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BMI-stratified cutoff values for spinal sarcopenia in Chinese adults based on CT measures: a multicentre study

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Abstract

Background Decreased size and mass of paraspinal muscles are associated with lower vertebral bone mineral density, more postoperative complications, increased mortality, and spinal sagittal imbalance. However, it is difficult to determine muscle loss in older adults with overweight and obesity. This study aimed to investigate the effects of body mass index (BMI) and central obesity on paraspinal muscle aging and to determine cutoff values for low paraspinal muscle mass/quality in Chinese community populations.

Methods In this nationwide cross-sectional study, abdominal CT scans and basic information were collected and analyzed from 4,305 community-dwelling adults from twelve representative cities in China between 2013 and 2017. Psoas and posterior paraspinal muscle index (PMI and PSMI) and density (PMD and PSMD) at the L3 level were measured using OsiriX software. Correlation analysis, multiple linear regression, and one-way ANOVA were performed for statistical analysis. Commonly used cutoff value calculations were applied to define low muscle index and density (Mean–2SD, 5th percentile in young people, and 20th percentile in older people) in the general population and individuals with different BMIs.

Results Correlation analysis showed that the paraspinal muscle index and density were primarily correlated with sex, BMI, and age. Multiple linear regression analysis indicated that the paraspinal muscle index (PSMI and PMI) was primarily influenced by sex (β=–0.391 and −0.599, $p<0.001$) and BMI (β = 0.442 and 0.371, $p<0.001$), followed by age and waist circumference. In contrast, muscle density (PSMD and PMD) was mainly associated with sex (β=–0.405 and −0.317, $p<0.001$) and age (β=–0.409 and −0.429, $p<0.001$), with a slight influence from WC and BMI. Considering the significant effect of BMI on muscle mass, we calculated BMI-stratified cutoffs for PSMI (as 12.3/10.6, 15.0/11.7, and 15.2/11.9 cm^2/m^2 in normal, overweight, and obese men/women using M-2SD), PMI (as 3.8/2.9, 5.0/3.4, and 4.9/3.9

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cm^2/m^2 in normal, overweight and obese men/women using M-2SD), and unstratified cutoffs for PSMD (as 36.3 and 31.1 HU in men and women) and PMD (as 40.1 and 36.9 HU in men and women).

Conclusions This study found that sex and BMI were key determinants of paraspinal muscle mass, with BMI influencing paraspinal muscle number more than age. In contrast, muscle density was primarily influenced by sex and age. This study provided BMI-stratified and non-stratified cutoff values for low paraspinal muscle index and density, which aided in the identification of spinal sarcopenia in individuals with different BMIs.

Keywords Sarcopenia, BMI, Muscle loss, paraspinal muscles, Cutoff values, Quantitative computed tomography

Introduction

The generalized loss of muscle mass and function, known as sarcopenia, is associated with an increased risk of falls, physical disability, frailty, reduced quality of life, and higher mortality rates [1–3]. Recent studies have reported muscle group differences in the rate of age-related muscle atrophy, with psoas muscle (29%) and posterior paraspinal muscles (24%) atrophies ranking the first and the third [4, 5]. However, due to the difficulties in trunk muscle measurements, less is known about the spinal muscle aging.

Paraspinal muscles play a crucial role in spine alignment, stability, and movement [6]. The size of psoas muscles, measured as the psoas muscle area (PMA) and psoas muscle index (PMI), is associated with generalized sarcopenia, postoperative complications, and mortality in different patients [7–13]. Several cutoff values have been reported to define low psoas muscle mass (mainly using PMI), however, no study has reported cutoff values for the posterior paraspinal muscles [10–13]. Therefore, establishing precise cutoff values to identify individuals with low paraspinal muscle mass and quality, often referred to as "spinal sarcopenia", is essential as a foundational step in comprehensive risk assessment [14–16].

Although the loss of paraspinal muscles is associated with various adverse outcomes, evaluating these muscles remains challenging. Computed Tomography (CT) and magnetic resonance imaging (MRI) are recommended by the latest sarcopenia consensus guidelines (EWGSOP2 and AWGS 2019) for assessing trunk muscle mass [17, 18]. CT- and MRI-based cross-sectional skeletal muscle index (SMI) at the L3 level closely correlate with whole-body muscle mass and are therefore reliable alternatives for assessing sarcopenia. Additionally, sarcopenia defined by PMI at the L3 level has also been shown to be associated with various adverse outcomes [19]. Obesity has been reported to be associated with fatty infiltration of the upper lumbar muscles and degeneration of the lower lumbar spine [20]. However, it remains unclear whether obesity (defined by body mass index, BMI) and central obesity (CO, defined by waist-hip ratio (WHR) or waist circumference (WC)) affect paraspinal muscle mass. A previous study in healthy Chinese adults found significant variations in L3 cross-sectional skeletal muscle area (SMA) and SMI across different BMI categories, suggesting a potential positive association between BMI and muscle mass [21]. However, many older individuals who are overweight or obese also experience severe muscle wasting and poor physical performance, a condition known as sarcopenic obesity [22, 23]. These individuals are difficult to identify using dual-energy x-ray absorptiometry (DXA) or bioelectrical impedance analysis (BIA), as people with obesity tend to have higher muscle mass but lower gait speed [24]. To maintain normal mobility, higher levels of muscle mass benchmarks should be proposed for obese individuals. Thus, establishing BMI-stratified muscle mass cutoff values is essential for accurately screening sarcopenia in individuals with different BMIs.

