Obesity metrics and fall severity in older adults: A cross-sectional analysis of weight-adjusted waist index and conventional anthropometric measures

Huihe Chen [a,1], Yi Luo [a,1], Yujuan Li [b], Jianfeng Zhang [a,*]

[a] Department of Emergency, Wuming Hospital of Guangxi Medical University, Nanning, Guangxi Province, China
[b] Department of Sports Medicine and Cardiopulmonary Rehabilitation Center, Jiangbin Hospital, Nanning, Guangxi Province, China

ARTICLE INFO

ABSTRACT

Aim: To examine the associations between conventional and novel obesity indices with fall risk and severity.
Methods: Data from 13,778 adults aged 65 years and older, obtained from the Chinese Longitudinal Healthy Longevity Survey, were analyzed. Logistic regression analyses, restricted cubic splines, and receiver operating characteristic curve were used to assess the relationships.
Results: After multivariable adjustment, central obesity, assessed by waist circumference, was inversely associated with fall risk. The odds ratio (OR) and 95% confidence interval (95%CI) was 0.91 (0.82–0.99, $p = 0.031$). In contrast, compared with the lowest quartile, the highest weight-adjusted waist index (WWI) quartile was positively associated with fall risk (OR: 1.15, 95%CI: 1.02–1.30, $p = 0.022$). WWI also exhibited significant associations with fall severity. Compared with the lowest quartile, the highest WWI quartile was significantly associated with one fall (OR: 1.6, 95%CI: 1.16–2.21, $p = 0.005$), recurrent falls (OR: 1.8, 95%CI: 1.31–2.47, $p < 0.001$), and injurious falls (OR: 1.76, 95%CI: 1.3–2.4, $p < 0.001$). These associations between WWI and fall outcomes remained consistent across multiple subgroup analyses. The area under the curve for WWI in discriminating fall risk and severity ranged from 0.55 to 0.58. A WWI ≥ 11.8 cm/$\sqrt{\text{kg}}$ was associated with 30% ($p = 0.034$), 65% ($p < 0.001$), and 52% ($p < 0.001$) higher risk of a single fall, recurrent falls, and fall injury, respectively. Sensitivity analysis using complete-case data confirmed the robustness of the main findings.
Conclusions: WWI was significantly associated with fall risk and severity in older adults. Further prospective studies are essential to validate its predictive value in fall risk stratification and prevention.

1. Introduction

Falls are the leading cause of injuries and injury-related deaths among older adults, posing a significant public health challenge (Denfeld et al., 2022). Each year, approximately 25% of older adults experience at least one fall, with severe consequences including fractures, disability, and increased mortality (Colón-Emeric et al., 2024). Notably, the age-adjusted mortality rate related to falls has risen sharply to 69.4 per 100,000 individuals—double that of two decades ago (Santos-Lozada, 2023). Given the accelerating global aging population, identifying individuals at high risk of falls is critical for implementing targeted prevention strategies and alleviating the growing burden on healthcare systems (Montero-Odasso et al., 2022; Ganz and Latham, 2020).

Obesity is a well-established modifiable risk factor for falls (GRN

et al., 2020). Conventional indices, such as body mass index (BMI), waist circumference (WC), and waist-to-height ratio (WHtR), have been linked to increased fall risk (Colón-Emeric et al., 2024; Batsis et al., 2023; Lin et al., 2024; Dowling et al., 2023a; Rosenblatt and Madigan, 2021; Shim et al., 2024). However, these measures primarily assess fat distribution and do not fully capture the complexity of body composition, particularly the interaction between muscle and fat—factors that are increasingly recognized as important determinants of fall risk. For example, sarcopenic obesity, a prevailing condition in older adults, has been shown to be a stronger predictor of falls than either low muscle mass or obesity alone. This condition is associated with decreased bone mass, an increased risk of falling, and fractures, highlighting the need to evaluate both fat and muscle tissue in fall risk assessments (Rossi-Izquierdo et al., 2016; Coelho de Amorim et al., 2024; Dowling et al., 2023b). Recently, novel obesity indices, such as the body shape index

---

* Corresponding author.
  E-mail address: zhangjianfeng@gxmu.edu.cn (J. Zhang).
[1] The authors contributed equally to this work.

(ABSI) (Krakauer and Krakauer, 2012, 2016; Yang et al., 2023), body roundness index (BRI) (Zhang et al., 2024, 2023a), and weight-adjusted waist index (WWI) (Yu et al., 2023; Zhao et al., 2024), provide more comprehensive insights by incorporating geometric and weight-adjusted metrics (Dowling et al., 2023a; Coelho de Amorim et al., 2024; Smith et al., 2024; Lv et al., 2022; Kirk et al., 2021; Nogueira Paranhos Amorim et al., 2021; Gandham et al., 2021). For instance, WWI reflects muscle quality and bone health, offering broader utility than traditional indices (Kim et al., 2021, 2023a, 2023b; Xu and Zhou, 2024). Despite their potential in predicting adverse health outcomes, the relationship between these novel indices and fall risk remains unexplored.

Furthermore, much of the existing research focuses on the occurrence of falls rather than their severity—the extent of injury or functional decline after a fall (GRN et al., 2020). Since severe fall-related outcomes contribute significantly to healthcare costs and mortality, understanding the risk factors of fall severity is equally crucial. Therefore, exploring the value of these indices in various fall-related consequences may yield insights for their applications in fall risk stratification.

To address this knowledge gap, we aimed to investigate the associations of novel and conventional obesity indices with fall risk and severity, using nationwide representative data from the Chinese Longitudinal Healthy Longevity Survey (CLHLS). By evaluating the potential of these indices, we aim to enhance fall risk stratification and inform targeted prevention strategies.

2. Methods

2.1. Study population

The nation-wide representative sample from the Chinese Longitudinal Healthy Longevity Survey (CLHLS) was utilized in this study. The CLHLS includes community-dwelling adults from 23 of the 31 provinces in China and is one of the largest national longitudinal cohort studies of healthy aging worldwide. Further details of the CLHLS have been reported elsewhere (Yi, 2008). The CLHLS obtained ethical approval and informed consent and was approved by the research ethics committees of Peking University (IRB00001052–13074).

Of the 15,874 participants from the 2018 wave of CLHLS, 406 were excluded due to missing information on falls. Additionally, 89 participants were excluded due to an age younger than 65 years, and 302 due to bedridden status. Participants lacking anthropometric data were excluded, including 874 participants without weight (Wt, kg), 34 without height (Ht, cm), 81 without WC (cm), and 61 without hip circumference (HC, cm). Based on prior research on the distribution of WC and BMI among Chinese older adults (Sun et al., 2024), 249 participants were excluded due to extreme values. Extreme values were defined as WC outside the range of 45 to 150 cm and BMI outsight the range of 10 to 50 kg/ m^2. After applying these criteria, the final study sample consisted of 13,778 community-dwelling adults aged 65 and older. Fig. S1 shows sample selection in this study.

