcopenia and presarcopenia pose individual health risks and steep healthcare costs for national governments[2] and both are linked with numerous comorbidities. Presarcopenia may also be a harbinger of metabolic and cardiovascular diseases.[47,48] Presarcopenia represents a unique opportunity not only to improve age-related disability and mortality but also societal-wide healthcare efficiency; it has been estimated that a 10% reduction in sarcopenia prevalence could save the US government approximately $1.1 billion.[2] This study demonstrating higher prevalence of presarcopenia in young and middle-aged Americans thus highlights an at-risk demographic group that can be targeted with risk reduction or attenuation efforts. Randomized controlled trials of interventions aimed at improving physical function and functional strength among presarcopenic older adults, including a 6-month home exercise program[49] and a 10-week resistance training regimen,[50] have been promising. These findings suggest the potential to not only reverse the progression of the disease in older individuals but also the potential to start these programs earlier in younger at-risk groups. Evidence suggests that such maintenance of skeletal muscle in young adulthood is necessary to prevent future muscle loss.[36] Still, research exploring the prevention of presarcopenia and sarcopenia specifically in young adults is lacking.

Balanced against the study's strengths are several notable limitations. Available race- and ethnicity-specific cut-offs were limited to European and East Asian samples, thereby limiting our analysis. Ideally, cut-offs specific to AA subgroups and other races/ethnicities and disaggregated NHANES data would have allowed for a more comprehensive analysis and understanding of the sarcopenia and presarcopenia burden on minority groups. The general health status and dietary health variables used in this analysis were self-reported, allowing factors such as social desirability bias to potentially skew results. The lack of association between dietary health and presarcopenia status may be due to US adults' inability to accurately assess their diet quality.[51] Therefore, this analysis is limited with respect to the conclusions that can be drawn regarding the influence of nutrition on presarcopenia status. Finally, our Asian sample size (*N* = 823) was insufficient to allow for disaggregated AA analysis (e.g. Koreans, Japanese).

CONCLUSIONS

The high prevalence of presarcopenia among young and middle-aged AA adults signals the future consequent risk on mortality, quality of life, and caregiver burden in this population, particularly among females, individuals with low educational attainment, and low physical activity. These data support prior findings highlighting the need for further research to advance early recognition and augmented interventions, including exercise and nutrition promotion, targeting AAs and other at-risk subgroups of the population.

ARTICLE INFORMATION

Received July 7, 2023; accepted December 19, 2023.

Affiliations

[1]Stanford Center for Asian Health Research and Education (CARE), Stanford University School of Medicine, Stanford CA, United States; [2]Undergraduate Medical Education Program, Faculty of Health Sciences, Michael G. DeGroote School of Medicine, McMaster University, Hamilton ON, Canada; [3]Department of Social and Behavioral Sciences, School of Public Health, New York University, NY, United States; [4]Division of Gastroenterology and Hepatology, Stanford University School of Medicine, Stanford CA, United States; [5]Division of Primary Care and Population Health, Stanford University School of Medicine, Stanford CA, United States; [6]Division of Cardiovascular Medicine, Stanford University School of Medicine, Stanford CA, United States; [7]Department of Pediatrics, Stanford University School of Medicine, Stanford CA, United States; [8]Department of Cardiothoracic Surgery, Stanford University School of Medicine, Stanford CA, United States; [9]Department of Chemical Engineering, Stanford University, Stanford CA, United States; [10]Stanford Cardiovascular Institute, Stanford University, Stanford CA, United States; [11]Center for Tissue Regeneration, Repair and Restoration; Veterans Affairs Palo Alto Health Care System

Acknowledgments

The authors greatly appreciate the methodological guidance provided by the 2021 and 2022 Stanford CARE Scholars faculty and CARE Team Science Fellows. team., including, but not limited to, Shozen Dan, Jaiveer Singh, Osika Tripathi, Nora Sharp, Dr. Rita Popat, Armaan Jamal, Dr. Gloria Kim, Dr. Sanah Vohra, and Dr. Adrian Bacong.

