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Association between the weight-adjusted waist index and incident falls among middle-aged and older adults: a longitudinal study based on CHARLS

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Abstract

Background

This study investigated the association between the weight-adjusted waist index (WWI) and incident falls among middle-aged and older adults.

Methods

Data were obtained from the China Health and Retirement Longitudinal Study (CHARLS). Participants aged ≥ 45 years with no falls at the 2011 baseline and complete WWI and covariate data were included. Incident falls were identified from the 2013, 2015, 2018, and 2020 follow-ups. Baseline WWI was categorized into quartiles. Multivariable logistic regression, trend tests, restricted cubic splines, subgroup analyses, and sensitivity analyses were performed. Receiver operating characteristic curves and paired DeLong tests with Holm correction were used to compare the discriminative performance of WWI, body mass index (BMI), waist circumference (WC), and waist-to-height ratio (WHtR).

Results

Among 10,034 participants, 3,748 experienced incident falls (37.4%). After full adjustment, Q4 was associated with higher odds of incident falls than Q1 (OR = 1.18, 95% CI: 1.04–1.35, *P* = 0.011), whereas Q2 and Q3 were not statistically significant. The odds of incident falls increased across WWI quartiles (*P* for trend = 0.0018). The overall association was significant in restricted cubic spline analysis (*P* = 0.0004), with no clear evidence of nonlinearity (*P* = 0.0835). No significant interactions were observed, and sensitivity analyses yielded consistent findings. WWI had an AUC of 0.560 (95% CI: 0.548–0.571), which was significantly higher than those of BMI, WC, and WHtR after Holm correction (all adjusted *P* < 0.001).

Conclusions

Higher baseline WWI was significantly associated with an increased risk of incident falls among middle-aged and older adults. Compared with BMI, WC, and WHtR, WWI showed the best discriminative performance for the early identification of middle-aged and older adults at high risk of falls and may serve as a primary simple indicator for early identification and risk stratification.

Introduction

As population ageing accelerates worldwide, falls have become one of the most common and serious health threats among middle-aged and older adults[1] and are an important cause of injury, disability, hospitalization, and death. In China, the prevalence of falls and serious falls among middle-aged and

older adults has been reported to be 17.42% and 6.86%, respectively, substantially affecting their physical and mental health and quality of life[2]. From a public health perspective, fall prevention should focus not only on post-fall treatment and rehabilitation, but also on the early identification and stratified management of high-risk populations. Previous studies have emphasized that fall prevention among community-dwelling older adults should include opportunistic screening, comprehensive risk assessment, and multidimensional interventions based on individual risk factors, including balance training, muscle-strengthening exercise, medication review, and chronic disease management[3, 4]. Identifying individuals at high risk of falls is important for implementing targeted prevention strategies and reducing the healthcare burden[5].

Previous studies have shown that obesity is an important and modifiable risk factor for falls[6]. Traditional anthropometric indicators, including body mass index (BMI), waist circumference (WC), and waist-to-height ratio (WHtR), have been associated with fall risk[7–9]. However, these indicators mainly reflect overall or abdominal adiposity and may not fully capture the combined effects of muscle mass, fat distribution, and their interaction on fall risk. Recent research on fall risk assessment suggests that body weight or conventional obesity indicators alone are insufficient to comprehensively identify high-risk individuals, because abnormal body composition, reduced muscle strength, and functional impairment are also important contributors to fall risk[10]. Sarcopenic obesity may predict adverse outcomes, including falls, fractures, and functional decline, more strongly than obesity or low muscle mass alone[11, 12]. In addition, dynapenic abdominal obesity is closely associated with an increased risk of falls[13, 14]. When abdominal obesity and reduced muscle strength coexist, the risks of single and recurrent falls increase substantially, and the combination of central fat accumulation and impaired muscle function is also closely related to functional impairment, including slower gait speed[15, 16]. Therefore, both adiposity and muscle status should be considered in fall risk assessment.

