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ORIGINAL ARTICLE

Sarcopenia-related features and factors associated with low muscle mass, weak muscle strength, and reduced function in Chinese rural residents: a cross-sectional study

Hong-qi Xu[1] · Ji-peng Shi[1] · Chong Shen[2] · Yu Liu[3] · Jing-Min Liu[4] · Xiu-yuan Zheng[4]

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Abstract

Summary Muscle strength and function declined more than the concomitant loss of muscle mass. Measures of muscle strength and function are an effective way to assess functional ability and physical health in older people. A healthy lifestyle such as physical exercise, good nutrition, and higher BMI can benefit older people.

Introduction The study investigated the characteristics of aging-related differences in appendicular lean mass (ALM/Ht^2), handgrip strength (HGS), usual gait speed (UGS), repeated chair stands (RCS), Timed Up and Go (TUG) test, and their associated factors in 6703 rural residents.

Methods We assessed their anthropometry, body composition, muscle strength and function, bone mineral density, blood pressure, and blood biochemical indices via clinical examination or laboratory tests and investigated demographic characteristics, lifestyle, medical history, physical activity, and dietary intake via questionnaire. Stepwise logistic regression was used to determine the associated factors of low muscle mass, weak muscle strength, reduced physical performance, and sarcopenia.

Results The mean values of muscle strength and function decreased more rapidly with age than the mean values of muscle mass, especially in females. The prevalence of low ALM/Ht^2, weak HGS, slow UGS, long RCS, long TUG, and sarcopenia increased ($P < 0.01$). Higher body mass index (BMI) and daytime sleep were associated with high ALM/Ht^2. Comorbidity factors such as hypertension, bone mineral density loss, central adiposity, metabolic syndrome, and tumors were associated with the risk of weak muscle strength and reduced physical performance, while physical activity and better nutrition were associated with better muscle strength and physical performance.

Conclusions At the higher decades of life, the decline of muscle strength and function is greater than the loss in muscle mass. Measures of muscle strength and function are an effective way to assess functional ability and physical health in older people. Maintaining a healthy lifestyle by means such as physical exercise, good nutrition, and higher BMI throughout the course of life may be benefit older people by improving their muscle mass, strength, and function.

Keywords Sarcopenia · Muscle mass · Muscle strength · Muscle function · Physical performance

✉ Jing-Min Liu
liu_jingmin2016@126.com

Hong-qi Xu
xu_hongqi0402@126.com

Ji-peng Shi
shijp2006@163.com

Chong Shen
sc100@126.com

Yu Liu
asialiuyu@163.com

Xiu-yuan Zheng
xyzheng34@163.com

1 Research Center of Sports and Health Science, School of Sports Science and Physical Education, Northeast Normal University, Changchun, Jilin Province, China

2 Department of Epidemiology and Biostatistics, School of Public Health, Nanjing Medical University, Nanjing, Jiangsu Province, China

3 Jurong Center for Disease Control and Prevention, Jurong, Jiangsu Province, China

4 Research Center of Sports and Health Science, Division of Sports Science and Physical Education, Tsinghua University, No.1 Tsinghua Yuan, Haidian District, Beijing 100084, China

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Introduction

Sarcopenia, an age-related loss of skeletal muscle mass resulting in loss of strength and function, is associated with disability, morbidity, and mortality [1]. This condition has become a subject of increased focus in geriatrics research. Although the definition and diagnostic criteria for sarcopenia remain controversial, a consensus maintains that the characteristics of sarcopenia should include not only loss of muscle mass but also the loss of muscle strength and function [2]. The reported prevalence of sarcopenia varies across studies due to differences in diagnostic criteria as well as in the ages, ethnicities, social and cultural backgrounds, and lifestyles of the study populations [2]. In 2014, the Asian Working Group for Sarcopenia (AWGS) [3], which followed the diagnostic approach of the European Working Group on Sarcopenia in Older People (EWGSOP) [1], proposed a diagnostic algorithm and cutoff points for three diagnostic parameters (muscle mass, muscle strength, and physical performance) [4]. As far as we know, few studies have examined the phenomenon of sarcopenia among Chinese rural residents using the AWGS definition.

The prevalence of sarcopenia varies across studies due to the differences in terms of diagnostic algorithm and recommended cutoff values, which might also have an impact on the risk factors of sarcopenia [5]. As sarcopenia is a geriatric syndrome characterized by the progressive loss of skeletal muscle mass and strength and a continuous attenuation in physical performance [6, 7], the various factors associated with low muscle mass, weak muscle strength, and reduced function can be used to guide and formulate protocols for sarcopenia intervention and prevention [4]. Furthermore, nutrition, lifestyle, and diseases play important roles in the multifactorial formation of sarcopenia [8]. Even though many sarcopenia-related features such as the diagnostic algorithm, cutoff values, prevalence, and associated risk factors have been studied, the precise factors associated with sarcopenia are not well defined [9]. Moreover, most studies to date have focused on Caucasian populations, with few conducted in China, particularly in Chinese rural residents.

Owing to the huge population size and the rapid population aging in China, sarcopenia will be a major threat to the health of the Chinese older people in the near future [4, 9]. For formulating and implementing effective strategies to intervene and reduce sarcopenia-related negative effects, it is essential to identify potential and modifiable risk factors for sarcopenia [8]. Thus, this study was designed to analyze the characteristics of aging-related differences in muscle mass, muscle strength, physical performance, and their associated factors in Chinese rural residents in order to develop prevention and treatment strategies for this syndrome in this population.

Materials and methods

Study population

All of the participants were rural residents from around the city of Jurong in southwest Jiangsu, China. Jurong is a small city near Nanjing, a multiethnic residential area dominated by the Han nationality. This city is experiencing the process of urbanization, a large area of cultivated land was expropriated, and the traditional rural lifestyle of the landless residents has changed dramatically. The comprehensive strength of Jurong ranks the 59th in China's top 100 counties. The local ethical committee of the public health school of Nanjing Medical University (NMU) and Jurong Center for Disease Control and Prevention (Jurong CDC) approved the study protocol. Each participant provided informed written consent prior to participation.

Our research data came from the survey on social factors for prevention and control of chronic non-communicable diseases in Jurong. The cross-sectional survey was conducted in rural residents aged 18–90 years using the multistage sampling method. The inclusion criteria were the following: (i) inhabitants who then lived in Jurong city without a plan to move in the near future and (ii) residents aged 18 years or older. A total of 176 villages in 13 townships in Jurong city were covered by 16 disease surveillance points (DSPs) of the grass-roots medical institutions. First, according to the number of population and the proportion of the population was included in every DSPs, i.e., the sampling number of every DSPs = the sample size/total population of Jurong city × total population of every DSPs, 60 villages were selected from 16 DSPs using the method of probability proportional to size sampling. We then chose two resident groups from each village and 60 households from each resident groups. A total of 120 resident groups and 7200 households were selected using cluster random sampling. Subsequently, one family member was randomly selected from each household using the Kish grid sampling method. Eventually, 7000 people agreed to participate in the project, and complete surveys, including medical history and physical and laboratory examination data, were obtained from 6703 subjects.