2.2. Fall history and fall severity

Fall history was assessed using the question, "Have you fallen in the past year?". Participants with a response of "No" were categorized into non-fall group, while those who answered "Yes" were categorized into fall history group. Fall severity was determined based on the frequency of falls and their consequences. Two questions from the survey were used: (1) "How many times have you fallen in the past year?" and (2) "During that/any fall, have you been seriously injured and need treatment?". Participants were categorized into the following severity groups accordingly: (1) no falls (reference group); (2) one fall: experienced one fall and without injury; (3) recurrent falls: experienced multiple falls and without injury; (4) fall injury: experienced falls and with injury. Recurrent falls and fall injury were considered as severe fall

consequences. Among the 3025 participants reporting any fall, 682 had one fall without injury, 784 had recurrent falls without injury, and 939 had falls with injury. The remaining 620 individuals had missing data on fall severity.

2.3. Obesity indices

Using measurements of Wt, Ht, WC, and HC from the survey, we calculated the conventional and new obesity indices. Conventional obesity indices included body mass index (BMI), waist-to-hip (WHR) ratio, and waist-to-height ratio (WHtR). New indices included a body shape index (ABSI) (Krakauer and Krakauer, 2012), body roundness index (BRI) (Thomas et al., 2013), and weight-adjusted-waist index (WWI) (Park et al., 2018). The equations used were: $BMI = Wt / Ht^2$ (kg/m^2); $WHR = WC / HC$; $WHtR = WC / Ht$; $WWI = WC / Wt^{1/2}$; $ABSI = WC \times Wt^{-2/3} \times Ht^{5/6}$; $BRI = 364.2 - 365.5 \times ((1 - [WC / 2\pi]^2 / [0.5 \times Ht]^2))^{1/2}$. The above anthropometric measurements were assessed by trained professionals using a tape and weighing scale, with participants instructed to remove shoes and heavy clothing.

Based on available standards and research practices, participants were divided into different obesity groups for further analysis. General obesity categories were defined using BMI: (1) normal weight: $18.5 \leq BMI < 24.0$ kg/m^2; (2) underweight: $BMI < 18.5$ kg/m^2; (3) overweight: $24.0 \leq BMI < 28.0$ kg/m^2; (4) obese: $BMI \geq 28.0$ kg/m^2. Central obesity categories were defined using sex-specific WC: (1) normal: $WC < 85$ cm in male and $WC < 80$ cm in female; (2) pre-central obesity: 85 cm $\leq WC < 90$ cm in male and 80 cm $\leq WC < 85$ cm in female; (3) central obesity: $WC \geq 90$ cm in male and $WC \geq 85$ cm in female (Zhang et al., 2023b).

For other anthropometric indices such as ABSI, WWI, and BRI, we adopted quartiles as an exploratory strategy due to the lack of widely accepted clinical cut-offs points. Consequently, these indices were categorized into sex-combined quartiles based on their value distribution, ranging from the lowest to the highest quartile, to facilitate exploratory comparisons across the population.

2.4. Covariates

A wide range of covariates was included in this study. Information on sociodemographic, lifestyle, and medical history were extracted from the survey. These covariates included age (year), sex (male/female), residence type (urban/rural), ethnicity (Han/others), marriage status (currently married/others), and education level (literacy/illiteracy). Yearly income was categorized as low (less than 30,000 yuan per year) and high (more than 30,000 yuan per year). Smoking, alcohol consumption, and exercise were categorized as current and none. Muscle mass was evaluated using calf circumference (CC). Low muscle mass was defined as CC < 33 cm for women and <34 cm for men. Frailty was evaluated using a 35-item frailty index (FI), with FI > 0.21 indicating frail status (Table S1). The measurement procedures and applied thresholds were determined in accordance with well-established methods described in the literature (Barbosa-Silva et al., 2016; Searle et al., 2008; Chen et al., 2022). Clinical conditions included hypertension, diabetes mellitus (DM), heart disease (HD), and stroke. Relevant medications were also recorded.

2.5. Statistical analysis

The proportion of missing data for each variable was less than 15%, and multiple imputation was applied to handle missing data using the Multivariate Imputation by Chained Equations (MICE) package in R, employing predictive mean matching for continuous variables and logistic regression for categorical variables. To evaluate the validity of the imputation, we compared the distribution and descriptive statistics of variables between the imputed and original datasets. No significant differences were observed (Table S2). Additionally, sensitivity analyses using complete cases (excluding participants with any missing values)

were also conducted. Continuous variables were presented as mean (standard deviation, SD). Categorical variables were presented as counts and percentages. *t*-Test, Wilcoxon rank sum test, and chi-squared test were used to compare group differences. General characteristics of the total sample were compared between groups of fall history and severity.

Odds ratios (ORs) and 95% confidence intervals (95% CIs) were examined using logistic regression analysis to investigate the associations between obesity indices and fall history. Model 1 was the crude model, containing only one obesity index. To control for potential co-founders, three additional models were developed. Model 2 was adjusted for sex, age, residence, ethnicity, marriage, education, income and lifestyles of smoking, alcohol consumption, and exercise. Model 3 was further adjusted medical conditions. Relevant medications, frailty, and low muscle mass were adjusted in Model 4, building on Model 3. To assess the incremental value of novel obesity indices beyond traditional measures, BMI was added as an additional covariate to Model 4. Multicollinearity was evaluated using Variance Inflation Factors (VIFs) and confirmed no evidence of collinearity (VIF values were less than 2). Indices showing significant associations with fall history were further analyzed for their relationship with fall severity using multivariable logistic analyses. Restricted cubic splines (RCS) using four knots were utilized to assess the dose-response relationships. The knots were placed at the 5th, 35th, 65th, and 95th percentiles of the WWI distribution. Receiver operating characteristics (ROC) analysis was used to determine optimal cutoff points. To minimize potential sex-confounding effect, sex was included as a covariate in all multivariable models, and subgroup analyses stratified by sex were conducted to examine the robustness of associations across sexes. In addition, subgroup analyses were also performed across different age groups (<75 vs ≥75 years) and in the presence of chronic diseases, with full covariate adjustment. All the above analyses were performed using R (version 2023.09.1). Two-sided $p < 0.05$ was considered statistically significant.

3. Results

3.1. General characteristics of the study population

In total, 13,778 participants with a mean age of 84.7y (standard deviation [SD]: 11.4) were included in this study. The prevalence of falls was 22.0%. More than half of the participants were (54.8%). The BMI, WC, WHR, WHtR, ABSI, BRI, and WWI mean values were 22.34 (SD: 4.14), 83.88 (SD: 11.08), 0.92 (SD: 0.08), 0.55 (SD: 0.07), 0.09 (SD: 0.01), 4.38 (SD: 1.50), and 11.64 (SD: 1.26), respectively (Table 1 and Tables S3–S4). Fallers were older, more likely to be female, and exhibited greater frailty and low muscle mass compared to non-fallers. They also had a higher prevalence of heart disease and stroke. Additionally, fallers presented with lower value of BMI and WC, but higher WWI values than non-fallers. Fallers experiencing severe fall-related outcomes tended to share similar characteristics compared to those without falls.