Conflict of interest and funding

The authors report no disclosures or conflicts of interest related to this work. This work was supported in part by grants to NFH from the US National Institutes of Health (5P30AG059307), the US Department of Veterans Affairs (1I01BX004259 and RX001222), the National Science Foundation (1829534), and a pilot grant from the Stanford Aging and Ethnogeriatrics Research Center. NFH is the recipient of a Research Career Scientist award (IK6BX006309) from the Department of Veterans Affairs. RJH is supported by the National Cancer Institute of the National Institutes of Health (K08CA252635). The content in this article is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Disclosure statement

The authors report no conflicts of interest.

Data availability statement

Data are available upon reasonable request.

REFERENCES

1. Cruz-Jentoft AJ, Bahat G, Bauer J, Boirie Y, Bruyère O, Cederholm T, Cooper C, Landi F, Rolland Y, Sayer AA, et al. Sarcopenia: revised European consensus on definition and diagnosis. *Age Ageing*. 2019;48(1):16–31. doi: 10.1093/ageing/afy169
2. Janssen I, Shepard DS, Katzmarzyk PT, Roubenoff R. The healthcare costs of sarcopenia in the United States. *J Am Geriatr Soc*. 2004;52(1):80–5. doi: 10.1111/j.1532-5415.2004.52014.x
3. Santilli V, Bernetti A, Mangone M, Paoloni M. Clinical definition of sarcopenia. *Clin Cases Miner Bone Metab*. 2014;11(3):177–80.
4. Cruz-Jentoft AJ, Baeyens JP, Bauer JM, Boirie Y, Cederholm T, Landi F, Martin FC, Michel J-P, Rolland Y, Schneider SM, et al. Sarcopenia: European consensus on definition and diagnosis. *Age Ageing*. 2010;39(4):412–23. doi: 10.1093/ageing/afq034
5. Melig koĐlu MA. Presarcopenia and its impact on disability in female patients with rheumatoid arthritis. *Arch Rheumatol*. 2017;32(1):053–9. doi: 10.5606/ArchRheumatol.2017.6078
6. Hairi NN, Cumming RG, Naganathan V, Handelsman DJ, Le Couteur DG, Creasey H, Waite LM, Seibel MJ, Sambrook PN. Loss of muscle strength, mass (sarcopenia), and quality (specific force) and its relationship with functional limitation and physical disability: the Concord Health and Ageing in Men Project. *J Am Geriatr Soc*. 2010;58(11):2055–62. doi: 10.1111/j.1532-5415.2010.03145.x
7. Veronese N, Koyanagi A, Cereda E, Maggi S, Barbagallo M, Dominguez LJ, Smith L Sarcopenia reduces quality of life in the long-term: longitudinal analyses from the English longitudinal study of ageing. *Eur Geriatr Med*. 2022;13(3):633–9. doi: 10.1007/s41999-022-00627-3
8. Ohashi K, Ishikawa T, Imai M, Suzuki M, Hoshii A, Abe H, Koyama F, Nakano T, Ueki A, Noguchi H, et al. Relationship between pre-sarcopenia and quality of life in patients with chronic liver disease: a cross-sectional