To be included in the prevalence and associated risk factors of sarcopenia analyses, participants were required to have height and weight, ALM (sum of lean mass in the arms and legs), grip strength, and gait speed measured at a single time point. Of the 6703 participants in the pooled data, 101 male and 130 female were ineligible because they lack effective muscle mass data (ALM/Ht^2) as the abnormal impedance data, height or weight; 78 male and 121 female were ineligible because they lack effective HGS (52) or UGS (147) as the impaired functions of the limbs, eyesight, hearing, or abnormal data. AWGS recommends using 60 or 65 years as the age cutoff value for sarcopenia diagnosis according to the definitions of elderly populations [3]. In our participants, 2633 elderly subjects over 60 years old in 6703 participants. And

2412 subjects have effective ALM/Ht^2, HGS and UGS at the same time in those 2633 elderly participants. As sarcopenia was characterized by low muscle mass plus low muscle strength and/or low physical performance [3], and for the consistency of follow-up analysis, we finally adopted the data of these 2412 elderly subjects for the analysis of risk factors associated with sarcopenia.

Measurement of anthropometrics, body composition, bone mineral density, and clinical characteristics

The body weight and height of participants were measured without shoes and in lightweight clothing. The body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2). Waist circumference (WC) was measured in the standing position and palpated at the iliac crest, crossing the midaxillary line. Body composition was measured by bioimpedance analysis using two BCA_{II} (Body Composition Analyzer II, TFHT, Beijing, China) tetrapolar eight-point tactile electrode systems in accordance with standardized procedures recommended by the manufacturer. The device has been used in many studies, and the details of the measurement of body mass by BCA_{II} have been published elsewhere [4, 6, 10]. The machine provides immediate detailed results, including quantitative values of total body and segmental lean body mass (LBM), fat mass (FM), muscle mass (MM), bone mass (BM), and percentage fat mass (FM%). Appendicular lean muscle mass (ALM) was calculated as the sum of lean muscle in the arms and legs. The ALM index (ALM/Ht^2) and LM index (LM/Ht^2) were obtained by dividing ALM and LBM by the square of height, respectively (kg/m^2). Bone mineral density (BMD) was measured by an ultrasound bone densitometer (Furuno CM-200, Nishinomiya, Hyogo, Japan), and the CM-200 utility software displayed the speed of sound (SOS) in the heel. The T score was calculated using the formula [11, 12]: T score = difference of the calcaneal quantitative ultrasound (QUS) value between the subject being measured and the young adult divided by the standard deviation (SD) of the young adult. We calculated the peak speed-of-sound value for young adults by estimating peak bone mass, which was itself defined as the average maximum bone mass achieved by young, sex- and race-matched adults. Blood samples were taken after a fast of at least 12 h and were measured in the clinical laboratory of the affiliated hospital of NMU. Blood pressure (BP) was measured twice in a sitting position, and the mean values were used in the assessment.

Survey of demographics, lifestyle, and comorbidities

A questionnaire was adapted from the Chronic Diseases and Related Risk Factors questionnaire compiled by the Chinese Center for Disease Control and Prevention to collect information on demographics, lifestyle, and disease history [13]. Participants were asked about their demographic characteristics, including age, gender, marital status, education level (primary school or below, middle school, high school/technical secondary school, college/undergraduate, or graduate school or above), smoking status (never smoker, ex-smoker, or current smoker), and alcohol consumption (never drinker or current drinker). Marital status was classified as married (living together, divorced, separated, or widowed) or not married/single. The presence of chronic conditions, including dyslipidemia, hypertension, diabetes mellitus, coronary heart disease, stroke, and tumors, was also recorded. The questions on dietary habits [14] and physical activity time [15] were adapted from validated questionnaires used in the China Kadoorie Biobank study, which was approved by the Chinese Center for Disease Control and Prevention. Data on dietary intake was collected using a food frequency questionnaire. The nutrient intake percentages were categorized into quartiles, which were compared with the Dietary Reference Intakes (DRIs). Participants were asked how often they took part in four types of physical activity (PA): occupational, transportation, household, and leisure. The intensity of a physical activity was expressed in metabolic equivalents (METs) according to the American Compendium of Physical Activities and the Physical Activity Questionnaire of Professionals in China [16]. METs were calculated as the MET level of each activity × minutes of activity × number of times the activity was done per day. Walking, moderate-intensity activity, and vigorous activity were multiplied by 3.3, 4.0, and 8.0, respectively. In addition, the sleep duration of the day and night was self-recorded by participants.

Dyslipidemia was determined by the level of serum lipids according to the 2016 Chinese Guidelines for the Prevention and Treatment of Dyslipidemia in Adults. Hypertension and diabetes were identified by medical history and positive screening results ($SBP \geq 140.0$ mmHg or $DBP \geq 90.0$ mmHg and $FBG \geq 7.0$ mmol/L, respectively). Central adiposity was defined as $WC \geq 85$ cm for men and ≥ 80 cm for women. The components of metabolic syndrome were defined by the third report of the American National Cholesterol Education Program [17]. For classifying subjects into the respective bone health status (normal, osteopenic, or osteoporotic), a classification scheme based on validation data using a device of the same series (CM-100) was adopted [11, 12], that is, normal = T score ≥ 1.12 SD, osteopenia = 1.80 SD < T score < 1.12 SD, and osteoporosis = T score ≤ − 1.80 SD.

Definitions of low muscle mass, weak muscle strength, reduced physical performance, and sarcopenia

Participants were classified as having sarcopenia based on the recommendations of AWGS [3]. Sarcopenia was characterized by low muscle mass plus low muscle strength and/or low physical performance. Low muscle mass was classified as ALM/Ht^2 less than the gender-specific 20th percentile of the study population. Muscle strength was assessed by handgrip strength (HGS), measured using a hand dynamometer (CSTF-WL, TFHT, Beijing, China). Low HGS was defined as < 26 kg and < 18 kg for males and females, respectively. Usual gait speed (UGS) on a 6-m course was used as an objective measure of physical performance; slow gait speed was defined as a walking speed slower than 0.8 m/s. The repeated chair stands (RCS) assessment required participants to rise from a chair with arms across their chest as quickly as they could, within a 30-s time limit; the average velocity was calculated by dividing 30 s by the number of repetitions, and the time was recorded as the average velocity multiplied by five [4, 18]. For the Timed Up and Go (TUG) test, individuals were asked to stand up from a chair, walk 3 m, turn around, return to the chair, and sit down [19, 20]. Reduced performance on RCS and TUG was defined as a value in excess of the 80th percentile of the RCS and TUG scores measured in the older participants in this study [4, 18, 19]. Hence, RCS ≥ 13.6 s and TUG ≥ 11.5 s were defined as reduced RCS and TUG performance.

Statistical analysis

Statistical analysis was performed using SPSS 17.0 statistical software (SPSS Inc., Chicago, IL, USA). Results were expressed as mean (SD) for continuous variables or percentages (frequencies) for categorical variables. We performed subgroup analyses according to age and gender. One-way analysis of variance (ANOVA) and Pearson's chi-square test were used to determine the differences between groups for the continuous variables and the categorical variables, respectively. Linear regression analysis was used to assess the change in muscle mass, strength, and function with age [21]. To compare the decline of muscle mass, strength, and function with age and plot them on the same scale, the variables were normalized by expressing them as a percentage of the mean value of the 18–60-year age group in each case [21]. Logistic regression models were used to determine which factors were independently associated with low muscle mass, weak muscle strength, reduced physical performance, and sarcopenia. Only variables significantly ($P < 0.05$) associated with sarcopenia in the univariate analysis were included in the subsequent model. A multivariable logistic model was then computed, which included all the variables that were associated with the outcome at an α level of 0.05. Finally, in order to remove unnecessary variables, a more parsimonious model was selected using a stepwise backward selection technique until the best model was selected.