The weight-adjusted waist index (WWI) is a novel adiposity indicator proposed in recent years[17]. Compared with conventional indicators such as BMI and WC, WWI retains the information on abdominal adiposity reflected by WC while reducing the influence of overall body weight and is therefore considered to better reflect central obesity and fat-muscle imbalance. Previous studies have shown that WWI is positively associated with fat mass but changes in the opposite direction to muscle mass and muscle strength, and may identify adverse health risks among middle-aged and older adults more sensitively than conventional obesity indicators[18]. WWI has also been proposed as an integrated indicator of fat, muscle, and bone health[19]. A study in older Chinese adults found that a higher WWI was associated with an increased risk of all-cause mortality and that its AUC was higher than those of BMI, WHtR, and WC, suggesting a potential advantage for risk stratification[20]. In addition to mortality, WWI has increasingly been used to assess other ageing-related adverse health outcomes. Longitudinal studies based on CHARLS have shown that higher WWI is associated with increased risks of frailty and disability among middle-aged and older adults[21, 22]. A population-based study using NHANES also found an inverse association between WWI and handgrip strength, suggesting that WWI may reflect impaired muscle function[23]. These findings indicate that WWI may be more than a single measure of adiposity;

it may be a simple anthropometric indicator that integrates central fat accumulation, impaired muscle function, and overall functional vulnerability.

A recent large cross-sectional study among older Chinese adults showed that WWI was significantly and positively associated with both the occurrence and severity of falls, with generally stable findings across multiple subgroup analyses, suggesting that WWI may be a simple indicator for identifying individuals at high risk of falls[24]. However, because that study used a cross-sectional design, it could not establish the temporal sequence between WWI and falls. Therefore, using data from the China Health and Retirement Longitudinal Study (CHARLS), the present study investigated the longitudinal association between baseline WWI and incident falls among middle-aged and older adults, with the aim of providing evidence for the early identification and targeted intervention of individuals at high risk of falls.

Methods

Study design and participants

Data for this study were obtained from CHARLS, a nationally representative longitudinal cohort study initiated in 2011. CHARLS used a multistage stratified sampling design to recruit residents aged ≥ 45 years and their spouses from 150 counties or districts and 450 urban and rural communities across 28 provinces in China. The 2011 baseline survey included more than 17,000 participants from approximately 10,000 households, with follow-up surveys conducted every 2–3 years thereafter[25]. CHARLS was approved by the Institutional Review Board of Peking University (IRB00001052-11015), and all participants provided written informed consent.

Participants from the 2011 baseline survey were included, and follow-up data from 2013, 2015, 2018, and 2020 were used to evaluate the association between baseline WWI and incident falls among middle-aged and older adults. The inclusion criteria were as follows: (1) age ≥ 45 years; (2) participation in the physical examination, with complete and plausible measurements required to calculate WWI; (3) no falls at baseline and sufficient follow-up information to determine incident fall status; and (4) complete data on the key covariates. WWI outliers were defined as values below P25–1.5 × IQR or above P75 + 1.5 × IQR. The exclusion criteria were as follows: (1) age < 45 years at baseline; (2) missing or implausible body weight or WC; (3) WWI outliers; (4) falls reported at baseline; (5) incident fall status could not be determined during follow-up; and (6) missing exposure or covariate data. A total of 10,034 participants were included in the final analysis (Fig. 1).

Assessment of incident falls

Information on falls was obtained from self-reported items in the health status and functioning questionnaires administered at each CHARLS wave. Falls reported in 2011 were used to exclude participants with falls at baseline, whereas information from the 2013, 2015, 2018, and 2020 follow-up surveys was used to construct the incident fall outcome. A response of “yes” at any wave was defined as

a fall, and a response of “no” was defined as no fall. Participants who reported a fall at any follow-up after 2011 were classified as having experienced an incident fall. Participants with at least one observed follow-up and no falls at all observed waves were classified as not having experienced an incident fall. Participants with missing fall information at all follow-up waves were classified as having missing outcome data.