3.2. Associations of different obesity indices with fall history

After full adjustment, BMI, WHR, WHtR, ABSI, and BRI were not associated with falls; only WC and WWI remained significant (Tables 2 and S5). Compared to participants with normal weight assessed by BMI, underweight participants (OR: 1.1, 95%CI: 0.98–1.23, $p = 0.064$) were more likely to fall. In contrast, participants with pre-central (OR: 0.9, 95%CI: 0.8–1.01, $p = 0.053$) or central (OR: 0.91, 95%CI: 0.82–0.99, $p = 0.031$) obesity assessed by WC, were less likely to fall compared to those without obesity. These associations became insignificant after additional adjustment for BMI (Table S6). Regarding WWI, the highest quartile exhibited a positive association with falls (OR: 1.15, 95%CI: 1.02–1.30, $p = 0.022$) compared with the lowest quartile of WWI. The relationship remained unchanged after further adjustment for BMI

Table 1
General characteristics of the study sample.

Variables	Fall history			Fall severity			
	Non-fall $N = 10,753$	Falls $N = 3025$	p	One fall $N = 682$	Recurrent falls $N = 784$	Fall severity $N = 939$	p
Age (year)	84.01 (11.36)	87.05 (11.32)	<0.001	87.27 (10.87)	86.50 (11.48)	87.60 (11.35)	<0.001
Sex			<0.001				0.001
Female	5690 (52.9%)	1853 (61.3%)		399 (58.5%)	488 (62.2%)	619 (65.9%)	
Male	5063 (47.1%)	1172 (38.7%)		283 (41.5%)	296 (37.8%)	320 (34.1%)	
Residence, urban	5926 (55.1%)	1722 (56.9%)	0.076	409 (60.0%)	436 (55.6%)	526 (56.0%)	0.32
Ethnicity, Han	727 (6.8%)	146 (4.8%)	<0.001	27 (4.0%)	33 (4.2%)	41 (4.4%)	<0.001
Currently married	4709 (43.8%)	1054 (34.8%)	<0.001	221 (32.4%)	289 (36.9%)	297 (31.6%)	0.001
Education, literacy	5019 (46.7%)	1624 (53.7%)	<0.001	352 (51.6%)	413 (52.7%)	524 (55.8%)	0.024
Smoking, current	1749 (16.3%)	396 (13.1%)	<0.001	89 (13.0%)	96 (12.2%)	119 (12.7%)	0.14
Exercise, current	3519 (32.7%)	943 (31.2%)	0.11	253 (37.1%)	211 (26.9%)	293 (31.2%)	<0.001
Hypertension, yes	4569 (42.5%)	1359 (44.9%)	0.017	305 (44.7%)	372 (47.4%)	440 (46.9%)	0.23
Diabetes mellitus, yes	1087 (10.1%)	327 (10.8%)	0.26	65 (9.5%)	99 (12.6%)	114 (12.1%)	0.27
Heart disease, yes	1821 (16.9%)	619 (20.5%)	<0.001	139 (20.4%)	175 (22.3%)	212 (22.6%)	0.17
Stroke, yes	1105 (10.3%)	469 (15.5%)	<0.001	93 (13.6%)	140 (17.9%)	176 (18.7%)	<0.001
Frailty, yes	3763 (35.0%)	1625 (53.7%)	<0.001	310 (45.5%)	424 (54.1%)	596(62.9%)	<0.001
Low muscle mass, yes	7553 (70.2%)	2297 (75.9%)	<0.001	507 (74.3%)	586 (74.7%)	729 (77.6%)	0.31
Anti-hypertension, yes	3962 (36.8%)	1172 (38.7%)	0.056	264 (38.7%)	323 (41.2%)	372 (39.6%)	0.66
Anti-diabetes mellitus, yes	960 (8.9%)	292 (9.7%)	0.22	61 (8.9%)	86 (11.0%)	97 (10.3%)	0.62
Anti-heart disease, yes	1479 (13.8%)	505 (16.7%)	<0.001	110 (16.1%)	149 (19.0%)	171 (18.2%)	0.057
Anti-stroke, yes	840 (7.8%)	390 (12.9%)	<0.001	77 (11.3%)	125 (15.9%)	140 (14.9%)	<0.001
BMI, kg/m^2	22.44 (4.13)	22.00 (4.17)	<0.001	22.01 (3.97)	22.09 (4.26)	21.91 (4.18)	0.058
WC, cm, mean (SD)	84.84 (10.79)	83.89 (11.09)	<0.001	84.28 (11.29)	84.16 (10.90)	83.99 (10.78)	0.92
HC, cm, mean (SD)	92.04 (9.98)	91.11 (10.53)	<0.001	91.23 (9.85)	91.92 (10.68)	91.00 (10.65)	0.27
Ht, cm, mean (SD)	155.54 (10.4)	153.34 (10.79)	<0.001	154.39 (10.98)	153.32 (10.62)	152.68 (10.51)	<0.001
Wt, kg, mean (SD)	54.64 (12.83)	52.05 (12.46)	<0.001	52.77 (12.32)	52.25 (12.57)	51.33 (12.03)	<0.001
WHR * 100, mean (SD)	92.29 (7.73)	92.20 (7.72)	0.59	92.42 (7.77)	91.71 (7.48)	92.48 (7.79)	0.18
WHtR * 100, mean (SD)	54.67 (7.01)	54.85 (54.85)	0.22	54.72 (7.27)	55.02 (7.11)	55.17 (7.33)	0.093
ABSI * 100, mean (SD)	8.63 (0.93)	8.72 (0.97)	<0.001	8.72 (0.97)	8.73 (0.96)	8.77 (0.96)	<0.001
BRI, mean (SD)	4.37 (1.48)	4.42 (1.55)	0.14	4.39 (1.53)	4.45 (1.53)	4.48 (1.57)	0.100
WWI, cm/√kg, mean (SD)	11.61 (1.26)	11.76 (1.30)	<0.001	11.72 (1.28)	11.78 (1.27)	11.85 (1.29)	<0.001

WC, waist circumference. Wt, weight. HC, hip circumference. Ht, height. BMI, body mass index. WHtR, waist to height ratio. WHR, waist to hip ratio. ABSI, a body shape index. BRI, body roundness index. WWI, weight-adjusted waist index.

Table 2
Associations of different obesity indices with fall history.

Variables	Model 1		Model 2		Model 3		Model 4	
	OR (95%CI) p		OR (95%CI) p		OR (95%CI) p		OR (95%CI) p	
General obesity categories by BMI								
Normal	Reference		Reference		Reference		Reference	
Underweight	1.27 (1.14, 1.41)	**<0.001**	1.11 (0.99, 1.24)	0.061	1.14 (1.02, 1.28)	**0.021**	1.1 (0.98, 1.23)	0.064
Overweight	0.88 (0.79, 0.97)	**0.012**	0.96 (0.86, 1.07)	0.457	0.93 (0.83, 1.03)	0.157	0.96 (0.85, 1.07)	0.417
Obesity	0.93 (0.79, 1.08)	0.353	1 (0.85, 1.17)	0.982	0.95 (0.81, 1.12)	0.567	0.98 (0.83, 1.16)	0.84
Central obesity categories by WC								
Normal	Reference		Reference		Reference		Reference	
Pre-central obesity	0.89 (0.80, 1.00)	**0.048**	0.92 (0.82, 1.03)	0.13	0.89 (0.79, 0.99)	**0.039**	0.90 (0.80, 1.01)	0.053
Central obesity	0.88 (0.81, 0.97)	**0.007**	0.92 (0.84, 1.01)	0.094	0.88 (0.80, 0.97)	**0.009**	0.91 (0.82, 0.99)	**0.031**
WWI								
Quartile 1	Reference		Reference		Reference		Reference	
Quartile 2	1.03 (0.92, 1.16)	0.621	1.04 (0.92, 1.17)	0.557	1.03 (0.91, 1.16)	0.661	1.04 (0.93, 1.18)	0.482
Quartile 3	1.15 (1.03, 1.29)	**0.017**	1.06 (0.94, 1.19)	0.343	1.06 (0.94, 1.19)	0.367	1.07 (0.95, 1.21)	0.257
Quartile 4	1.41 (1.26, 1.58)	**<0.001**	1.14 (1.01, 1.29)	**0.029**	1.14 (1.01, 1.29)	**0.029**	1.15 (1.02, 1.30)	**0.022**