Results

Characteristics of the study population

The difference in anthropometry, body composition, muscle strength, physical performance, bone mineral density, physical activity, nutrient intake, and comorbidity by age and gender is shown in Table 1. For males, the highest of mean values for height, weight, LBM, ALM, HGS, UGS, BMI, LM/Ht^2, ALM/Ht^2, calcaneal SOS, TEI, and PI occurred in the 18–40-year age group. The first six variables were significantly lower in the above 40-year age group ($P < 0.01$), and the last six variables were significantly lower in the above 60-year age group ($P < 0.05$). The highest of mean value for FM also occurred in the youngest group, but no significant differences were observed among the three groups ($P > 0.05$). The highest of mean values for WC and PA occurred in the 40–60-year age group, and the variables decreased significantly in the above 60-year age group ($P < 0.05$). The highest of mean values for RCS and TUG occurred in the oldest group, and distinct increments in older age were evident in males ($P < 0.01$). The highest of mean rate for dyslipidemia occurred in the youngest group. For smoking, drinking, and MS, the highest of mean rates occurred in the 40–60-year age group. And these four rates were significantly lower in the above 60-year age group ($P < 0.01$). Besides, the highest of mean rates for hypertension, CHD, stroke, DM, and tumor occurred in the oldest group. The first three rates were significantly higher in the above 60-year age group ($P < 0.05$), and no significant differences were observed in the last two rates among the three groups ($P > 0.05$).

For females, the highest of mean values for height, HGS, UGS, calcaneal SOS, and PI occurred in the 18–40-year age group. The first four variables were significantly lower in the above 40-year age group ($P < 0.01$), and the last one variables were significantly lower in the above 60-year age group ($P < 0.01$). For BMI, LM/Ht^2, FM, ALM/Ht^2, and PA, the highest of mean values occurred in the 40–60-year age group, the lowest of mean values occurred in the 18–40-year age group, and all five variables increased significantly in the above 40-year age group ($P < 0.05$). For weight, LBM, ALM, and TEI, the highest of mean values occurred in the 40–60-year age group, the lowest of mean values occurred in the above 60-year age group, and all four variables decreased significantly in the above 60-year age group ($P < 0.01$). The highest of mean values for RCS, TUG, and WC occurred in the oldest group, and distinct increments in older age were evident in females ($P < 0.01$). The highest of mean rates for smoking and comorbidities occurred in the oldest group, and distinct increments in the above 60-year age group were evident in females ($P < 0.05$). Additionally, no significant differences were observed in the mean rates of drinking among the three groups ($P > 0.05$).

Table 1 Characteristics of anthropometry, body composition, muscle strength, and physical performance in 6703 rural residents

Characteristic	Male				Female			
	18–40 years[1] (*n* = 159)	40–60 years[2] (*n* = 1598)	≥ 60 years[3] (*n* = 1110)	Total (*n* = 2867)	18–40 years[1] (*n* = 309)	40–60 years[2] (*n* = 2004)	≥ 60 years[3] (*n* = 1523)	Total (*n* = 3836)
Age (years)	34.45 (5.15)	51.82 (5.17)**	68.86 (6.47)##△△	61.40 (11.35)	34.04 (4.50)	51.32 (4.98)**	68.13 (6.14)##△△	59.10 (11.33)▽▽
Height (cm)	169.74 (6.13)	166.81 (6.18)**	163.63 (6.35)##△△	165.01 (6.52)	157.43 (5.99)	155.89 (5.51)**	152.96 (5.64)##△△	154.47 (5.81)▽▽
Weight (kg)	73.53 (11.74)	69.80 (10.55)**	65.01 (10.70)##△△	67.06 (11.00)	59.14 (9.26)	61.40 (9.64)**	59.04 (9.66) △△	60.09 (9.70)▽▽
WC (cm)	84.50 (9.26)	84.65 (9.37)	82.51 (9.80)#△△	83.36 (9.68)	74.60 (8.57)	80.33 (9.05)**	82.93 (9.73)##△△	81.39 (9.58)▽▽
BMI (kg/m^2)	25.46 (3.53)	25.18 (3.27)	24.33 (3.38)##△△	24.68 (3.37)	23.96 (3.57)	25.45 (3.54)**	25.30 (3.53)##	25.31 (3.55)▽▽
FM (kg)	17.11 (7.05)	16.88 (5.87)	16.92 (5.88)	16.91 (5.92)	18.81 (5.63)	20.46 (6.36)**	20.23 (6.37)##	20.27 (6.34)▽▽
LBM (kg)	56.13 (8.68)	53.19 (6.94)**	48.28 (6.60)##△△	50.34 (7.29)	40.81 (4.89)	41.46 (5.44)	39.04 (6.07)##△△	40.19 (5.87)▽▽
LM/Ht^2 (kg/m^2)	19.41 (2.55)	19.06 (1.77)	17.99 (2.16)##△△	18.43 (2.12)	16.41 (1.66)	17.02 (1.77)**	16.65 (2.12) △△	16.80 (1.96)▽▽
ALM (kg)	23.16 (3.77)	22.36 (3.03)**	21.27 (2.83)##△△	21.73 (3.00)	15.57 (2.13)	16.05 (2.89)*	15.42 (3.36) △△	15.71 (3.13)▽▽
ALM/Ht^2 (kg/m^2)	8.04 (1.08)	8.03 (0.85)	7.93 (0.82) △△	7.97 (0.85)	6.24 (0.61)	6.58 (1.00)**	6.57 (1.23)##	6.56 (1.12)▽▽
HGS (kg)	45.48 (8.99)	40.87 (8.85)**	33.55 (8.16)##△△	36.66 (9.30)	28.13 (5.00)	26.75 (5.29)**	22.19 (5.74)##△△	24.50 (6.00)▽▽
UGS (m/s)	1.34 (0.27)	1.15 (0.25)**	1.04 (0.24)##△△	1.10 (0.26)	1.25 (0.25)	1.14 (0.25)**	1.02 (0.27)##△△	1.09 (0.27)
RCS (s)	8.28 (1.96)	10.23 (2.67)**	12.28 (3.58)##△△	11.42 (3.43)	8.60 (2.08)	10.43 (2.66)**	12.35 (3.75)##△△	11.33 (3.41)
TUG (s)	7.54 (1.26)	8.90 (4.57)**	9.94 (3.22)##△△	9.44 (3.78)	7.92 (1.25)	8.82 (3.26)**	10.19 (4.33)##△△	9.43 (3.82)
Married (%)	87.4 (139)	96.6 (1544)**	97.1 (1078)##	96.3 (2761)	97.1 (300)	99.7 (1998)**	99.4 (1514)##	99.4 (3812)▽▽
Current smoker (%)	61.0 (97)	62.6 (1000)	50.8 (564)#△△	57.9 (1661)	0.6 (2)	0.5 (10)	2.8 (43)#△△	1.4 (55)▽▽
Current drinker (%)	56.6 (90)	60.5 (967)	52.4 (582) △△	57.2 (1639)	6.1 (19)	8.8 (176)	9.4 (143)	8.8 (338)▽▽
Hypertension (%)	6.3 (10)	9.6 (153)	14.2 (158)#△△	11.2 (321)	1.9 (6)	7.8 (156)**	13.0 (198)##△△	9.4 (360)▽
DM (%)	1.3 (2)	3.9 (62)	4.2 (47)	3.9 (111)	0.0 (0)	2.8 (56)*	5.3 (81)##△△	3.6 (137)
CHD (%)	0.0 (0)	0.4 (6)	1.9 (21) △△	0.9 (27)	0.0 (0)	0.3 (6)	1.6 (24) △△	0.8 (30)
Stoke (%)	0.6 (1)	0.7 (11)	2.2 (24) △△	1.3 (36)	0.0 (0)	0.9 (18)	3.0 (46)#△△	1.7 (64)
Tumor (%)	0.6 (1)	0.2 (3)	0.6 (7)	0.4 (11)	0.0 (0)	0.2 (4)	0.6 (9) △	0.3 (13)
Dyslipidemia (%)	39.0 (62)	32.6 (521)	20.7 (230)##△△	28.4 (813)	14.2 (44)	24.4 (489)**	29.4 (448)##△△	25.6 (981)
MS (%)	18.9 (30)	19.3 (308)	13.9 (154) △△	17.2 (492)	9.1 (28)	23.2 (465)**	37.4 (570)##△△	27.7 (1063)▽▽
Calcaneal SOS (m/s)	1530.47 (22.37)	1526.49 (26.85)	1519.64 (27.87)##△△	1522.50 (27.56)	1539.11 (26.66)	1528.63 (26.55)**	1506.23 (23.32)##△△	1517.59 (27.62)▽▽
PA (Mets-h/day)	18.84 (17.41)	22.80 (20.96)	18.60 (18.58)△△	20.12 (19.54)	12.12 (9.75)	15.85 (13.43)**	14.35 (12.17)#△△	14.96 (12.72)▽▽
TEI (kcal)	1281.65 (459.71)	1265.30 (466.90)	1165.01 (654.39)#△△	1205.76 (588.38)	989.27 (328.92)	997.48 (414.00)	941.34 (370.15)#△△	968.48 (389.49)▽▽
PI (g)	65.63 (27.13)	62.11 (27.34)	54.92 (29.52)##△△	57.93 (28.90)	51.31 (20.39)	48.94 (28.07)	43.27 (20.85)##△△	46.16 (24.49)▽▽