study. *Eur J Gastroenterol Hepatol*. 2019;31(11):1408–13. doi: 10.1097/MEG.0000000000001415
9. Lera L, Angel B, Marquez C, Saguez R, Albala C. Besides sarcopenia, pre-sarcopenia also predicts all-cause mortality in older Chileans. *CIA*. 2021;16:611–9. doi: 10.2147/CIA.S289769
10. Woo J, Leung J, Morley JE. Defining sarcopenia in terms of incident adverse outcomes. *J Am Med Dir Assoc*. 2015;16(3):247–52. doi: 10.1016/j.jamda.2014.11.013
11. Kobayashi K, Ando K, Tsushima M, Machino M, Ota K, Morozumi M, Tanaka S, Kanbara S, Ishiguro N, Hasegawa Y, et al. Predictors of presarcopenia in community-dwelling older adults: a 5-year longitudinal study. *Mod Rheumatol*. 2019;29(6):1053–8. doi: 10.1080/14397595.2018.1551171
12. Jeng C, Zhao LJ, Wu K, Zhou Y, Chen T, Deng HW. Race and socioeconomic effect on sarcopenia and sarcopenic obesity in the Louisiana Osteoporosis Study (LOS). *JCSM Clin Rep*. 2018;3(2):e00027.
13. Dhar M, Kapoor N, Suastika K, Khamseh ME, Selim S, Kumar V, Raza SA, Azmat U, Pathania M, Rai Mahadeb YP, et al. South Asian Working Action Group on SARCOpenia (SWAG-SARCO) – a consensus document. *Osteoporos Sarcopenia*. 2022;8(2):35–57. doi: 10.1016/j.afos.2022.04.001
14. Silva AM, Shen W, Heo M, Gallagher D, Wang Z, Sardinha LB, Heymsfield SB. Ethnicity-related skeletal muscle differences across the lifespan. *Am J Hum Biol*. 2010;22(1):76–82. doi: 10.1002/ajhb.20956
15. Chen L-K, Liu L-K, Woo J, Assantachai P, Auyeung T-W, Bahyah KS, Chou M-Y, Chen L-Y, Hsu P-S, Krairit O, et al. Sarcopenia in Asia: consensus report of the Asian Working Group for Sarcopenia. *J Am Med Dir Assoc*. 2014;15(2):95–101. doi: 10.1016/j.jamda.2013.11.025
16. Bigman G, Rayan AS. Implications of race and ethnicity in sarcopenia US national prevalence of sarcopenia by muscle mass, strength, and function indices. *Gerontol Geriatr Res*. 2021;4(1):126.
17. Sayer AA, Syddall H, Martin H, Patel H, Baylis D, Cooper C. The developmental origins of sarcopenia. *J Nutr Health Aging*. 2008;12(7):427–32.
18. Kim KM, Jang HC, Lim S. Differences among skeletal muscle mass indices derived from height-, weight-, and body mass index-adjusted models in assessing sarcopenia. *Korean J Intern* Med. 2016;31(4):643–50. doi: 10.3904/kjim.2016.015
19. Chen L-K, Woo J, Assantachai P, Auyeung T-W, Chou M-Y, Iijima K, Jang HC, Kang L, Kim M, Kim S, et al. Asian Working Group for Sarcopenia: 2019 consensus update on sarcopenia diagnosis and treatment. *J Am Med Dir Assocation*. 2020;21(3):300.e2–7.e2. doi: 10.1016/j.jamda.2019.12.012
20. Shafiee G, Keshtkar A, Soltani A, Ahadi Z, Larijani B, Heshmat R. Prevalence of sarcopenia in the world: a systematic review and meta-analysis of general population studies. *J Diabetes Metab Disord*. 2017;16:21. doi: 10.1186/s40200-017-0302-x
21. Budiman A, Ruiz NG. Asian Americans are the fastest-growing racial or ethnic group in the U.S. *Pew Research Center*. Available from: https://www.pewre- search.org/fact-tank/2021/04/09/asian-americans-are-the-fastest-growing-racial-or-ethnic-group-in-the-u-s/ [cited 3 July 2021].
22. Johnson CL, Paulose-Ram R, Ogden CL, Carroll MD, Kruszon-Moran D, Dohrmann SM, Curtin LR. National Health and Nutrition Examination Survey: analytic guidelines, 1999–2010. *Vital Health Stat* 2. 2013;(161):1–24.
23. Paulose-Ram R, Burt V, Broitman L, Ahluwalia N. Overview of Asian American data collection, release, and analysis: National Health and Nutrition Examination Survey 2011–2018. *Am J Public Health*. 2017;107(6):916–21. doi: 10.2105/AJPH.2017.303815
24. National Health and Nutrition Examination Survey: Analytic Guidelines, 2011–2014 and 2015–2016. Available from: https://wwwn.cdc.gov/nchs/data/nhanes/analyticguidelines/11-16-analytic-guidelines.pdf [cited 3 July 2021].
25. WHO Expert Consultation. Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. *Lancet*. 2004;363(9403):157–63. doi: 10.1016/S0140-6736(03)15268-3
26. CDC. Defining adult overweight and obesity. Centers for Disease Control and Prevention. 2022. Available from: https://www.cdc.gov/obesity/basics/adult-defining.html [cited 7 January 2023].
27. Kobayashi K, Imagama S, Ando K, Nakashima H, Machino M, Morozumi M, Kanbara S, Ito S, Inoue T, Yamaguchi H, et al. Dynapenia and physical performance in community-dwelling elderly people in Japan. *Nagoya J Med Sci*. 2020;82(3): 415–24. doi: 10.18999/nagjms.82.3.415
28. Rodríguez-García WD, García-Castañeda L, Vaquero-Barbosa N, Mendoza-Núñez VM, Orea-Tejeda A, Perkisas S, Vandewoude M, Castillo-Martínez L. Prevalence of dynapenia and presarcopenia related to aging in adult community-dwelling Mexicans using two different cut-off points. *Eur Geriatr Med*. 2018;9(2):219–25. doi: 10.1007/s41999-018-0032-8