This study aims to investigate the correlation between age, BMI, WHR, WC, and paraspinal muscle parameters (muscle index and density) in Chinese adults and to establish corresponding cutoff values for low paraspinal muscle mass and quality.

Methods

Study design and population

This cross-sectional study conducted a retrospective analysis of baseline CT data from the China Action on Spine and Hip (CASH, see https://clinicaltrials.gov/study/NCT01758770) multicenter, community-based cohort [25]. The protocol and informed consent procedures for the CASH study underwent thorough review and received approval from the institutional review board of Beijing Jishuitan Hospital (approval numbers 201210-01, 201512-02) [26].

This study used a multi-stage cluster sampling approach in twelve representative cities in China. A total of 4,305 participants underwent CT scans between 2013 and 2017. The selection processes for communities, families, and individuals closely followed the procedures outlined in a previous study [25]. Exclusion criteria included pregnant women, individuals with a history of lumbar surgery or implants, those with diseases or medications that significantly influenced lumbar spine BMD, and individuals unable to provide informed consent. Ultimately, 4,120 individuals were included in the final analysis. Men and women were categorized as young (21–40 years), middle-aged (41–60 years), or older (61–80 years) individuals. BMI categories were defined as underweight (< 18.5), normal (18.5 to < 24), overweight (24 to < 28), or obese (≥ 28) according to Chinese recommendations [27]. Central obesity was classified using both WHR (≥ 0.90 for men and ≥ 0.85 for women) and WC (> 90 cm for men and > 80 cm for women) based on WHO expert consultation definitions for the Chinese population [28]. To enhance the reproducibility of our cutoff values, we also provided BMI-stratified cutoffs based on WHO BMI classifications.

CT acquisition and data collection

All CT scans were performed at 120 kVp, with detailed information on the CT scanners and scanning parameters provided in a previous study [5]. Rigorously Quality control measures were implemented throughout the study, including daily calibration and cross-calibration between systems using the European Spine Phantom (ESP, No. 145, QRM GmbH, Möhrendorf, Germany) [29]. The Hounsfield unit (HU) values of the water-equivalent material within ESP-145 were measured and used for cross-calibration of muscle attenuation across the twelve centers. Quality assurance (QA) results showed that the ESP water-equivalent material measured at each center differed by an average of less than 2.6 HU [30]. Consequently, the original HU values were used for subsequent analyses.

In total 4,305 participants from twelve centers underwent abdominal quantitative computed tomography (QCT) scans, accompanied by the collection of height, weight, waist circumference (measured at the approximate midpoint between the lower margin of the last palpable rib and the top of the iliac crest), and hip circumference (the largest circumference around the iliac crest) [28]. Rigorous quality control measures were implemented for the CT data, ensuring the exclusion of abnormal scans (with internal fixation or deformity), incomplete records (lacking essential information), and poor-quality images, resulting in the removal of 163 participants. Data cleaning procedures included the identification and re-evaluation of outliers that exceeded the mean ± 3 standard deviations (SD). These outliers were labeled, re-measured, and either retained if verified as accurate or excluded if attributed to poor image quality. Following this procedure, an additional 22 participants were removed, leaving 4,120 participants for the final analysis.

Assessments of muscle index and density

Muscle density and fat fraction assessments were conducted on the psoas muscles and posterior paraspinal muscles. The latter was defined as the longissimus thoracis, iliocostalis lumborum, and multifidus muscles. Measurements were performed at the mid-vertebral level of the third lumbar vertebra, as described in previous studies (Supplementary Figure S1) [5].

In each selected CT section, the psoas and posterior paraspinal muscles were meticulously segmented within a threshold range of − 29 HU to 150 HU using OsiriX software (Lite version 10.0.2, Pixmeo, Geneva, Switzerland), as described in prior studies [5, 31]. Through manual muscle contour delineation and threshold segmentation, the software automatically differentiated muscle tissue from intermuscular adipose tissue within the selected muscle regions and generated measurements for muscle tissue area (cm^2) and muscle tissue density (HU, representing the average CT attenuation of muscle tissue). This approach enabled accurate quantification of functional muscle tissue area (fCSA) while mitigating the influence of myosteatosis. To better represent true muscle mass, fCSA was further normalized to a muscle index (cm^2/m^2, muscle tissue area/height^2). However, due to the limited resolution of CT, intramyofibrillar lipid droplet accumulation and intermyofibrillar adipocytosis resulting from myosteatosis could not be directly visualized. Nevertheless, these cellular and subcellular levels of fat infiltration were reflected as a reduction in muscle tissue density [32]. Therefore, for the final analysis, we collected the psoas muscle index (PMI), psoas muscle density (PMD), posterior paraspinal muscle index (PSMI), and posterior paraspinal muscle density (PSMD). All measurements were performed by five experienced radiologists with at least five years of experience. The intra- and inter-observer agreement for these measurements was satisfactory, as previously reported [5].