LM lean body mass (kg), *LM/Ht^2* lean body mass(kg)/height^2 (m^2) (kg/m^2), *FM* fat mass (kg), ALM appendicular lean mass (kg), *ALM/Ht^2* appendicular lean mass(kg)/height^2 (m^2) (kg/m^2), *HGS* handgrip strength (kg), *UGS* usual gait speed (m/s), *RCS* repeated chair stands (s), *TUG* Timed Up and Go test (s), *WC* waist circumference (cm), *SOS* speed of sound (m/s), *DM* diabetes mellitus, *CHD* coronary heart disease, *MS* metabolic syndrome, *PA* physical activity (Mets-h/day), *TEI* total energy intake (kcal), *PI* protein intake (g)

Age difference, 1–2 *$P < 0.05$, **$P < 0.01$, 1–3# $P < 0.05$, ## $P < 0.01$, 2–3△ $P < 0.05$, △△ $P < 0.01$; gender difference (across full sample), ▽ $P < 0.05$, ▽▽ $P < 0.01$

Males had significant higher age, height, weight, WC, LBM, LM/Ht^2, ALM, ALM/Ht^2, HGS, calcaneal SOS, PA, TEI, and PI, but lower BMI and FM than females ($P < 0.01$). The gender difference for UGS, RCS, and TUG was not significant ($P > 0.05$). Moreover, smoking, drinking, and hypertension were more prevalent in the male, whereas married and MS were more common in female ($P < 0.01$). The gender difference in the prevalence of DM, CHD, stroke, tumor, and dyslipidemia was not significant ($P > 0.05$).

Differences in muscle mass, muscle strength, and physical performance by age and gender

Figure 1 shows the differences in mean values for ALM, ALM/Ht^2, HGS, UGS, RCS, and TUG among different age groups. For the muscle mass parameter, ALM and ALM/Ht^2 were significantly higher in males than in females in all groups ($P < 0.01$). The mean values of both indices increased and later decreased in multiple age groups. The mean values of ALM for male and female subjects peaked at the 30–40-year age group and 40–50-year age group, respectively. The mean values of ALM/Ht^2 reached the top later than ALM for 10 years and then decreased. Compared to the mean value of the 18–60 year age group, the mean value of ALM decreased in the 60–70-, 70–80-, and 80–90-year age groups by 3.65%, 7.56%, and 9.34%, respectively, in males, and by 1.48%, 7.08%, and 14.58%, respectively, in females. Moreover, the mean value of ALM/Ht^2 decreased in the 60–70-, 70–80-, and 80–90-year age groups by 0.60%, 2.15%, and 2.89%, respectively, in males and by 0.05%, 1.57%, and 6.28%, respectively, in females.

For the muscle strength and physical performance parameters, HGS was significantly higher in males than in females in all groups ($P < 0.01$). Meanwhile, the mean values of UGS, RCS, and TUG were equal for males and females in most age groups, with the exceptions of UGS in the 30–40-year age group and RCS and TUG in the 80–90-year age group. The mean values of HGS and UGS were lower in subjects at the higher decades of life. Compared to the 18–60-year age group, the mean values of HGS decreased in the 60–70-, 70–80-, and 80–90-year age groups by 13.48%, 25.98%, and 36.10%, respectively, in males, and by 12.94%, 24.61%, and 40.86%, respectively, in females. Additionally, the mean values of UGS decreased in the 60–70-, 70–80-, and 80–90-year age groups by 8.29%, 16.17%, and 23.20%, respectively, in males and by 8.57%, 16.39%, and 25.37%, respectively, in females. Meanwhile, the mean values of RCS and TUG were higher in subjects at the higher decades of life. Compared to the 18–60-year age group, the mean values of RCS increased in the 60–70-, 70–80-, and 80–90-year age groups by 17.94%, 29.22%, and 32.50%, respectively, in males and by 15.94%, 28.42%, and 41.77%, respectively, in females. Moreover, the mean values of TUG increased in the 60–70-, 70–80-, and 80–90-year age groups by 9.67%, 19.00%, and 28.71%, respectively, in males and by 12.90%, 24.31%, and 40.90%, respectively, in females.

Changes in muscle mass, muscle strength, and function in subjects over 60 years old

Figure 2 shows the decline in adjusted muscle mass and adjusted muscle strength and function of subjects over 60 years old. In male, muscle strength and function (HGS, $\beta = -0.01338$; UGS, $\beta = -0.00933$; TUG, $\beta = -0.00703$) declined more rapidly than did muscle mass (ALM/Ht^2, $\beta = -0.00111$) in subjects at the higher decades of life, respectively. In female, muscle strength and function (HGS, $\beta = -0.01338$; UGS, $\beta = -0.00942$; TUG, $\beta = -0.01014$) also declined more rapidly than did muscle mass (ALM/Ht^2, $\beta = -0.00179$).