Model 1 was the crude model. Model 2 was adjusted for age, sex, residence, ethnicity, marriage, education, income, and habits of smoking, alcohol drinking, and exercise. Model 3 was further adjusted for chronic conditions of hypertension, diabetes mellitus, heart disease, and stroke. Model 4 was further adjusted for relevant medications, frailty, and low muscle mass. WC, waist circumference. BMI, body mass index. WWI, weight-adjusted waist index. Values in bold indicate statistical significance ($p < 0.05$)

(Table S6).

3.3. Associations of different obesity indices with of fall severity

We further evaluated the associations between fall severity and both WC and WWI (Fig. 1). Only WWI was significantly associated with different severities of falls.

In the fully adjusted models, participants in the highest WWI quartile had a higher risk of experiencing one fall, recurrent falls, and fall injuries compared to those in the lowest quartile. The ORs (95%CI) were 1.6 (95%CI: 1.16–2.21, $p = 0.005$), 1.8 (95%CI: 1.31–2.7, $p < 0.001$), and 1.76 (95%CI: 1.3–2.4, $p < 0.001$), respectively. These associations remained robust after additional adjustment for BMI (Table S6). Subgroup analyses indicated that the associations between WWI and fall severity were largely consistent in the highest quartile compared to the lowest quartile (Fig. 2). The main findings remained unchanged while using complete cases before imputation (Tables S7–S8).

3.4. The dose-response relationship and ROC analysis

The dose-response relationships between WWI and fall severity were assessed using RCS. Fig. 3 illustrates an S-shaped relationship pattern between WWI and different fall severity. Of note, the p value for non-linearity was significant in recurrent falls ($p = 0.032$). The area under the curves (AUC) and best cut-off values were 0.55 and 11.9 cm/$\sqrt{\text{kg}}$ for one fall, 0.57 and 11.8 cm/$\sqrt{\text{kg}}$ for recurrent falls, and 0.58 and 11.9 cm/$\sqrt{\text{kg}}$ for fall injury was (Table S9). Participants with WWI ≥ 11.8 cm/$\sqrt{\text{kg}}$ exhibited a significant elevated fall risk compared to those with lower values (OR: 1.11, 95%CI: 1.02–1.22, $p = 0.016$). Specifically, the risks of experiencing one fall, recurrent falls, and fall injury were increased by 30% ($p = 0.034$), 65% ($p < 0.001$), and 52% ($p < 0.001$), respectively (Table 3).

4. Discussion

This study investigated the associations of conventional and new

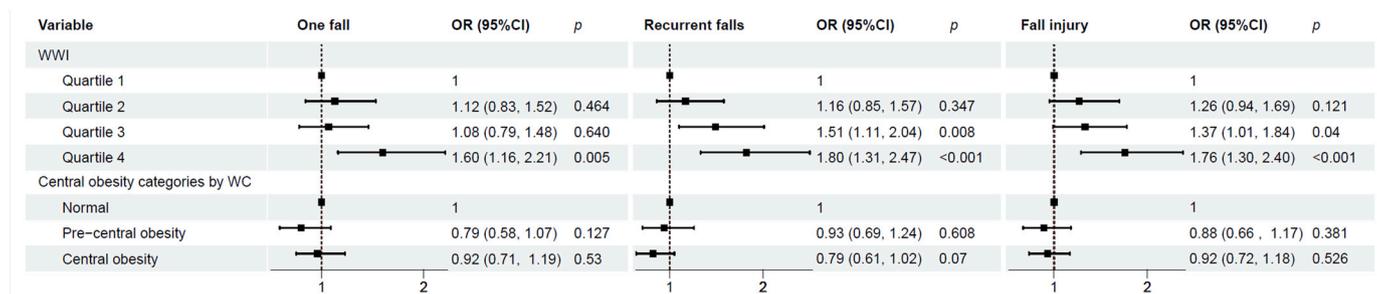| Variable	One fall	OR (95%CI)	p	Recurrent falls	OR (95%CI)	p	Fall injury	OR (95%CI)	p
WWI									
Quartile 1		1			1			1	
Quartile 2		1.12 (0.83, 1.52)	0.464		1.16 (0.85, 1.57)	0.347		1.26 (0.94, 1.69)	0.121
Quartile 3		1.08 (0.79, 1.48)	0.640		1.51 (1.11, 2.04)	0.008		1.37 (1.01, 1.84)	0.04
Quartile 4		1.60 (1.16, 2.21)	0.005		1.80 (1.31, 2.47)	<0.001		1.76 (1.30, 2.40)	<0.001
Central obesity categories by WC									
Normal		1			1			1	
Pre−central obesity		0.79 (0.58, 1.07)	0.127		0.93 (0.69, 1.24)	0.608		0.88 (0.66 , 1.17)	0.381
Central obesity		0.92 (0.71, 1.19)	0.53		0.79 (0.61, 1.02)	0.07		0.92 (0.72, 1.18)	0.526