Statistical analyses

The normality of continuous variables was assessed using the Kolmogorov-Smirnov test and visual histograms (Supplementary Table S1 and Figure S2). Descriptive statistics were used to present the general characteristics of women and men, as well as BMI-specific muscle parameters across young, middle-aged, and older groups, expressed as mean ± standard deviation (Tables 1 and 2). Pearson correlation coefficients were calculated to examine the correlation between age, BMI, WHR, WC, and paraspinal muscle index and density (Table 3). Independent samples t-tests and one-way analysis of variance (ANOVA) with post-hoc Tukey's test were used to compare muscle parameters between different sexes and BMI subgroups. Multiple linear regression analyses were conducted to evaluate the effects of sex (men = 1, women = 2, with men used as the control group), age, BMI, and WC (as continuous variables) on paraspinal muscle index and density (Tables 3 and 4). Missing WHR ($n = 101$, 41 men and 60 women) and WC ($n = 5$, 2 men and 3 women) values were imputed using the mean values of the

Table 1 General characteristics and muscle parameters of the study population

	Total ($N=4120$)	Men ($N=1558$)	Women ($N=2562$)	p values
Age (years)	57.5 ± 12.7	57.5 ± 13.4	57.5 ± 12.3	$p=0.969$
Height (cm)	160.9 ± 8.4	167.6 ± 7.1	156.9 ± 6.2	$p<0.001$
Weight (kg)	64.4 ± 11. 7	70. 5 ± 12.0	60.6 ± 9.8	$p<0.001$
BMI (kg/m^2)	24.8 ± 3.6	25.0 ± 3.4	24.6 ± 3.6	$p<0.010$
WHR	0.9 ± 0.1	0. 9 ± 0.1	0.9 ± 0.1	$p<0.001$
WC (cm)	83.6 ± 10.2	86.8 ± 10.1	81.6 ± 9. 8	$p<0.001$
L3-PSMI (cm^2/m^2)	15.9 ± 3.0	17.3 ± 3.1	15.0 ± 2.6	$p<0.001$
L3-PMI (cm^2/m^2)	6.1 ± 1.8	7.4 ± 1.7	5.3 ± 1.3	$p<0.001$
L3-PSMD (HU)	40.3 ± 7.8	43.7 ± 7.1	38.1 ± 7.5	$p<0.001$
L3-PMD (HU)	44.1 ± 5.5	46.1 ± 5.2	42.9 ± 5.4	$p<0.001$

Note: p values represent the significance of t-tests between men and women. BMI, body mass index; WHR, waist-hip ratio; WC, waist circumference; PSMI, paraspinal muscle index; PMI, psoas muscle index; PSMD, paraspinal muscle density; PMD, psoas muscle density

corresponding gender (for men, mean WHR = 0.89, mean WC = 86.81 cm; for women, mean WHR = 0.85, mean WC = 81.64 cm). Dancey and Reidy's classification was used to interpret the strength of correlation coefficients: 0.1–0.3 indicated a weak correlation, 0.4–0.6 moderate, 0.7–0.9 strong, and 1 represented a perfect correlation [33]. Statistical analyses were performed using SPSS 22.0 software (IBM Corp., Armonk, NY, USA) and R software (version 4.2.3), with significance set at $P<0.05$.

Calculation of cutoff values for paraspinal muscle parameters

Based on previous studies calculating cutoff values for low muscle mass and quality in younger and older individuals, this study determined cutoff values for low paraspinal muscle index and density by calculating the lowest 5th percentile (P5) and the mean minus two standard deviations (M–2SD) for young adults (21–40 years), as well as the lowest 20th percentile for older individuals (> 60 years) [11, 34–36]. Unstratified cutoff values were calculated for all paraspinal muscle parameters. BMI-stratified cutoff values (normal, overweight, and obese subgroups) were provided for PSMI and PMI, given their significant correlation with BMI (Table 5). Cutoff values were not calculated for the underweight group due to the small sample size (28 men and 55 women).

Table 2 The characteristics of the Psoas and posterior paraspinal muscle index and density in different gender, age, and BMI groups