Prevalence of low muscle mass, weak muscle strength, reduced physical performance, and sarcopenia in different gender and age groups

The prevalence of low muscle mass, weak muscle strength, reduced physical performance, and sarcopenia in the elderly is shown in Table 2. At the higher decades of life, the prevalence of low ALM/Ht^2, weak HGS, slower UGS, longer RCS, longer TUG, and sarcopenia increased steeply ($P < 0.01$), with the exception of low ALM/Ht^2 in males ($P = 0.107$). The incidence rate of sarcopenia-related parameters was generally lower in males than in females. A total of 156 subjects (6.5%) were identified as being affected by sarcopenia; 58 (5.7%) were males and 98 (7.0%) were females. Among the subjects with sarcopenia, 129 (5.3%) were sarcopenic because of low UGS ($n = 46$ [1.9%]; 19 males and 27 females) or poor HGS ($n = 83$ [3.4%]; 29 males and 54 females), whereas 27 (1.1%; 10 males and 17 females) had the concomitant presence of reduced muscle strength and slow gait speed.

Factors associated with low muscle mass, weak muscle strength, reduced physical performance, and sarcopenia in the oldest group

Factors associated with low muscle mass, weak muscle strength, reduced physical performance, and sarcopenia in the oldest group are shown in Table 3. For anthropometrics and demographic factors, aging was associated with the risk of low muscle mass, weak muscle strength, and reduced physical performance. Meanwhile, BMI was associated with high ALM/Ht^2 and strong HGS, and a higher education level was associated with better physical performance in HGS, UGS, TUG, and RCS. For lifestyle factors, smoking was associated with weak HGS, while drinking was associated with better performance in HGS and UGS. In addition, daytime sleep was associated with high ALM/Ht^2 and faster RCS. For clinical characteristics and health status factors, hypertension was

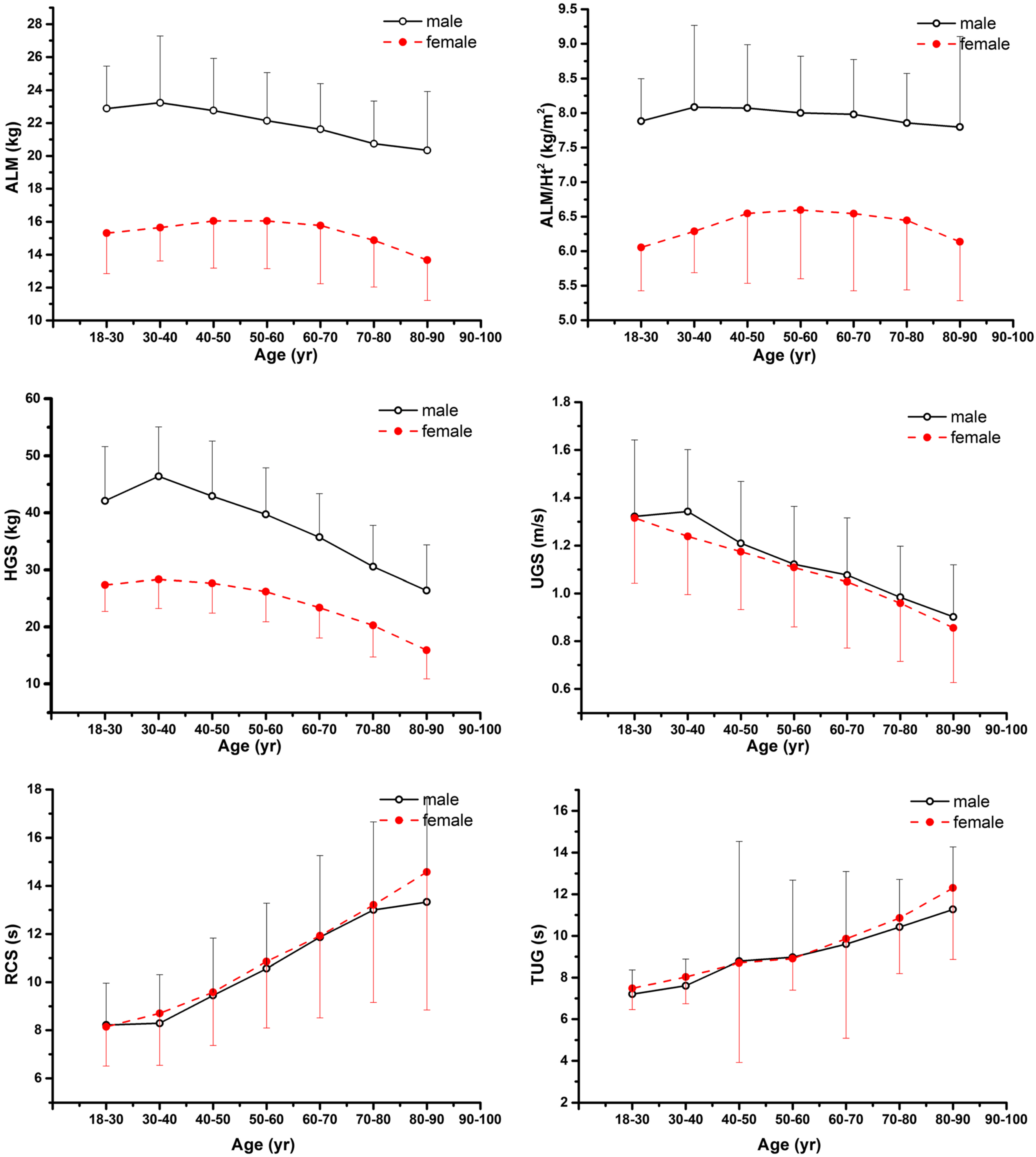

Fig. 1 The degrees of difference in muscle mass, muscle strength, and physical performance with aging. ALM appendicular lean mass (kg), ALM/Ht^2 appendicular lean mass (kg)/height^2 (m^2) (kg/m^2), HGS handgrip strength (kg), UGS usual gait speed (m/s), RCS repeated chair stands (s), TUG Timed Up and Go test (s)

associated with slower RCS, while bone mineral density loss was associated with low ALM/Ht^2, weak HGS, and slower RCS. Central adiposity and tumors were associated with reduced performance on TUG and RCS. Metabolic syndrome was associated with slower UGS. For physical activity and dietary intake factors, engagement in physical activity was associated with strong HGS and faster UGS, total energy intake was associated with strong HGS, and protein intake was associated with better performance in both TUG and RCS.