Assessment of the weight-adjusted waist index

WWI was calculated as WC (cm) divided by the square root of body weight (kg). Body weight and WC were obtained from the 2011 baseline physical examination. Body weight was restricted to 20–150 kg and WC to 40–200 cm; values outside these ranges were considered implausible and excluded. Extreme values were further identified using the IQR method, and participants with WWI values below P25–1.5 × IQR or above P75 + 1.5 × IQR were excluded. Participants were then categorized into Q1-Q4 according to quartiles of baseline WWI.

Covariates

The following covariates were included based on the baseline survey: age, sex, residence, educational level, marital status, smoking, drinking, hypertension, diabetes, heart disease, and stroke. Age was included as a continuous variable. Sex was categorized as male or female; residence as rural or urban; educational level as no formal education, primary or middle school, or high school or above; marital status as yes or no; and smoking and drinking as yes or no. Hypertension, diabetes, heart disease, and stroke were defined as yes or no according to self-reported disease information at baseline. BMI was calculated as body weight (kg) divided by height squared (m^2), and WHtR as WC (cm) divided by height (cm). BMI was categorized as < 18.5 kg/m^2, 18.5–23.9 kg/m^2, or ≥ 24.0 kg/m^2.

Statistical analysis

Data management and statistical analyses were performed using R version 4.5.2. Participants were categorized into Q1-Q4 according to quartiles of baseline WWI. Continuous variables were expressed as medians and interquartile ranges, M (P25, P75), according to their distributions, and categorical variables as frequencies and percentages, n (%). Baseline characteristics were compared using the Kruskal-Wallis test for continuous variables and Pearson’s χ^2 test for categorical variables. Multivariable logistic regression models were used to evaluate the association between WWI levels and incident falls, with Q1 as the reference group. Three models were constructed. Model 1 was unadjusted. Model 2 was adjusted for age and sex. Model 3 was additionally adjusted for residence, educational level, marital status, smoking, drinking, hypertension, diabetes, heart disease, and stroke. A test for trend was performed by entering the WWI quartile groups into Model 3 as an ordinal categorical variable.

A three-knot restricted cubic spline was used to examine the dose-response relationship between continuous WWI and incident falls and to test for nonlinearity. Subgroup analyses were further conducted according to age, sex, smoking, drinking, marital status, educational level, residence, and BMI. To ensure a common effect scale across subgroups, standardized WWI was entered as a continuous variable, and ORs with 95% CIs were reported for each 1-standard-deviation increase in WWI. Differences in the associations across strata were assessed by including interaction terms and using likelihood ratio tests. Because the primary aim was to examine the overall association between baseline WWI and whether an incident fall occurred during follow-up, logistic regression was used.

Three sensitivity analyses were conducted to evaluate the stability of the main findings under different sample restrictions. First, participants who had already experienced a fall by the 2013 follow-up were excluded to reduce the influence of early outcomes on the association estimates. Second, participants with hypertension, diabetes, heart disease, or stroke at baseline were excluded to assess the influence of underlying chronic diseases. Third, the analyses were repeated among participants with complete fall information in 2013, 2015, 2018, and 2020. In addition, ROC curves were used to evaluate the discriminative performance of WWI, BMI, WC, and WHtR for incident falls, and the AUC and 95% CI were calculated for each indicator. Because all ROC curves were derived from the same study population, paired DeLong tests were used to compare the AUC of WWI with those of BMI, WC, and WHtR, and Holm correction was applied for multiple comparisons. All tests were two-sided, with $\alpha = 0.05$.

Results

Baseline characteristics

A total of 10,034 participants were included. The median age was 58.00 (51.00, 64.00) years; 5,102 participants (50.8%) were women and 4,932 (49.2%) were men. According to quartiles of baseline WWI, 2,589 participants were classified into Q1, 2,615 into Q2, 2,509 into Q3, and 2,321 into Q4. Age, sex, residence, educational level, marital status, smoking, drinking, and the distribution of chronic diseases differed significantly across WWI quartiles (all $P < 0.05$; Table 1). Overall, participants in the higher WWI groups were older and more likely to be women, have no formal education, and have chronic diseases, whereas the proportions of smokers and drinkers were lower.