29. Li JB, Wu Y, Gu D, Li H, Zhang X. Prevalence and temporal trends of pre-sarcopenia metrics and related body composition measurements from the 1999 to 2006 NHANES. *BMJ Open*. 2020;10(8):e034495. doi: 10.1136/bmjopen-2019-034495
30. Droomers M, Schrijvers CTM, Mackenbach JP. Educational level and decreases in leisure time physical activity: predictors from the longitudinal GLOBE study. *J Epidemiol Commun Health*. 2001;55(8):562–8. doi: 10.1136/jech.55.8.562
31. Viinikainen J, Bryson A, Böckerman P, Kari JT, Lehtimäki T, Raitakari O, Viikari J, Pehkonen J. Does better education mitigate risky health behavior? A mendelian randomization study. *Econ Hum Biol*. 2022;46:101134. doi: 10.1016/j.ehb.2022.101134
32. Vogel C, Ntani G, Inskip H, Barker M, Cummins S, Cooper C, Moon G, Baird J. Education and the relationship between supermarket environment and diet. *Am J Prev Med*. 2016;51(2):e27–34. doi: 10.1016/j.amepre.2016.02.030
33. Nesbitt L, Meitner MJ, Girling C, Sheppard SRJ, Lu Y. Who has access to urban vegetation? A spatial analysis of distributional green equity in 10 US cities. *Landsc Urban Plan*. 2019;181:51–79. doi: 10.1016/j.landurbplan.2018.08.007
34. Mijnarends DM, Koster A, Schols JMGA, Meijers JMM, Halfens RJG, Gudnason V, Eiriksdottir G, Siggeirsdottir K, Sigurdsson S, Jónsson PV, et al. Physical activity and incidence of sarcopenia: the population-based AGES-Reykjavik Study. *Age Ageing*. 2016;45(5):614–20. doi: 10.1093/ageing/afw090
35. Oliveira JS, Pinheiro MB, Fairhall N, Walsh S, Franks TC, Kwok W, Bauman A, Sherrington C. Evidence on physical activity and the prevention of frailty and sarcopenia among older people: a systematic review to inform the World Health Organization physical activity guidelines. *J Phys Act Health*. 2020;17(12):1247–58. doi: 10.1123/jpah.2020-0323
36. Oshita K, Myotsuzono R. An association between the physical activity level and skeletal muscle mass index in female university students with a past exercise habituation. *Osteoporos Sarcopenia*. 2021;7(4):146–52. doi: 10.1016/j.afos.2021.10.002
37. Rostron ZP, Green RA, Kingsley M, Zacharias A. Associations between measures of physical activity and muscle size and strength: a systematic review. *Archiv Rehabil Res Clin Transl*. 2021;3(2):100124. doi: 10.1016/j.arrct.2021.100124
38. Tomlinson DJ, Erskine RM, Morse CI, Winwood K, Onambélé-Pearson G. The impact of obesity on skeletal muscle strength and structure through adolescence to old age. *Biogerontology*. 2016;17(3):467–83. doi: 10.1007/s10522-015-9626-4
39. Morgan PT, Smeuninx B, Breen L. Exploring the impact of obesity on skeletal muscle function in older age. *Front Nutr*. 2020;7:569904. doi: 10.3389/fnut.2020.569904
40. Fielding RA, Vellas B, Evans WJ, Bhasin S, Morley JE, Newman AB, Abellan van Kan G, Andrieu S, Bauer J, Breuille D, et al. Sarcopenia: an undiagnosed condition in older adults. Current consensus definition: prevalence, etiology, and consequences. International Working Group on Sarcopenia. *J Am Med Dir Assoc*. 2011;12(4):249–56. doi: 10.1016/j.jamda.2011.01.003
41. Cawthon PM, Manini T, Patel SM, Newman A, Travison T, Kiel DP, Santanasto AJ, Ensrud KE, Xue Q-L, Shardell M, et al. Putative cut-points in sarcopenia components and incident adverse health outcomes: an SDOC Analysis. *J Am Geriatr Soc*. 2020;68(7):1429–37. doi: 10.1111/jgs.16517
42. Bhasin V, Carrillo M, Ghosh B, Moin D, Maglione TJ, Kassotis J. Reversible complete heart block in a patient with coronavirus disease 2019. *Pacing Clin Electrophysiol*. 2021;44(11):1939–43. doi: 10.1111/pace.14321
43. Baumgartner RN, Koehler KM, Gallagher D, Romero L, Heymsfield SB, Ross RR, Garry PJ, Lindeman RD. Epidemiology of sarcopenia among the elderly in New Mexico. *Am J Epidemiol*. 1998;147(8):755–63. doi: 10.1093/oxfordjournals.aje.a009520
44. Morley JE, Abbatecola AM, Argiles JM, Baracos V, Bauer J, Bhasin S, Cederholm T, Stewart Coats AJ, Cummings SR, Evans WJ, et al. Sarcopenia with limited mobility: an international consensus. *J Am Med Dir Assoc*. 2011;12(6):403–9. doi: 10.1016/j.jamda.2011.04.014
45. Delmonico MJ, Harris TB, Lee J-S, Visser M, Nevitt M, Kritchevsky SB, Tylavsky FA, Newman AB. Alternative definitions of sarcopenia, lower extremity performance, and functional impairment with aging in older men and women. *J Am Geriatr Soc*. 2007;55(5):769–74. doi: 10.1111/j.1532-5415.2007.01140.x
46. Studenski SA, Peters KW, Alley DE, Cawthon PM, McLean RR, Harris TB, Ferrucci L, Guralnik JM, Fragala MS, Kenny AM, et al. The FNIH Sarcopenia Project: rationale, study description, conference recommendations, and final estimates. *J Gerontol A Biol Sci Med Sci*. 2014;69(5):547–58. doi: 10.1093/gerona/glu010