Men				Women			
21 ~ 40 years	**normal ($N=57$)**	**overweight ($N=88$)**	**obesity ($N=55$)**	**21 ~ 40 years**	**normal ($N=144$)**	**overweight ($N=58$)**	**obesity ($N=28$)**
PSMI (cm^2/m^2)^b	16.9 ± 2.3	19.1 ± 2.1	20.7 ± 2.8	**PSMI (cm^2/m^2)^b**	14.1 ± 1.7	15.9 ± 2.1	18.3 ± 3.2
PMI (cm^2/m^2)^b	7.1 ± 1.6	7.8 ± 1.4	8.7 ± 1.9	**PMI (cm^2/m^2)^b**	4.9 ± 1.0	5.6 ± 1.1	6.2 ± 1.1
PSMD (HU)^a	50.1 ± 5.8	47.9 ± 6.0	47.0 ± 5.8	**PSMD (HU)^a**	44.6 ± 6.2	43.2 ± 6.6	41.5 ± 6.7
PMD (HU)^b	51.6 ± 4.7	49.4 ± 5.0	48.3 ± 4.0	**PMD (HU)$^{\#}$**	48.0 ± 5.8	47.6 ± 4.6	46.8 ± 4.8
41 ~ 60 years	**normal (N = 205)**	**overweight (N = 261)**	**obesity (N = 111)**	**41 ~ 60 years**	**normal (N = 512)**	**overweight (N = 406)**	**obesity (N = 194)**
PSMI (cm^2/m^2)^b	16.7 ± 2.7	18.2 ± 2.7	19.5 ± 2.7	**PSMI (cm^2/m^2)^b**	14.7 ± 2.2	15.8 ± 2.5	16.6 ± 2.8
PMI (cm^2/m^2)^b	6.9 ± 1.7	7.7 ± 1.7	8.4 ± 1.8	**PMI (cm^2/m^2)^b**	5.2 ± 1.3	5. 6 ± 1.4	6.0 ± 1.5
PSMD (HU)^b	47.1 ± 6.5	45.4 ± 5.9	43.1 ± 6.1	**PSMD (HU)^b**	41.3 ± 6.5	39.1 ± 6.6	38.4 ± 6.6
PMD (HU)^a	47.9 ± 5.0	47.0 ± 4.8	46.0 ± 4.9	**PMD (HU)^a**	44.7 ± 4.6	43.7 ± 4.8	44.2 ± 4.8
61 ~ 80 years	**normal (N = 318)**	**overweight (N = 310)**	**obesity (N = 125)**	**61 ~ 80 years**	**normal (N = 463)**	**overweight (N = 477)**	**obesity (N = 225)**
PSMI (cm^2/m^2)^b	15.7 ± 2.8	16.6 ± 2.9	17.8 ± 3.2	**PSMI (cm^2/m^2)^b**	13.9 ± 2.5	15.2 ± 2.4	15.4 ± 2.4
PMI (cm^2/m^2)^b	6.7 ± 1.5	7.2 ± 1.5	7.9 ± 1.6	**PMI (cm^2/m^2)^b**	5.0 ± 1.1	5.4 ± 1.9	5.5 ± 1.5
PSMD (HU)^a	42.0 ± 6.3	40.6 ± 7.4	39.9 ± 6.8	**PSMD (HU)^a**	36.3 ± 7.1	34.7 ± 6.9	32.9 ± 6.9
PMD (HU)$^{\#}$	44.3 ± 4.5	44.1 ± 4.7	44.5 ± 5.1	**PMD (HU)$^{\#}$**	40.8 ± 4.7	40.4 ± 4.8	40.4 ± 5.3

Note: The differences between normal, overweight, and obesity subgroups (one-way ANOVA) were marked as # ($p>0.05$), a ($p<0.05$), and b ($p<0.001$). PSMI, paraspinal muscle index; PMI, psoas muscle index; PSMD, paraspinal muscle density; PMD, psoas muscle density

Table 3 Pearson correlation coefficient matrix for age, BMI, WHR, and paraspinal muscle parameters in women and men

	Men				Women			
	Age	**BMI**	**WHR**	**WC**	**Age**	**BMI**	**WHR**	**WC**
L3-PSMI	-0.349**	0.369**	0.153**	0.203**	-0.120**	0.315**	0.101**	0.155**
L3-PMI	-0.205**	0.317**	0.099**	0.152**	-0.051**	0.247**	0.081**	0.087**
L3-PSMD	-0.438**	-0.138**	-0.152**	-0.229**	-0.473**	-0.235**	-0.217**	-0.321**
L3-PMD	-0.432**	-0.065*	-0.165**	-0.152**	-0.481**	-0.103**	-0.197**	-0.185**

Note: *: $p<0.05$, **: $p<0.001$. BMI, body mass index; WHR, waist-hip ratio; WC, waist circumference; PSMI, paraspinal muscle index; PMI, psoas muscle index; PSMD, paraspinal muscle density; PMD, psoas muscle density

Table 4 Results of multiple linear regression analysis for the impact of sex, age, BMI, and WC on paraspinal muscle parameters

Models		Unstandardized Coefficients		Standardized Coefficients	*t* values	*p* values	95.0% confidence interval	
		B	Std. Error	Beta			Lower	Upper
L3 PSMI	Constant	17.367	0.415		41.823	0.000	16.553	18.181
	Sex	-2.403	0.086	**-0.391**	-28.099	0.000	-2.571	-2.236
	Age	-0.046	0.003	**-0.198**	-14.938	0.000	-0.053	-0.04
	BMI	0.371	0.018	**0.442**	20.932	0.000	0.336	0.406
	WC	-0.049	0.006	**-0.169**	-7.744	0.000	-0.062	-0.037
L3 PMI	Constant	8.522	0.225		37.931	0.000	8.082	8.963
	Sex	-2.169	0.046	**-0.599**	-46.871	0.000	-2.26	-2.078
	Age	-0.013	0.002	**-0.090**	-7.435	0.000	-0.016	-0.009
	BMI	0.184	0.01	**0.371**	19.149	0.000	0.165	0.202
	WC	-0.033	0.003	**-0.192**	-9.581	0.000	-0.04	-0.026
L3 PSMD	Constant	80.629	1.035		77.891	0.000	78.599	82.658
	Sex	-6.532	0.213	**-0.405**	-30.637	0.000	-6.95	-6.114
	Age	-0.252	0.008	**-0.409**	-32.493	0.000	-0.267	-0.237
	BMI	-0.011	0.044	**-0.005**	-0.244	0.807	-0.097	0.076
	WC	-0.18	0.016	**-0.235**	-11.311	0.000	-0.211	-0.149
L3 PMD	Constant	66.533	0.772		86.156	0.000	65.019	68.047
	Sex	-3.619	0.159	**-0.317**	-22.753	0.000	-3.931	-3.307
	Age	-0.187	0.006	**-0.429**	-32.365	0.000	-0.199	-0.176
	BMI	0.078	0.033	**0.050**	2.353	0.019	0.013	0.142
	WC	-0.093	0.012	**-0.170**	-7.796	0.000	-0.116	-0.069