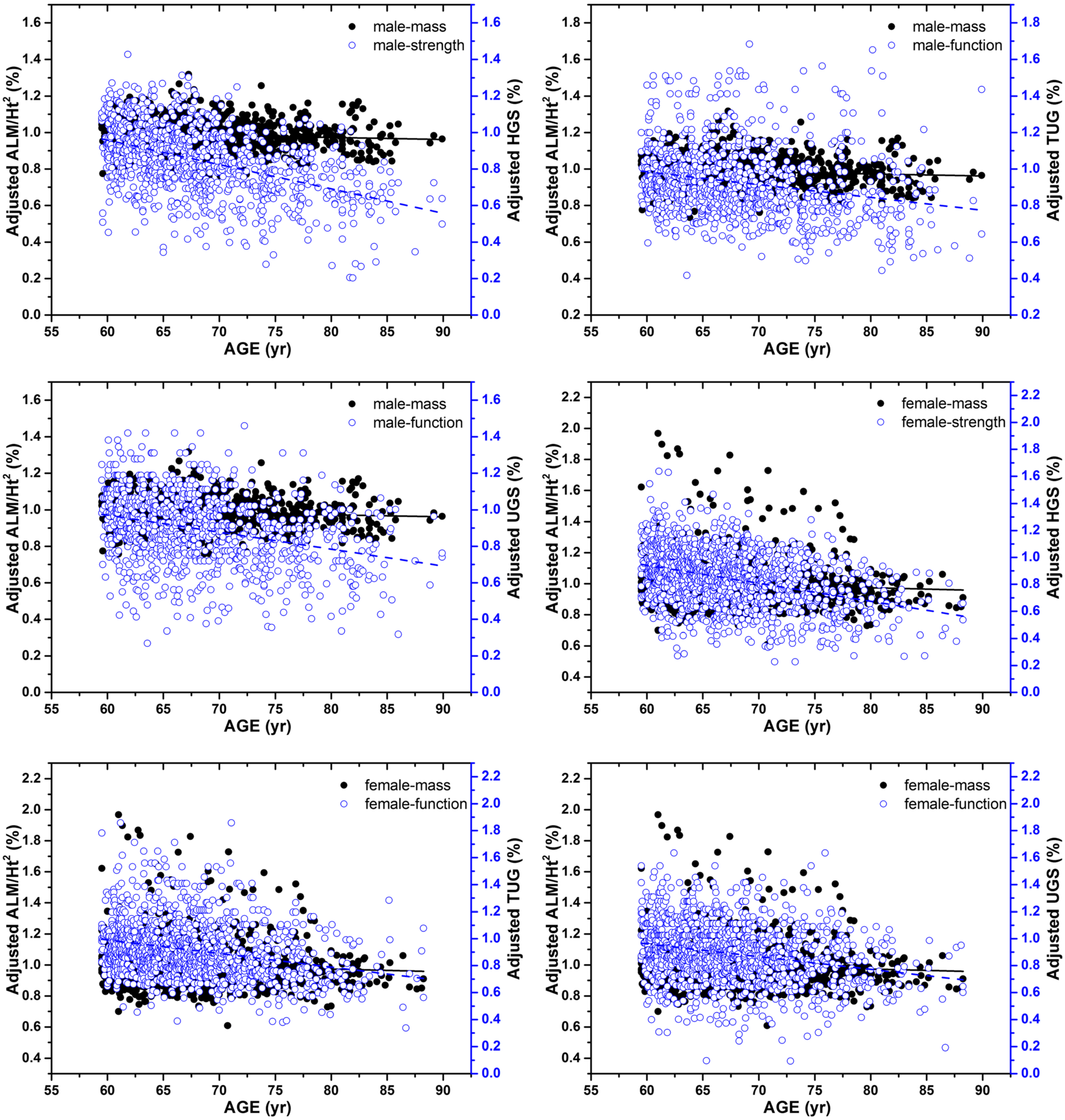

Fig. 2 The decline in adjusted muscle mass and adjusted muscle strength and function of subjects over 60 years old. ALM/Ht^2 appendicular lean mass (kg)/height^2 (m^2) (kg/m^2), HGS handgrip strength (kg), UGS usual gait speed (m/s), TUG Timed Up and Go test (s). In male, HGS ($\beta = -0.01338$), UGS ($\beta = -0.00933$), TUG ($\beta = -0.00703$) vs ALM/Ht^2 ($\beta = -0.00111$), respectively; in female, HGS ($\beta = -0.01338$), UGS ($\beta = -0.00942$), TUG ($\beta = -0.01014$) vs ALM/Ht^2 ($\beta = -0.00179$), respectively

Table 3 also presents the risk factors selected by the multivariate logistic models and the best logistic models, which were associated with sarcopenia as defined by the AWGS criteria. After adjusting for potential confounders, we found that aging (OR 1.53, 95% CI 1.34–1.74) and bone mineral density loss (OR 1.44, 95% CI 1.16–1.78) were associated with significantly increased risk for sarcopenia. Meanwhile, higher BMI (OR 0.16, 95% CI 0.11–0.24), education level (OR 0.84, 95% CI 0.72–0.96), drinking (OR 0.58, 95% CI 0.37–0.91), and total energy intake (OR 0.87, 95% CI 0.74–1.02) were associated with decreased probability of sarcopenia.

Table 2 Prevalence of low muscle mass, weak muscle strength, reduced physical performance, and sarcopenia in different gender and age groups

	Age group	Number	Low ALM/Ht^2	Weak HGS	Slow UGS	Sarcopenia	Number	Long RCS	Number	Long TUG
Male	60–90 years	1012	19.6% (198)	11.8% (119)	14.8% (150)	5.7% (58)	999	30.6% (306)	1010	17.2% (174)
	60–70 years	673	18.3% (123)	6.4% (43)	10.5% (71)	3.6% (24)	668	26.8% (179)	672	10.7% (72)
	70–80 years	265	20.4% (54)	18.5% (49)	19.6% (52)	6.8% (18)	259	37.5% (97)	264	25.4% (67)
	80–90 years	74	28.4% (21)	36.5% (27)	36.5% (27)	21.6% (16)	72	41.7% (30)	74	47.3% (35)
	χ^2		4.474	73.881	42.077	40.976		14.420		79.215
	P value		0.107	0.000	0.000	0.000		0.001		0.000
Female	60-90 years	1400	19.7% (276)	19.3% (270)	17.1% (240)	7.0% (98)	1378	30.6% (422)	1395	22.2% (310)
	60-70 years	1009	18.1% (183)	13.8% (139)	13.0% (131)	4.6% (46)	997	27.4% (273)	1005	14.6% (147)
	70–80 years	348	22.4% (78)	30.7% (107)	25.6% (89)	11.8% (41)	342	38.0% (130)	348	39.7% (138)
	80-90 years	43	34.9% (15)	55.8% (24)	46.5% (20)	25.6% (11)	39	48.7% (19)	42	59.5% (25)
	χ^2		9.440	85.903	55.821	44.263		19.727		128.545
	P value		0.009	0.000	0.000	0.000		0.000		0.000

The Pearson χ^2 test was used for the categorical variables. During testing, $P < 0.05$ was considered to be statistically significant