47. Cao Y, Zhong M, Zhang Y, Zheng Z, Liu Y, Ni X, Han L, Song M, Zhang W, Wang Z. Presarcopenia is an independent risk factor for carotid atherosclerosis in Chinese population with metabolic syndrome. *Diabetes Metab Syndr Obes*. 2020;13:81–8. doi: 10.2147/DMSO.S235335
48. Kim SR, Lee G, Choi S, Oh YH, Son JS, Park M, Park SM. Changes in predicted lean body mass, appendicular skeletal muscle mass, and body fat mass and cardiovascular disease. *J Cachexia Sarcopenia Muscle*. 2022;13(2):1113–23. doi: 10.1002/jcsm.12962
49. Maruya K, Asakawa Y, Ishibashi H, Fujita H, Arai T, Yamaguchi H. Effect of a simple and adherent home exercise program on the physical function of community dwelling adults sixty years of age and older with pre-sarcopenia or sarcopenia. *J Phys Ther Sci*. 2016;28(11):3183–8. doi: 10.1589/jpts.28.3183
50. Vikberg S, Sörlén N, Brandén L, Johansson J, Nordström A, Hult A, Nordström P. Effects of resistance training on functional strength and muscle mass in 70-year-old individuals with pre-sarcopenia: a randomized controlled trial. *J Am Med Dir Assoc*. 2019;20(1):28–34. doi: 10.1016/j.jamda.2018.09.011
51. Thomson JL, Landry AS, Walls TI. Can United States adults accurately assess their diet quality? *Am J Health Promot*. 2023;37(4):499–506 doi: 10.1177/08901171221137056