Fig. 1. Associations of different obesity indices and fall severity.
All the models were adjusted for covariates in Model 4 and BMI. The reference group was the no falls group. OR, odds ratio. CI, confidence interval. BMI, body mass index. WC, waist circumference. ABSI, a body shape index. WWI, weight-adjusted waist index. The black squares represent the calculated ORs of different obesity indices, while the horizontal bars indicate the 95% CI.
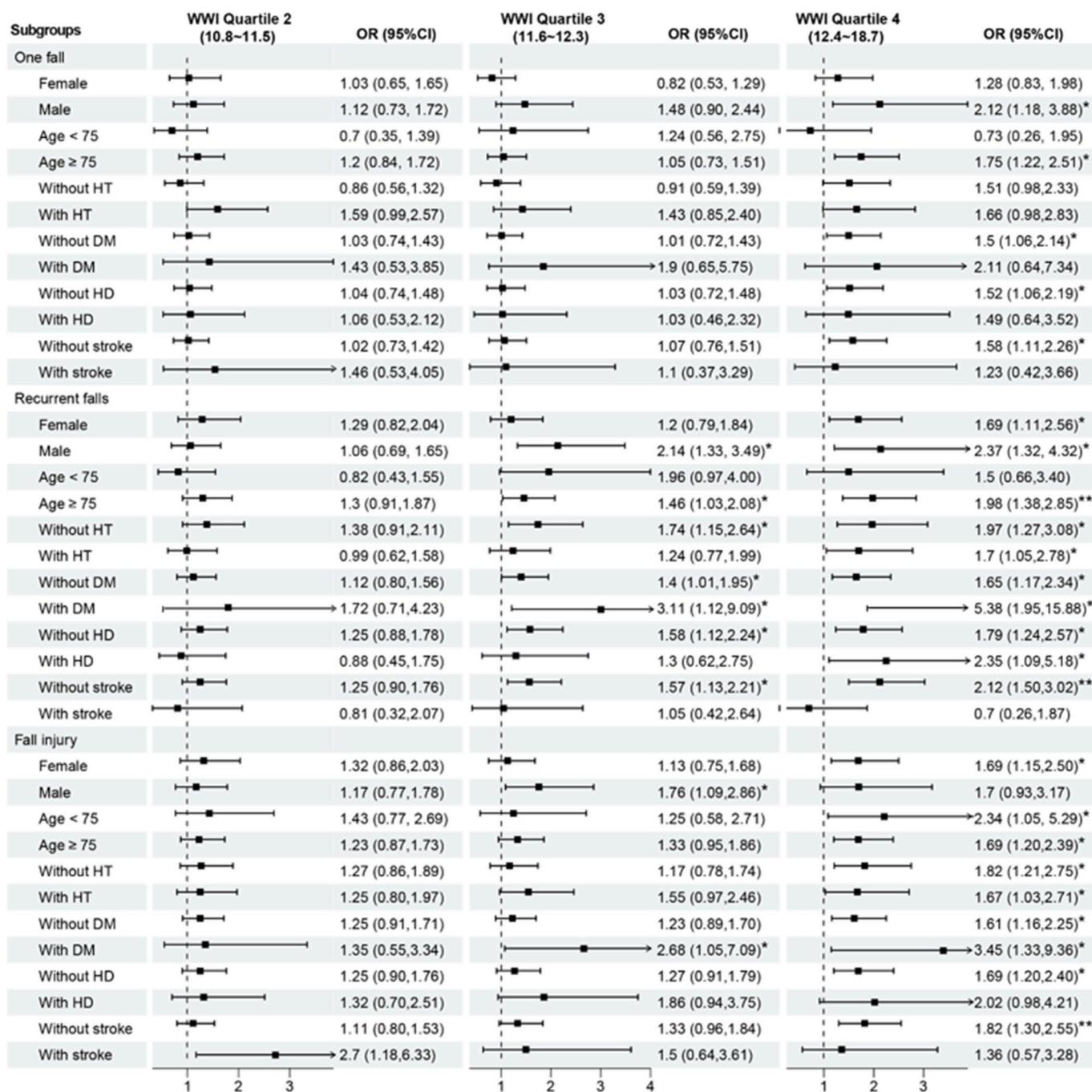
Fig. 2. Subgroup analysis of WWI with different severity of falls.
All the models were adjusted for covariates in Model 4 and BMI. * *p* < 0.05. ** *p* < 0.001. OR, odds ratio.
CI, confidence interval. WWI, weight-adjusted waist index. HT, hypertension. DM, diabetes mellitus. HD, heart disease. The black squares represent the calculated ORs of WWI, while the horizontal bars indicate the 95% CIs. The arrows indicate a value that exceeds the range of the x-axis.

obesity indices with fall history and severity in community-dwelling older adults. The results demonstrated that only WWI was associated with both fall history and severity. These associations remained largely significant across multiple subgroup analyses. The discriminative ability of WWI for fall risk and severity was modest, with AUC values ranging from 0.55 to 0.58. Specifically, a WWI ≥ 11.8 cm/√kg was associated with 30% (*p* = 0.034), 65% (*p* < 0.001), and 52% (*p* < 0.001) higher risk of a single fall, recurrent falls and fall injury, respectively. These findings suggest that WWI was significantly associated with fall risk and severity among older adults.

Our study is the first to demonstrate a significant association between WWI and both fall risk and fall severity in older adults. While

previous research primarily relied on conventional obesity indices, such as BMI and WC, to assess fall risk, our study advances the field by investigating novel obesity indices and their relationships to fall severity as well. Our results showed that WWI consistently outperformed both conventional and other emerging obesity indices, including ABSI and BRI, in assessing fall risk and severity. Notably, these associations persisted even after adjustment for BMI, highlighting WWI's value beyond traditional obesity measures. Furthermore, we observed an S-shaped relationship between WWI and fall severity and identified a threshold at 11.8 cm/√kg. Above this threshold, the risk of falls and fall-related injuries increased significantly. This cut-off aligns with a prior research reported a similar threshold (11.0 cm/√kg) for evaluated hip-
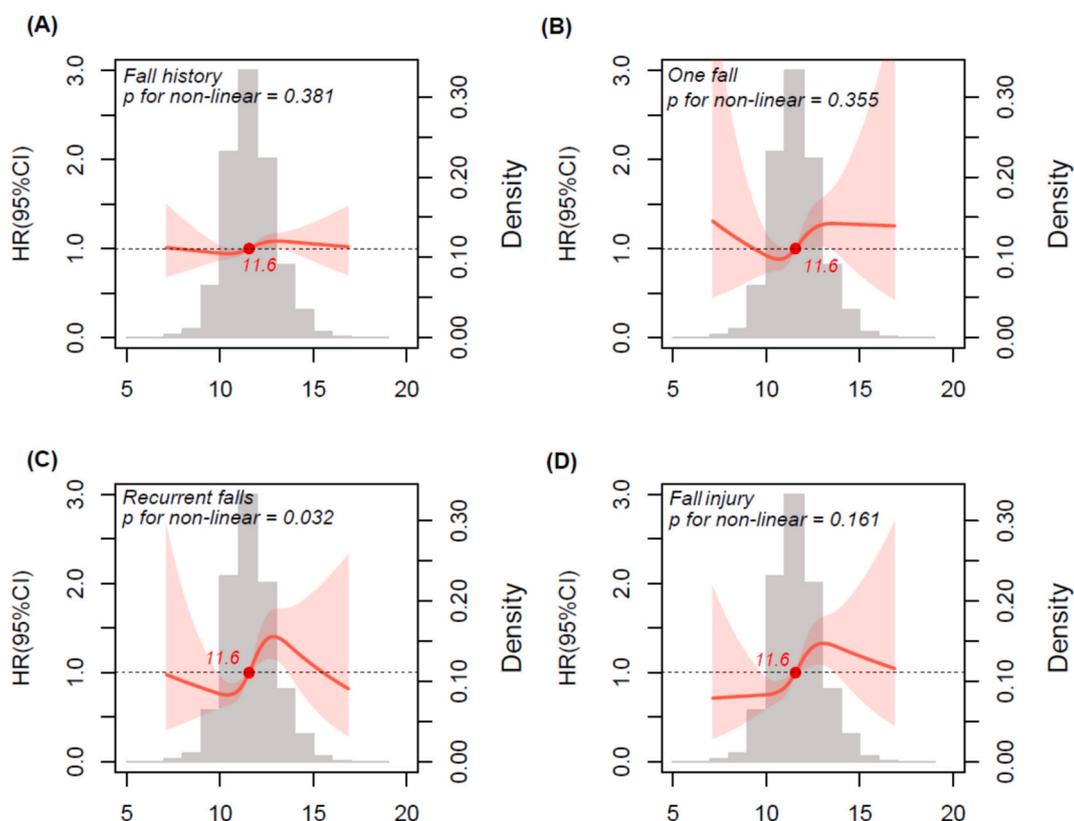
Fig. 3. Restricted cubic spline curves for WWI with fall history and fall severity.
(A) Fall history. (B) One fall. (C) Recurrent falls. (D) Fall injury. All the models were adjusted for covariates in Model 4 and BMI. OR, odds ratio. CI, confidence interval. WWI, weight-adjusted waist index. The red lines represent the spline curves, with the red rainbow shading indicating the confidence intervals. The red spot marks the estimated effect at the reference point. The histogram in the background shows the distribution of WWI.