Note: The L3 level PSMI, PMI, PSMD, and PMD were analyzed using multivariate regression models, adjusting for sex, age, BMI, and WC. BMI, body mass index; WC, waist circumference; PSMI, paraspinal muscle index; PMI, psoas muscle index; PSMD, paraspinal muscle density; PMD, psoas muscle density

Table 5 Unstratified and BMI-stratified cutoff values for low paraspinal muscle index and density

		Men			Women		
		P5	M-2SD	P20	P5	M-2SD	P20
All BMI	**L3-PSMI (cm^2/m^2)**	14.9	13.5	14.1	11.4	10.0	12.7
	L3-PMI (cm^2/m^2)	5.2	4.4	5.8	3.4	3.0	4.2
	L3_PSMD (HU)	38.6	36.3	35.7	32.4	31.1	29.4
	L3_PMD (HU)	42.2	40.1	40.8	39.4	36.9	36.9
Normal	**L3-PSMI (cm^2/m^2)**	13.5	12.3	13.4	11.2	10.6	11.9
	L3-PMI (cm^2/m^2)	4.4	3.8	5.5	3.2	2.9	4.1
Overweight	**L3-PSMI (cm^2/m^2)**	16.1	15.0	14.4	12.4	11.7	13.3
	L3-PMI (cm^2/m^2)	5.8	5.0	5.9	3.5	3.4	4.3
Obesity	**L3-PSMI (cm^2/m^2)**	16.5	15.2	15.3	13.8	11.9	13.6
	L3-PMI (cm^2/m^2)	5.2	4.9	6.4	4.7	3.9	4.5

Note: P20: the lowest 20% percentile value in the elderly participants (>60 years), P5: the lowest 5th percentile value in young adults (21–40 years), M-2SD: mean value minus two times standard deviation in young adults. BMI, body mass index; PSMI, paraspinal muscle index; PMI, psoas muscle index; PSMD, paraspinal muscle density; PMD, psoas muscle density

Results

General characteristics of the study population

Table 1 presents the general characteristics and muscle parameters of the study population (expressed as mean ± SD). The final analysis included 4,120 adults, comprising 1,558 men (57.46 ± 13.40 years) and 2,562 women (57.45 ± 12.25 years). Men had a BMI of 24.99 ± 3.40 kg/m^2, WHR of 0.89 ± 0.06, and a WC of 86.81 ± 10.06 cm, while women had a BMI of 24.62 ± 3.63 kg/m^2, WHR of 0.85 ± 0.06 and a WC of 81.65 ± 9.78 cm. Men had significantly higher values of BMI, WHR, WC, PSMI, PMI, PSMD, and PMD compared to women ($p < 0.001$), but there was no significant difference in age ($P = 0.969$).

Paraspinal muscle index and density in different age and BMI groups

Pearson correlation analysis examined the relationships between age, BMI, WHR, WC, and paraspinal muscle parameters in women and men (Table 3). Muscle index was most strongly correlated with BMI, but still weakly positively correlated (men: BMI-L3 PSMI, $r = 0.369$; BMI-L3 PMI, $r = 0.317$; women: BMI-L3 PSMI, $r = 0.315$; BMI-L3 PMI, $r = 0.247$; all $p < 0.001$). Muscle density showed the strongest correlation with age, showing a moderate negative correlation (men: age-L3 PSMD, r=-0.438; age-L3 PMD, r=-0.432; women: age-L3 PSMD, r=-0.473; age-L3 PMD, r=-0.481; all $p<0.001$). WHR and WC both displayed weak correlations with muscle index and density, with WHR relatively lower.

Table 2 summarizes paraspinal muscle index and density across different BMI (normal, overweight, and obesity) and age groups (young, middle-aged, and older adults) for women and men. One-way ANOVA revealed significantly greater PSMI (all $p<0.001$) and PMI (all $p<0.001$), along with lower PSMD (all $p<0.05$) in the higher BMI subgroups. However, PMD did not show a significant decline in higher BMI subgroups in young women, older women, or older men ($p>0.05$), except for middle-aged individuals ($p<0.05$) and young men ($p<0.001$).

Figure 1 illustrates the distribution of paraspinal muscle mass indicators (PSMI and PMI) across sex, age, and BMI groups. Overweight and obese individuals had higher PSMI and PMI values than their normal-weight counterparts, regardless of age. However, the gains in muscle mass associated with overweight and obesity decreased with age, especially in older women. This suggests that the muscle gains linked to higher BMI gradually decline with aging. Obese older adults may lack sufficient muscle mass to support their body weight, potentially leading to reduced mobility.