Discussion

In this study, the characteristics of aging-related differences in muscle mass, muscle strength, and physical performance and their associated factors were analyzed in a Chinese rural population. Our findings were in agreement with earlier studies indicating loss of skeletal muscle mass and strength and declining physical performance in older age [1, 3]. A continuous attenuation was observed in muscle mass, muscle strength, and physical performance after 60 years of age. These results imply that before the age of 60 years, there could be opportunities to intervene and prevent the decline of muscle mass or muscle physical function. Moreover, muscle mass and muscle strength showed significant gender differences, with females having lower muscle mass and poorer muscle strength. However, there were almost no gender differences in tests of physical performance. There were no significant differences in UGS, TUG, or RCS between male and female subjects in most age groups. This may be explained by the complexity and intensity of the physical and muscle function tests [22]. UGS, TUG, and RCS are complex tasks involving multiple systems and are of low intensity. Meanwhile, HGS is a simple task that only involves one muscle group (low complexity) and requires a maximal voluntary contraction to be performed (high intensity). On this test, male subjects tended to outperform females. Previous studies have shown that muscle mass is associated with muscle strength and function [21, 23]. Our study found that the muscle mass (ALM, ALM/Ht^2) and muscle strength (HGS) indices all presented an increase and later a decrease in multiple age groups in male and female subjects. In males, the mean values of the three indices peaked at the same age group (30–40 years old). In females, however, the mean values of ALM and ALM/Ht^2 reached the top later than HGS for 10 to 20 years. For physical performance indices, the mean values of UGS were lower in subjects at the higher decades of life, while RCS and TUG times showed the opposite trend. These trends showed that the functional capacity of the elderly continues to decline at the higher decades of life. Taken together, these results indicate that the mean values of muscle strength and function decreased more rapidly than the mean values of muscle mass, especially in females. The age-dependent decline in strength and function was not explained by the loss of muscle mass alone [24], and the relationship between muscle mass and strength or function was gender-specific [21, 25]. Our findings suggest that efforts to improve the functional capacity of the elderly should take into account gender differences.

At the higher decades of life, the prevalence of low muscle mass, weak muscle strength, reduced physical performance, and sarcopenia increased steeply in our study. Using the AWGS criteria, we found that in our older subjects, 19.6% of males and 19.7% of females had low ALM/Ht^2; 11.8% of males and 19.3% of females had weak HGS; 14.8% of males and 17.1% of females had slow UGS; and 5.7% of males and 7.0% of females had sarcopenia. Among researchers using AWGS criteria, the estimated prevalence of sarcopenia among the general older population ranges between 4.1 and 11.5% [26]. As muscle mass measurement is the last screening test in the recommended diagnostic algorithm of AWGS [3], the cutoff points used for muscle mass may affect the reported prevalence rates for sarcopenia and in turn affect comparability between studies [27]. AWGS recommends using two standard deviations below the mean muscle mass of the young reference group or the lower quintile as the cutoff value [3]. Using the former criterion, our study found an extremely low prevalence of low ALM/Ht^2 (1.3% for males, 0.7% for females) and sarcopenia (0.3% for males, 0.4% for females). We therefore chose the latter criterion and found the prevalence of sarcopenia after age 60 years to be 5.7% for males and 7.0% for females. In our study, the recommended cutoff value for ALM/Ht^2 was 7.41 kg/m^2 for males and 5.93 kg/m^2 for females. This value is higher than the value suggested by AWGS. In fact, China is a huge and densely populated country

Table 3 Factors associated with low muscle mass, weak muscle strength, reduced physical performance, and sarcopenia in oldest group

Variables	Low ALM/Ht^2		Weak HGS		Slow UGS		Long TUG		Long RCS		Sarcopenia	
	OR:95% CI	*P*	OR:95% CI	*P*	OR:95% CI	*P*	OR:95% CI	*P*	OR:95% CI	*P*	OR:95% CI	*P*
Gender												
Age increased 5 years	1.11 (1.01–1.21)	0.038	1.56 (1.42–1.72)	0.000	1.46 (1.33–1.59)	0.000	1.70 (1.56–1.85)	0.000	1.24 (1.14–1.34)	0.000	1.53 (1.34–1.74)	0.000
BMI	0.12 (0.09–0.15)	0.000	0.82 (0.70–0.96)	0.013							0.16 (0.11–0.24)	0.000
Education level			0.73 (0.66–0.80)	0.000	0.85 (0.78–0.93)	0.001	0.79 (0.73–0.86)	0.000	0.90 (0.84–0.97)	0.004	0.84 (0.72–0.96)	0.014
Smoking			1.26 (1.05–1.50)	0.012								
Drinking			0.68 (0.50–0.93)	0.017	0.71 (0.54–0.95)	0.020					0.58 (0.37–0.91)	0.018
Sleeping time of night												
Sleeping time of day	0.78 (0.63–0.98)	0.032							0.77 (0.65–0.92)	0.004		
Dyslipidemia												
Hypertension									1.34 (1.02–1.75)	0.034		
Bone mineral density	1.27 (1.11–1.45)	0.001	1.13 (0.99–1.31)	0.077					1.12 (1.01–1.24)	0.040	1.44 (1.16–1.78)	0.001
Central adiposity							1.45 (1.17–1.80)	0.001	1.27 (1.06–1.52)	0.010		
Diabetes mellitus												
Metabolic syndrome					1.38 (1.09–1.76)	0.008						
Coronary heart disease												
Stoke												
Tumor							3.18 (1.11–9.16)	0.032	2.41 (0.88–6.56)	0.087		
Physical activity			0.91 (0.81–1.01)	0.079	0.88 (0.79–0.97)	0.015						
Total energy/EER(%)			0.87 (0.79–0.97)	0.013							0.87 (0.74–1.02)	0.089
Protein/RNI (%)							0.89 (0.81–0.98)	0.018	0.89 (0.82–0.97)	0.005		

Gender: male = 1, female = 2; BMI: 1 = <24.0 kg/m^2 , 2 = 24.0–27.9 kg/m^2 , 3 = ≥ 28 kg/m^2 ; education level: 1 = primary school or below, 2 = middle school, 3 = high school/technical secondary school, 4 = college/undergraduate, 5 = graduate school or above; smoking: 1 = never, 2 = former, 3 = current; drinking: 1 = never, 2 = current; sleeping time of night: 1 = <7 h, 2 = 7–9 h, 3 = ≥ 9 h; sleeping time of day: 1 = 0 h, 2 = 0–2 h, 3 = ≥ 2 h; bone mineral density: 1 = normal, 2 = osteopenic, 3 = osteoporotic. The analyses of physical activity, total energy/EER, and protein/RNI were performed by quartile with a wide range of ethnic, cultural, social, and religious backgrounds and lifestyles. Therefore, developing a consensus for sarcopenia diagnosis in China based on the evidence derived from Chinese populations is essential for research on and therapeutic approaches to sarcopenia in China. Similar to previous reports in China, our study found that the incidence rate of sarcopenia-related parameters in males was generally lower than that in females [2, 9, 28].

Although RCS and TUG were not the parameters proposed by AWGS for sarcopenia screening, other researchers have found RCS and TUG to be two sensitive indicators of the muscle strength and function of the lower limbs [29, 30]; therefore, they were included in our list of parameters. Poor performance on the RCS (≥ 10 s) and TUG (≥ 9 s) is useful for stratifying the risk of disability development in older people [30]. For the RCS and TUG, previous prospective cohort studies demonstrated that cut-off times of 12–15 s and 10–15 s, respectively, were associated with an increased risk of falling [30]. Following the method of previous studies to determine the cutoff points, a value in excess of the 80th percentile of RCSs (13.6 s) and TUGs (11.5 s) measured in the older participants in this study [4, 31] was used as the criterion indicating reduced RCS and TUG performance. We found that 30.6% of older males and females presented reduced RCS performance, while 17.2% of older males and 22.2% of older females presented reduced TUG performance. A similar cross-sectional study in China defined a cutoff point of 12.5 s and found that 18.36% of older males and 27.60% of older females presented reduced RCS performance [4]. Moreover, the cutoff point that predicted sarcopenia in a Brazilian study was 10.85 s on the TUG test [20]. Unfortunately, no reference values for the RCS or TUG test exist for the prediction of sarcopenia according to the definitions of the consensus of AWGS in Older People, which limits comparisons with reference values. Furthermore, factors such as subject status, instructions given, and measurement environment can all lead to test heterogeneity of RCS and TUG [19].