Table 3
Segmental analysis of WWI on fall history and severity.

WWI	Fall history		One fall		Recurrent falls		Fall injury	
	OR (95%CI)	*p*	OR (95%CI)	*p*	OR (95%CI)	*p*	OR (95%CI)	*p*
<11.8	Reference							
≥11.8	1.11 (1.02, 1.22)	0.016	1.3 (1.02, 1.65)	0.034	1.65 (1.31, 2.07)	<0.001	1.52 (1.21, 1.90)	<0.001

All models were adjusted for covariates in Model 4. WWI, weight-adjusted waist index.

fracture risk (Yu et al., 2023), suggesting that WWI may serve as a valuable indicator for identifying individuals prone to severe fall outcomes. Nevertheless, it is important to note that the discriminative ability of WWI remained modest (AUC: 0.55 to 0.58). Although originally developed to assess cardiometabolic risk (Park et al., 2018), accumulating evidence indicates that WWI reflects not only adiposity but also muscle and skeletal health. Large cohorts from the United States and Korea have demonstrated that WWI values exceeding 10.6 cm/$\sqrt{kg}$ are associated with higher fat mass, reduced bone mass, and diminished muscle mass and strength (Kim et al., 2023a; Xu and Zhou, 2024). These factors collectively increase fall risk and severity. Consequently, the superior performance of WWI observed in our study may be partially attributable to its ability to capture sarcopenic obesity, a condition characterized by excess fat mass coupled with loss of muscle mass and strength. Sarcopenic obesity is well-established as a potent risk factor for falls and related injuries in older adults, as it simultaneously compromises physical function and imposes greater mechanical burdens from adipose tissue (Gandham et al., 2021; Li et al., 2024). Thus, WWI may serve as a simple, practical anthropometric tool that integrates both adiposity excess and muscle deficits, thereby offering a more

comprehensive assessment of fall risk than traditional obesity indices. Prospective studies are required to validate these findings and clarify the precise role of WWI in fall-risk stratification. Future research should also explore whether combining WWI with other clinical measures could improve its predictive accuracy, making it a more effective tool for fall prevention programs.

Although ABSI and BRI are valuable predictors for adverse health outcomes, we found no significant associations between these new indices and fall history. These results may stem from the methodologies used to develop ABSI and BRI. ABSI is calculated using Wt, Ht, and WC, emphasizing fat distribution. A recent study from China found that incorporating height into the equations may improve the accuracy of abdominal fat evaluated using computed tomography scans (Liu et al., 2024). This calculation complements BMI by identifying abdominal adipose depots. In contrast, BRI combines WC and Ht, reflecting body roundness without accounting for Wt. The emphasis and limitation of these measurements may hinder their ability to accurately reflect overall body composition, particularly muscle tissue. Furthermore, both indices were developed using an American population, which may introduce population variability when applying to an Asian sample. Consequently,

their relationships with falls and fall severity were less pronounced than those of the WWI, which was developed using a Korean population and is significantly associated with both fat tissue and mass quality.

Findings regarding the relationship between WC and falls remain inconsistent across studies. In our study, high WC was found to be a potential protective factor against falls in older adults. This contrasts with Zhao et al.'s findings, which reported the opposite association in nonagenarians using the CLHLS data (Zhao et al., 2022). A study from Ireland found no significant association (Rossi-Izquierdo et al., 2016), while most studies on Western populations have reported a positive correlation between WC and falls (Dowling et al., 2023b; Zhang et al., 2022; Máximo et al., 2019). Several factors may explain these discrepancies. For example, Zhao et al. adjusted for socioeconomic variables and self-reported health, whereas our study included a broader range of confounders, such as chronic diseases and medications, which are well-established fall risk factors (Colón-Emeric et al., 2024; Ganz and Latham, 2020). Additionally, differences in sample characteristics and study designs could also account for the varied results. Western studies typically defined central obesity with WC cut-off values of 102 cm for males and 88 cm for females, with participant ages ranging from 60 to 70 years, showing a positive association with falls. In contrast, our study used lower cut-offs (90 cm for males and 85 cm for females), and participants were older (mean age: 84 years), which may explain the inverse association observed. These findings emphasize the need for caution when applying WC-based evidence to older adults, as the relationship between WC and fall risk may vary with age and other demographic factors.

Our findings reveal distinct associations between different anthropometric measures and fall risk. Notably, while we found no significant association between obesity defined by BMI and fall risk, central obesity defined by WC was associated with a 12% lower fall risk compared to normal WC. This discrepancy may be explained by the relatively lower severity of obesity in our sample, where the mean BMI (31.1 kg/m^2) in our obesity group was considerably lower than the threshold ($\geq$37 kg/m^2) typically associated with increased fall risk (Colón-Emeric et al., 2024; Dowling et al., 2023a). Interestingly, the protective effect of central obesity contrasts with the 14% increased risk observed in underweight individuals (defined by BMI), supporting the "obesity paradox"—where moderate obesity may not confer the same level of fall risk as more severe obesity. Additionally, the highest WWI quartile was associated with a 15% greater fall risk, suggesting that WWI may capture distinct risk pathways not identified by traditional measures. These findings highlight the need for a more nuanced approach to body composition assessment in fall risk prediction.

The current study was the first to assess the potential value of several new obesity indices for falls. However, several limitations exist. First, a major limitation of this cross-sectional study is its inability to establish causal relationships. Although higher WWI was associated with increased fall risk and severity, the possibility of reverse causation cannot be excluded. Older adults who have experienced injurious falls often experience subsequent declines in mobility and undergo unintentional weight loss or even sarcopenia, which can alter obesity-related indices. Therefore, part of the observed association between these indices and fall severity may reflect the consequences of prior falls rather than solely representing antecedent risk. Further longitudinal studies with repeated measurements of anthropometric indices before and after fall events are needed to clarify the direction of these relationships. Second, fall-related data was collected through self-reported questionnaires, which may introduce recall bias and misclassification, particularly among older adults. Although standardized questions and trained interviewers were employed to minimize bias, it remains an inherent limitation of large-scale surveys. Furthermore, the lack of objective fall-related outcomes, such as fractures or hospitalizations, limited our ability to precisely quantify fall severity. Future studies incorporating these clinical outcomes could offer a more accurate and meaningful assessment. Additionally, other well-recognized fall risk factors were not

included due to data limitations, such as fear of falling and grip strength, leading to residual confounding effect. Moreover, other promising allometric indices, such as the anthropometric risk index (ARI) (Krakauer and Krakauer, 2016), were not analyzed in this study. Future research that incorporates these indices could provide valuable insights into the role of body composition in fall risk assessment. Finally, as the number of participants in some subgroups was small, the confidence intervals were wide. Relevant results should be interpreted with caution. Therefore, a larger cohort could provide more evidence on the associations between WWI and fall severity in future studies.