Regression analysis of factors affecting paraspinal muscle index and density

To investigate the effects of sex, age, BMI, and WC on muscle parameters (PSMI, PMI, PSMD, and PMD), multiple linear regression analyses were performed, with standardized regression coefficients (β) presented in Table 4. In adjusted models, paraspinal muscle index (PSMI and PMI) demonstrated the strongest association with sex (β=−0.391 and −0.599, $p<0.001$) and BMI (β = 0.442 and 0.371, $p<0.001$), followed by weaker associations with age (β=−0.198 and −0.09; $p<0.001$) and WC (β=−0.169 and −0.192; $p<0.001$). However, paraspinal muscle density (PSMD and PMD) exhibited the strongest association with sex (β=−0.405 and −0.317; $p<0.001$) and age (β=−0.409 and −0.429; $p<0.001$), and lesser associations with WC (β=−0.235 and −0.17; $p<0.001$). Of note, BMI only showed a very weak association with PMD (β = 0.05; $p=0.019$) and no significant association with PSMD (β=−0.05; $p=0.807$). These results highlight a significant moderate association between BMI and muscle mass, along with a very weak correlation between BMI and muscle density. Given that the influence of BMI on muscle mass is second only to that of sex and exceeds that of age, we established BMI-stratified cutoffs for PSMI and PMI.

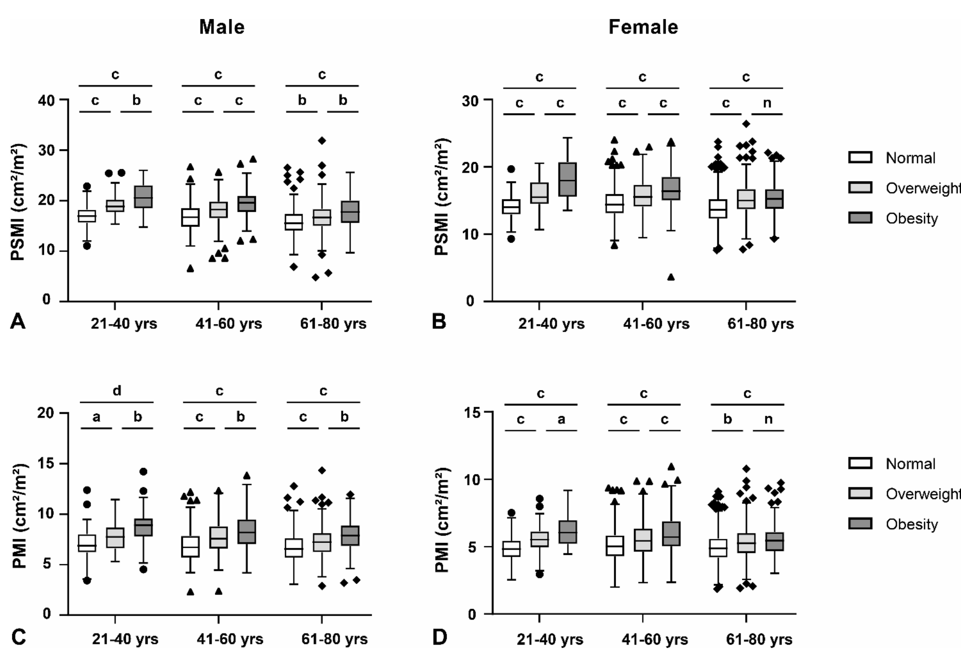

Fig. 1 Distribution of L3-PSMI (**A**, **B**) and L3-PMI (**C**, **D**) in young, middle-aged and older Chinese adults by sex and BMI subgroups. Notes: One-way ANOVA with post-hoc Tukey's test was used to assess the differences between BMI subgroups (normal-weight, overweight, and obese individuals). The p-values for differences between BMI subgroups in post hoc analyses are represented by **a** ($p<0.05$), **b** ($p<0.01$), **c** ($p<0.0001$), and n ($p>0.05$). In young and middle-aged adults, obesity was associated with a significantly higher muscle index; however, in older women, the muscle index did not increase in the obese population. PSMI, paraspinal muscle index; PMI, psoas muscle index

Calculation of BMI-stratified cutoff values for paraspinal muscle parameters

Overall and BMI-stratified cutoff values for paraspinal muscle parameters were calculated using the P5, M–2SD, and P20 methods for both women and men (Table 5). The BMI-stratified cutoffs for low L3-PSMI were 12.3/10.6, 15.0/11.7, and 15.2/11.9 cm^2/m^2 in normal-weight, overweight, and obese men/women (using M-2SD). For low L3-PMI, the cutoffs were 3.8/2.9, 5.0/3.4, and 4.9/3.9 cm^2/m^2 in normal-weight, overweight and obese men/women (using M-2SD). The unstratified cutoffs for low L3-PSMD were 38.58/36.29/35.74 HU in men (P5/M–2SD/P20) and 32.35/31.08/29.40 HU in women, while those for low L3-PMD were 42.19/40.08/40.78 HU in men and 39.38/36.91/36.94 HU in women. Additionally, BMI-stratified cutoffs for PSMI and PMI were also calculated for normal-weight, overweight, and obese subgroups based on WHO standards (Supplementary Table S2). As expected, overweight and obese subgroups had higher PSMI and PMI cutoffs compared to normal-weight subgroups. The unstratified muscle index cutoffs fell between those of the normal-weight and overweight groups.