Similar to most studies, our study found that advanced age was associated with low muscle mass, weak muscle strength, reduced physical performance, and sarcopenia [6, 32]. Past Chinese studies have found that being underweight is strongly associated with sarcopenia [33]. While weight gain in older persons is a major risk factor for several diseases and conditions, weight loss in the elderly may be indicative of poor or declining health and is a risk factor for mortality [34]. Therefore, high BMI might serve as a protective buffer in countering losses in muscle performance in an older population [33]. We also reaffirmed the findings that maintaining a higher BMI could be beneficial in the prevention of muscle mass loss, weak muscle strength, and sarcopenia. Additionally, our findings reinforced the potential role of higher educational level in preserving good health in later life. Even after adjusting for several potential confounders, higher education level was associated with increased muscle strength and function. Indeed, a higher educational level might favor a healthier lifestyle and may as a result be related to better muscle function and better overall health status in late life [8]. Current smoking was a risk factor for weak muscle strength, as reported previously [35]. The reason may be attributed to increased oxidative stress and the activation of signaling pathways that trigger upregulation of muscle-specific E_3 ubiquitin ligases [35]. Whether alcohol consumption is a risk factor for sarcopenia is unclear. Some studies suggest that chronic alcohol consumption may promote the loss of muscle mass and strength in old age [35]. However, a systematic review indicated that alcohol consumption was not a risk factor for the development of sarcopenia and could even have a protective effect against sarcopenia [36]. Similarly, our study found that present drinking was associated with strong HGS, faster UGS, and a lower incidence of sarcopenia. Based on our findings and previous research, we believe that alcohol consumption is not a risk factor for the development of sarcopenia. Most studies examined the associations of self-reported sleep duration and sleep quality at night with sarcopenia. Results of epidemiological studies among adults about sleep duration and sarcopenia (or low muscle mass) are not consistent as they reported either no association [37], a U-shaped association [38, 39], or a negative association [40, 41]; decreased sleep quality was associated with low muscle mass [42] and poorer neuromuscular performance [43] which contribute to an increased risk of sarcopenia. In our study, we only found that the sleeping time during the day was associated with high ALM/Ht^2 and faster RCS. However, very little research has been performed regarding the effect of daytime sleep on sarcopenia in older adults. Therefore, further research is needed to assess these associations. Due to low bone mass and muscle deterioration with advancing age, osteoporosis and sarcopenia are two health problems and often occur concurrently in the elderly [44, 45]. Hence, low bone density is associated with low muscle mass, weak muscle strength, reduced physical performance, and risk for sarcopenia. Our study also demonstrated that physical performance is likely to be correlated with comorbidity factors [46, 47]. This result reminds us that physical function tests may convey additional information about the health status in the older population [48]. Our findings support the importance of measuring TUG and RCS to evaluate lower extremity functions in older people. In addition, physical exercise, in combination with adequate protein intake, is considered to be a key component in the prevention and management of sarcopenia [49, 50]. This study also found that physical exercise and better nutrition were associated with better muscle strength and physical performance.

Our study has several limitations. First, it is a cross-sectional study, which limits its ability to confirm the changes in muscle mass, muscle strength, and physical performance with aging. Also, due to some confounders, such as vitamin D status, sex hormone levels, or chronic kidney disease, functional characteristics (i.e., ADL, IADL) in the elderly may influence muscle mass, muscle strength, and function that were not considered in this study; the potential factors associated with low muscle mass, weak muscle strength, reduced function, and sarcopenia cannot be evaluated. Moreover, causality between sarcopenia and associated factors cannot be inferred. Thus, ideally, longitudinal studies are needed to assess these associations and examine the factors (such as sleeping time of day and moderate alcohol consumption) that may help to prevent sarcopenia. Second, the five-repetition RCS test and 30-s RCS test are two RCS tests that have been used frequently in older adults [29, 51]. The former test measures the time required to complete five movements, whereas the latter test measures the number of movements that can be completed in 30 s. When our RCS test results are applied to the general older population, we should recognize the heterogeneity between the two RCS tests [29, 51]. Finally, selection bias should be considered. Although this study used a multistage sampling method and included a large sample, most participants seemed to have a good function because they were able to independently participate in the assessments at the community center. Specifically, we only adopted the data of these 2412 elderly subjects for the analysis of risk factors associated with sarcopenia as they have effective ALM/Ht^2, HGS, and UGS at the same time; the exclusion of 221 participants may present a selection bias in the results. In addition, the study was conducted on a typical city which is experiencing the process of urbanization, and our cohort in this area today leading a westernized or more urbanized lifestyle instead of a traditional rural lifestyle in the past. These changes, e.g., the physical activity of landless residents decreased owing to the modernization of lifestyle, may affect the prevalence of sarcopenia, functional decline, and its associated health impact. Due to this, findings should not be generalized to those who are institutionalized or frailer or with higher education levels. However, at a time when related studies in China are still scarce, our study provides valuable information that can help guide potential strategies for early intervention and prevention of sarcopenia in older rural Chinese residents.

Conclusion

In summary, at the higher decades of life, the decline of muscle strength and function is greater than the concomitant loss in muscle mass. Measures of muscle strength and function are an effective way to assess functional ability and physical health in older people. Maintaining a healthy lifestyle by means such as physical exercise, good nutrition, and higher BMI throughout the course of life may benefit older people by improving their muscle mass, strength, and function.

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Authors' contributions HX participated in the design, data collection and analysis, and drafted the manuscript. JS, CS, YL, and JL contributed to data acquisition, interpretation, and performed the statistical analysis. JL and XZ conceived of the study and participated in its design and coordination and helped to draft the manuscript. All authors have read and approved the final version of the manuscript and agree with the order of presentation of the authors.

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Ethics approval and consent to participate The authors declare that all the experiments of this study complied with the current laws of China in which they were performed. The study was approved by the local ethical committee of the public health school of Nanjing Medical University (NMU) and Jurong Center for Disease Control and Prevention (Jurong CDC) approved the study protocol. Each participant provided informed written consent prior to participation.

Consent for publication Not applicable.

Conflicts of interest None.

Abbreviations AWGS, Asian Working Group for Sarcopenia; EWGSOP, European Working Group on Sarcopenia in Older People; NMU, Nanjing Medical University; BMI, body mass index; WC, waist circumference; BCA_{II}, Body Composition Analyzer II; LBM, lean body mass; FM, fat mass; MM, muscle mass; BM, bone mass; FM%, percentage fat mass; ALM, appendicular lean muscle mass; ALM/Ht^2, dividing ALM by the square of height; LM/Ht^2, dividing LBM by the square of height; BMD, bone mineral density; SOS, speed of sound; BP, blood pressure; DRIs, Dietary Reference Intakes; PA, physical activity; METs, metabolic equivalents; BMD, bone mass density; HGS, handgrip strength; UGS, usual gait speed; RCS, repeated chair stands; TUG, Timed Up and Go; OR, odds ratios

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