Despite these limitations, this study still has some advantages. First, the study focused on the major challenges of falls, the sever fall consequences, and identify a feasible marker for risk screening. Second, the finial models constructed in this study were adjusted for a wide range of covariates, leading to more accurate estimates of the relationship between the studied indices and fall severity. Moreover, the main findings of WWI were unchanged when further adjusted for BMI and in multiple subgroup analyses. Furthermore, the study analyzed most of the conventional obesity indices and three newly constructed ones. Under this study design, it allows a broader and more comprehensive understanding of the value between different variables. Finally, by using a nationally representative sample of community-dwelling older adults, our findings may provide additional insight into falls screening and prevention in this aging society.

In conclusion, higher WWI was independently associated with increased fall risk and severity among Chinese older adults. WWI may serve as a simple and valuable indicator to identify individuals at high risk of severe fall outcomes. Prospective studies are warranted to validate its predictive utility and potential role in fall risk stratification and prevention.

CRediT authorship contribution statement

Huihe Chen: Writing – original draft, Software, Resources, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Yi Luo:** Investigation, Conceptualization. **Yujuan Li:** Validation, Resources, Methodology, Formal analysis. **Jianfeng Zhang:** Writing – review & editing, Validation, Supervision.

Ethical approval

This study was conducted in accordance with the Declaration of Helsinki. The CLHLS obtained ethical approval and informed consent and was approved by the research ethics committees of Peking University (IRB00001052–13074).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.exger.2026.113099.

Data availability

The data that support the findings of this study are available at https://opendata.pku.edu.cn/dataverse/CHADS.

References

Barbosa-Silva, T.G., Menezes, A.M.B., Bielemann, R.M., Malmstrom, T.K., Gonzalez, M. C., 2016. Enhancing SARC-F: improving sarcopenia screening in the clinical practice. J. Am. Med. Dir. Assoc. 17 (12), 1136–1141.

Batsis, J.A., Haudenschild, C., Crow, R.S., Gilliam, M., Mackenzie, T.A., 2023. Sarcopenia definition outcome consortium - defined weakness and risk of falls: the National Health and Aging Trends Survey. Geriatr. Gerontol. Int. 23 (3), 213–220. https://doi.org/10.1111/ggi.14548.

Chen, H., Huang, L., Xiang, W., Liu, Y., Xu, J.W., 2022. Association between cognitive frailty and falls among older community dwellers in China: a Chinese longitudinal healthy longevity survey-based study. Front. Aging Neurosci. 14, 1048961. https://doi.org/10.3389/fnagi.2022.1048961.

Coelho de Amorim, J.S., Perracini, M.R., Alexandre, T.D.S., Máximo, R.O., Nascimento-Souza, M.A., 2024. Dynapenic abdominal obesity, single and recurrent falls in older Brazilian adults: Elsi-Brazil results. J. Aging Health 36 (1–2), 35–45. https://doi.org/10.1177/08982643231169315 (Jan).

Colón-Emeric, C.S., McDermott, C.L., Lee, D.S., Berry, S.D., 2024. Risk assessment and prevention of falls in older community-dwelling adults: a review. Jama 331 (16), 1397–1406. https://doi.org/10.1001/jama.2024.1416 (Apr 23).

Denfeld, Q.E., Turrise, S., MacLaughlin, E.J., et al., 2022. Preventing and managing falls in adults with cardiovascular disease: a scientific statement from the American Heart Association. Circ. Cardiovasc. Qual. Outcomes 15 (6), e000108. https://doi.org/10.1161/HCQ.0000000000000108 (2022/06/01).

Dowling, L., Cuthbertson, D.J., Walsh, J.S., 2023a. Reduced muscle strength (dynapenia) in women with obesity confers a greater risk of falls and fractures in the UK Biobank. Obesity 31 (2), 496–505. https://doi.org/10.1002/oby.23609 (Feb).

Dowling, L., McCloskey, E., Cuthbertson, D.J., Walsh, J.S., 2023b. Dynapenic abdominal obesity as a risk factor for falls. J. Frailty Aging 12 (1), 37–42. https://doi.org/10.14283/jfa.2022.18.

Gandham, A., Mesinovic, J., Jansons, P., et al., 2021. Falls, fractures, and areal bone mineral density in older adults with sarcopenic obesity: a systematic review and meta-analysis. Obes. Rev. 22 (5), e13187. https://doi.org/10.1111/obr.13187 (May).

Ganz, D.A., Latham, N.K., 2020. Prevention of falls in community-dwelling older adults (Feb 20). N. Engl. J. Med. 382 (8), 734–743. https://doi.org/10.1056/NEJMcp1903252.

GRN, S., SO, J., BD, A., ML, R., Tiedemann, A., 2020. Does obesity increase the risk and severity of falls in people aged 60 years and older? A systematic review and meta-analysis of observational studies. J. Gerontol. Ser. A Biol. Sci. Med. Sci. 75 (5), 952–960. https://doi.org/10.1093/gerona/glz272 (Apr 17).

Kim, J.E., Choi, J., Kim, M., Won, C.W., 2023b. Assessment of existing anthropometric indices for screening sarcopenic obesity in older adults. Br. J. Nutr. 129 (5), 875–887. https://doi.org/10.1017/s0007114522001817 (Mar 14).

Kim, K.J., Son, S., Kim, K.J., Kim, S.G., Kim, N.H., 2023a. Weight-adjusted waist as an integrated index for fat, muscle and bone health in adults. J. Cachexia. Sarcopenia Muscle 14 (5), 2196–2203. https://doi.org/10.1002/jcsm.13302 (Oct).

Kim, N.H., Park, Y., Kim, N.H., Kim, S.G., 2021. Weight-adjusted waist index reflects fat and muscle mass in the opposite direction in older adults. Age Ageing 50 (3), 780–786. https://doi.org/10.1093/ageing/afaa208 (May 5).

Kirk, B., Zanker, J., Bani Hassan, E., Bird, S., Brennan-Olsen, S., Duque, G., 2021. Sarcopenia Definitions and Outcomes Consortium (SDOC) criteria are strongly associated with malnutrition, depression, falls, and fractures in high-risk older persons. J. Am. Med. Dir. Assoc. 22 (4), 741–745. https://doi.org/10.1016/j.jamda.2020.06.050 (Apr).

Krakauer, N.Y., Krakauer, J.C., 2012. A new body shape index predicts mortality hazard independently of body mass index. PloS One 7 (7), e39504. https://doi.org/10.1371/journal.pone.0039504.

Krakauer, N.Y., Krakauer, J.C., 2016. An anthropometric risk index based on combining height, weight, waist, and hip measurements. J. Obes. 2016, 8094275. https://doi.org/10.1155/2016/8094275.

Li, R., Chen, X., Tang, H., et al., 2024. Sarcopenic obesity and falls in older adults: a validation study of ESPEN/EASO criteria and modifications in Western China communities. Arch. Gerontol. Geriatr. 127, 105557. https://doi.org/10.1016/j.archger.2024.105557 (2024/12/01/).