Discussion

This study characterized paraspinal muscles on computed tomography at the L3 level in Chinese community-dwelling adults. We found that paraspinal muscle mass, as indicated by the muscle index, was more strongly associated with sex and BMI than with age or WC. However, muscle density was primarily associated with sex and age, and weakly associated with WC and BMI. To classify low paraspinal muscle mass and quality in populations with different BMIs, we established cutoff values for PSMI, PMI, PSMD, and PMD, as well as BMI-stratified cutoff values for PSMI and PMI, applicable to both adult Chinese women and men.

Paraspinal muscle index is more influenced by sex and BMI than age, while muscle density is mainly influenced by sex and age

Our correlation analyses and adjusted multiple linear regression models revealed a moderate positive association between paraspinal muscle index (L3 PSMI and PMI) and BMI, which was secondary only to sex and considerably stronger than the negative impacts of age and WC (Table 4). These findings emphasize the requirement for BMI stratification when assessing paraspinal muscle mass using the paraspinal muscle index.

In addition, we found that muscle density was moderately associated with sex and age, and weakly associated with WC and BMI. Muscle density, a proxy for muscle quality, is closely linked to intramuscular fat content [37]. These findings suggest that reduced paraspinal muscle density, potentially due to fat infiltration, is primarily associated with aging and influenced by central obesity rather than body mass index.

BMI-related increase in muscle mass diminishes in older individuals with obesity

The psoas major and posterior paravertebral muscles are similarly influenced by sex, age, BMI, and WC, but there are some differences (Table 4). Compared to PSMI, PMI showed a weaker association with BMI and age (for PSMI and PMI, β=–0.198 and −0.09 in age, and β = 0.442 and 0.371 in BMI, $p < 0.001$), suggesting that the psoas muscle tends to remain relatively stable across different BMI and age groups, possibly due to its regular engagement in movement. Consistent with our findings, a 3-year longitudinal study of 353 patients (54.4% female, median age 60.1 years) with low back pain reported a significant reduction in the functional cross-sectional area (fCSA) of the posterior paraspinal muscles (–1.1% in women and −7.2% in men, $p < 0.001$). In contrast, the psoas fCSA showed no significant change in women (1.6%, $P = 0.726$) and a small decrease in men (–0.23%, $P = 0.004$) [38]. These results suggest that while the posterior paraspinal muscle mass increases with higher BMI, it also carries a relatively higher risk of age-related muscle atrophy. This may be associated with decreased physical activity in older adults, potentially leading to low back pain, muscle atrophy, and spinal degeneration.

In general, the overweight and obese subgroups exhibited a higher muscle index than the normal BMI subgroup, especially in young and middle-aged adults. However, the BMI-related increase in muscle mass appeared to diminish with age, most notably in older women with obesity (Fig. 1). A study involving 380 Japanese individuals reported that low and high BMI were associated with reduced paraspinal muscle mass ratios, which decreased rapidly after peaking at a BMI of 22–23 kg/m^2 ($p < 0.0001$) [39]. While the pathological mechanisms underlying obesity-induced muscle loss (or sarcopenic obesity) remain unclear, potential contributors include muscle fat infiltration, insulin resistance, chronic inflammation, and metabolic dysregulation [40, 41]. In this study, we found that although BMI showed a moderate positive correlation with muscle mass, there was a statistically significant weak negative correlation between WC and paraspinal muscle mass, suggesting that central obesity may be one of the factors contributing to sarcopenic obesity.

The BMI-stratified cut-off values for paraspinal muscles in Chinese adults

Given the significant influence of BMI on the paraspinal muscle index, stratifying cutoff values by BMI is crucial to accurately identify low paraspinal muscle mass

Table 6 Studies establishing CT-derived cutoff values at the L3 level to evaluate Psoas and trunk muscle index and density

Author	Year	Country	Study population	Individual numbers	Age (years)	Parameters	Methods	Cutoff values	
								Men	Women
Kim, JS et al.[10]	2017	Korea	patients in the health screening department	$N=571$ (M/F = 208/363)	20 ~ 39	L3-PMI (cm^2/m^2)	M-2SD	5.92	3.99
Kong, M et al.[11]	2022	China	no obvious abnormality abdominal CT reports in the radiology department	$N=354$ (M/F = 185/169)	20 ~ 29	L3-PMI (cm^2/m^2)	M-2SD	4.57	2.79
							P5	5.41	3.32
				$N=344$ (M/F = 176/168)	30 ~ 39	L3-PMI (cm^2/m^2)	M-2SD	4.16	2.7
							P5	4.71	3.4
Hamaguchi, Y et al.[12]	2016	Japan	healthy liver donor candidates	$N=391$	20 ~ 49	L3-PMI (cm^2/m^2)	M-2SD	6.36	3.92
Bahat, G et al.[13]	2021	Turkey		$N=482$ (M/F = 268/214)	18 ~ 40	L3-PMI (cm^2/m^2)	M-2SD	4.6	2.7
							P5	5.4	3.6
Derstine, BA et al.[50]	2018	USA	healthy kidney donor candidates	$N=727$ (M/F = 317/410)	18 ~ 40	L3-SMD (HU)	M-2SD	38.5	34.3
van der Werf, A et al.[37]	2018	Netherlands		$N=300$ (M/F = 126/174) (20 ~ 60 years)	20 ~ 29	L3-SMD (HU)	P5	35.5	34.6
					30 ~ 39		P5	33.5	31.1

Note: M/F, men/women; P5, the 5th percentile value in young adults (age = 21 ~ 40 years); M-2SD, mean value minus two times standard deviation in young adults (age = 21 ~ 40 years); PMI, psoas muscle index; SMD, cross-sectional skeletal muscle density

across different BMI groups. We calculated composite cutoff values for paraspinal muscle parameters, as well as BMI-stratified cutoff values for PSMI and PMI in Chinese women and men (Table 5). Compared with previously reported PMI cutoffs for healthy populations, the unstratified L3-PMI cutoff values we provided (5.24/4.40/5.79 cm^2/m^2 for men and 3.39/2.95/4.22 cm^2/m^2 for women, by P5/M–2SD/P20) closely align with previous Chinese data, and are slightly lower than those reported in Japan and Korea. (Table 6) [10–12]. The BMI-stratified L3-PSMI and L3-PMI cutoff values provide tailored reference criteria for identifying individuals with low paraspinal muscle mass and quality across different BMI categories.

Although the association between posterior paraspinal muscle loss and various adverse outcomes has been extensively demonstrated, no studies have yet reported cutoff values for posterior paraspinal muscle loss. Our study is the first to report cutoff values for the posterior paraspinal muscles in community-dwelling Chinese adults. These cutoff values provide a framework for assessing paraspinal muscle quality in future research. However, the value of these cutoffs for predicting spinal and systemic disability and adverse outcomes remains to be validated in future prospective studies.

Muscle density, a critical indicator of muscle quality and muscle fat content (myosteatosis), has been shown in recent studies to correlate well with muscle strength, fracture risk, and postoperative complications [37, 42–44]. Additionally, lower PMI and PMD have been independently linked to an increased risk of all-cause mortality in patients undergoing hemodialysis [45]. Currently, there is also no established cutoff value for low paraspinal muscle density. Existing cutoff values for cross-sectional SMD at the L3 level range from 28.8 to 38.5 HU in men and 23.5 to 34.6 HU in women, closely aligning with our PSMD cutoff values (Table 5) [13, 35, 46]. This study established PSMD and PMD cutoff values for community-dwelling Chinese adults for the first time, providing a valuable reference for assessing paraspinal muscle quality in future studies.

This study has several limitations. First, as a cross-sectional analysis, it was unable to establish a causal relationship between BMI, age, and paraspinal muscle parameters. Second, the absence of muscle function data and external validation limits the diagnostic utility of our CT-based cutoffs. Third, due to the limited number of younger individuals in our dataset, the cutoffs derived from this group may require further validation, though this had little effect on the P20 cutoffs from older individuals. Additionally, we applied mean imputation for WC and WHR data, which may introduce some bias but has a minor impact on muscle cutoff values. Individuals with degenerative spinal disease may influence muscle cutoff calculations. However, as these conditions are common in older adults, we considered them characteristic of the community population and excluded only those with a history of lumbar spine surgery or internal fixation. Additionally, measuring spinal muscles at the mid-level of L3 helps minimize the impact of lumbar degeneration and lower back pain on the lower spinal muscles. Furthermore, due to the small sample size, cutoff values for underweight individuals were not calculated. Future studies should validate the applicability of these cutoffs in diverse populations and further investigate the impact of factors such as body fat percentage and appendicular muscle mass index on spinal muscle mass and function across different BMI categories.

Conclusions

This study investigated paraspinal muscle parameters in Chinese adults across different age, sex, and BMI categories. Sex and BMI are important determinants of paraspinal muscle mass, with the influence of BMI on paraspinal muscle mass surpassing that of age and WC. In contrast, muscle density is primarily influenced by sex and age, with a weak effect of WC and BMI. To identify paraspinal muscle deficiencies in older overweight and obese populations, we established both BMI-stratified and unstratified cutoff values for low paraspinal muscle index and density. These findings serve as a valuable reference for recognizing spinal sarcopenia across populations with different BMI levels.

Abbreviations

BMI	Body mass index
PMA	Psoas muscle area
PMI	Psoas muscle index
PMD	Psoas muscle density
PSMI	Posterior paraspinal muscle index
PSMD	Posterior paraspinal muscle density
MD	Muscle density
MI	Muscle index
MA	Muscle cross-sectional area
QCT	Quantitative Computed Tomography
EWGSOP2	The European Working Group on Sarcopenia in Older People 2 (updated in 2019)
AWGS 2019	The Asian Working Group on Sarcopenia (updated in 2020)
CASH	China Action on Spine and Hip
SMI	Skeletal muscle index
SMD	Skeletal muscle density
WHR	Waist-hip ratio
WC	Waist circumference

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

Supplementary Material 3

Supplementary Material 4

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Author contributions
Conceptualization: W.W., F.D., Z.L., L.W., B.H., and Y.L.; Data curation: W.W., Z.L., G.Y., and C.L.; Interpretation of data and statistical analysis: W.W. and F.D.; Writing - drafting of the manuscript: W.W., Writing - review & editing: W.W., F.D., R.W., and X.C; Methodology: W.W., and F.D.; Funding acquisition: W.W., L.W., and Y.L.; Resources: Z.L., L.W., B.H. and Y.L., Supervision: L.W., B.H. and Y.L.

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Data availability
The data that support the findings of this study are available on request from the corresponding author Y. L., upon reasonable request.

Declarations

Competing interests
The authors declare no competing interests.

Conflict of interest
All authors declare that there are no relevant conflicts of interest.

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