Lin, W.Q., Chen, J.M., Yuan, L.X., et al., 2024. Association between abdominal obesity indices and falls among older community-dwellers in Guangzhou, China: a prospective cohort study. BMC Geriatr. 24 (1), 732. https://doi.org/10.1186/s12877-024-05319-0 (Sep 4).

Liu, Y., He, H., Qian, K., et al., 2024. Evaluation of health associations with height-normalised abdominal body composition indices: a single-centre cross-sectional study. J. Cachexia. Sarcopenia Muscle. https://doi.org/10.1002/jcsm.13609 (Oct 7).

Lv, D., Shen, S., Chen, X., 2022. Association between dynapenic abdominal obesity and fall risk in older adults. Clin. Interv. Aging 17, 439–445. https://doi.org/10.2147/cia.S347053.

Máximo, R.O., Santos, J.L.F., Perracini, M.R., Oliveira, C., Duarte, Y.A.O., Alexandre, T. D.S., 2019. Abdominal obesity, dynapenia and dynapenic-abdominal obesity as factors associated with falls. Braz. J. Phys. Ther. 23 (6), 497–505. https://doi.org/10.1016/j.bjpt.2018.10.009 (Nov-Dec).

Montero-Odasso, M., van der Velde, N., Martin, F.C., et al., 2022. World guidelines for falls prevention and management for older adults: a global initiative. Age Ageing 51 (9). https://doi.org/10.1093/ageing/afac205.

Nogueira Paranhos Amorim, D., Nascimento, D.C., Stone, W., Alves, V.P., Moraes, C.F., Coelho Vilaça, E.S.K.H., 2021. Muscle quality is associated with history of falls in octogenarians. J. Nutr. Health Aging 25 (1), 120–125. https://doi.org/10.1007/s12603-020-1485-2.

Park, Y., Kim, N.H., Kwon, T.Y., Kim, S.G., 2018. A novel adiposity index as an integrated predictor of cardiometabolic disease morbidity and mortality. Sci. Rep. 8 (1). https://doi.org/10.1038/s41598-018-35073-4.

Rosenblatt, N.J., Madigan, M.L., 2021. Exploring the association between measures of obesity and measures of trip-induced fall risk among older adults. Arch. Phys. Med. Rehabil. 102 (12), 2362–2368. https://doi.org/10.1016/j.apmr.2021.06.013 (Dec).

Rossi-Izquierdo, M., Santos-Pérez, S., Faraldo-García, A., et al., 2016. Impact of obesity in elderly patients with postural instability. Aging Clin. Exp. Res. 28 (3), 423–428. https://doi.org/10.1007/s40520-015-0414-4 (Jun).

Santos-Lozada, A.R., 2023. Trends in deaths from falls among adults aged 65 years or older in the US, 1999–2020. JAMA 329 (18), 1605–1607. https://doi.org/10.1001/jama.2023.3054 (%J JAMA).

Searle, S.D., Mitnitski, A., Gahbauer, E.A., Gill, T.M., Rockwood, K., 2008. A standard procedure for creating a frailty index. BMC Geriatr. 8 (1), 24.

Shim, G.Y., Yoo, M.C., Soh, Y., Chon, J., Won, C.W., 2024. Obesity, physical performance, balance confidence, and falls in community-dwelling older adults: results from the Korean Frailty and Aging Cohort Study. Nutrients 16 (5), 614.

Smith, L., López Sánchez, G.F., Veronese, N., et al., 2024. Dynapenic abdominal obesity increases risk for falls among adults aged ≥50 years: a prospective analysis of the Irish Longitudinal Study on Ageing. J. Gerontol. A Biol. Sci. Med. Sci. 79 (1). https://doi.org/10.1093/gerona/glad104 (Jan 1).

Sun, J., Lin, J., Shen, W., et al., 2024. Associations of body mass index, waist circumference and the weight-adjusted waist index with daily living ability impairment in older Chinese people: a cross-sectional study of the Chinese Longitudinal Healthy Longevity Survey. Diabetes Obes. Metab. 26 (9), 4069–4077. https://doi.org/10.1111/dom.15762 (Sep).

Thomas, D.M., Bredlau, C., Bosy-Westphal, A., et al., 2013. Relationships between body roundness with body fat and visceral adipose tissue emerging from a new geometrical model. Obesity 21 (11), 2264–2271. https://doi.org/10.1002/oby.20408.

Xu, L., Zhou, H., 2024. The association between weight-adjusted-waist index and muscle strength in adults: a population-based study. Front. Public Health 12, 1429244. https://doi.org/10.3389/fpubh.2024.1429244.

Yang, N., Zhuo, J., Xie, S., et al., 2023. A body shape index and its changes in relation to all-cause mortality among the Chinese elderly: a retrospective cohort study. Nutrients 15 (13). https://doi.org/10.3390/nu15132943 (Jun 28).

Yi, Z., 2008. Introduction to the Chinese longitudinal healthy longevity survey (CLHLS). In: Healthy Longevity in China: Demographic, Socioeconomic, and Psychological Dimensions, pp. 23–38.

Yu, H., Tao, L., Li, Y.G., et al., 2023. Association between triglyceride-glucose index trajectories and carotid atherosclerosis progression. Cardiovasc. Diabetol. 22 (1), 130. https://doi.org/10.1186/s12933-023-01847-y (May 31).

Zhang, C., Wang, W., Chang, X., et al., 2023b. Obesity and risk of hearing loss in the middle-aged and elderly: a national cohort of Chinese adults. BMC Public Health 23 (1), 1048. https://doi.org/10.1186/s12889-023-15974-4 (2023/06/01).

Zhang, L., Liu, S., Wang, W., et al., 2022. Dynapenic abdominal obesity and the effect on long-term gait speed and falls in older adults. Clin. Nutr. 41 (1), 91–96. https://doi.org/10.1016/j.clnu.2021.11.011 (Jan).

Zhang, X., Ding, L., Hu, H., He, H., Xiong, Z., Zhu, X., 2023a. Associations of body-roundness index and sarcopenia with cardiovascular disease among middle-aged and older adults: findings from CHARLS. J. Nutr. Health Aging 27 (11), 953–959. https://doi.org/10.1007/s12603-023-2001-2.

Zhang, X., Ma, N., Lin, Q., et al., 2024. Body roundness index and all-cause mortality among US adults. JAMA Netw. Open 7 (6), e2415051. https://doi.org/10.1001/jamanetworkopen.2024.15051 (Jun 3).

Zhao, J., Cai, X., Hu, J., et al., 2024. J-shaped relationship between weight-adjusted-waist index and cardiovascular disease risk in hypertensive patients with obstructive sleep apnea: a cohort study. Diabetes, Metab. Syndr. Obes. 17, 2671–2681. https://doi.org/10.2147/dmso.S469376.

Zhao, X., Yu, J., Hu, F., Chen, S., Liu, N., 2022. Association of body mass index and waist circumference with falls in Chinese older adults. Geriatr. Nurs. (New York, N. Y.) 44, 245–250. https://doi.org/10.1016/j.gerinurse.2022.02.020 (Mar-Apr).