Table 1
Baseline characteristics of participants in 2011 according to WWI quartiles

Variable	Overall N = 10034	Q1 N = 2589	Q2 N = 2615	Q3 N = 2509	Q4 N = 2321	p-value
Age (years)	58.00 (51.00, 64.00)	55.00 (49.00, 61.00)	56.00 (49.00, 63.00)	58.00 (52.00, 64.00)	62.00 (56.00, 69.00)	< 0.001
Sex						< 0.001
Female	5102 (51%)	805 (31%)	1069 (41%)	1424 (57%)	1804 (78%)	
Male	4932 (49%)	1784 (69%)	1546 (59%)	1085 (43%)	517 (22%)	
Residence						0.033
Rural	9161 (91%)	2351 (91%)	2369 (91%)	2288 (91%)	2153 (93%)	
Urban	873 (8.7%)	238 (9.2%)	246 (9.4%)	221 (8.8%)	168 (7.2%)	
Educational level						< 0.001
No formal education	2622 (26%)	443 (17%)	524 (20%)	696 (28%)	959 (41%)	
Primary or middle school	6255 (62%)	1724 (67%)	1742 (67%)	1542 (61%)	1247 (54%)	
High school or above	1157 (12%)	422 (16%)	349 (13%)	271 (11%)	115 (5.0%)	
Marital status						< 0.001
No	1600 (16%)	373 (14%)	374 (14%)	374 (15%)	479 (21%)	
Yes	8434 (84%)	2216 (86%)	2241 (86%)	2135 (85%)	1842 (79%)	
Smoking						< 0.001
No	5985 (60%)	1167 (45%)	1381 (53%)	1625 (65%)	1812 (78%)	

Continuous variables are presented as median (P25, P75), and categorical variables as n (%). Between-group comparisons were performed using the Kruskal-Wallis test or Pearson's χ^2 test, as appropriate.

Variable	Overall N = 10034	Q1 N = 2589	Q2 N = 2615	Q3 N = 2509	Q4 N = 2321	p-value
Yes	4049 (40%)	1422 (55%)	1234 (47%)	884 (35%)	509 (22%)	
Drinking						< 0.001
No	6739 (67%)	1480 (57%)	1601 (61%)	1771 (71%)	1887 (81%)	
Yes	3295 (33%)	1109 (43%)	1014 (39%)	738 (29%)	434 (19%)	
Hypertension						< 0.001
No	7753 (77%)	2218 (86%)	2072 (79%)	1852 (74%)	1611 (69%)	
Yes	2281 (23%)	371 (14%)	543 (21%)	657 (26%)	710 (31%)	
Diabetes						< 0.001
No	9513 (95%)	2533 (98%)	2490 (95%)	2354 (94%)	2136 (92%)	
Yes	521 (5.2%)	56 (2.2%)	125 (4.8%)	155 (6.2%)	185 (8.0%)	
Heart disease						< 0.001
No	8939 (89%)	2375 (92%)	2360 (90%)	2204 (88%)	2000 (86%)	
Yes	1095 (11%)	214 (8.3%)	255 (9.8%)	305 (12%)	321 (14%)	
Stroke						< 0.001
No	9860 (98%)	2558 (99%)	2579 (99%)	2462 (98%)	2261 (97%)	
Yes	174 (1.7%)	31 (1.2%)	36 (1.4%)	47 (1.9%)	60 (2.6%)	

Continuous variables are presented as median (P25, P75), and categorical variables as n (%). Between-group comparisons were performed using the Kruskal-Wallis test or Pearson's χ^2 test, as appropriate.

Association between baseline WWI and incident falls

Multivariable regression analysis

During follow-up, 3,748 participants experienced incident falls, corresponding to an incidence proportion of 37.4%. In the unadjusted model, compared with Q1, the odds of incident falls were 31.8% higher in Q3 (OR = 1.32, 95% CI: 1.17–1.48) and 65.8% higher in Q4 (OR = 1.66, 95% CI: 1.48–1.86). After adjustment for age and sex, the odds of incident falls remained higher in Q4 than in Q1 (OR = 1.20, 95% CI: 1.06–1.37). After further adjustment for residence, educational level, marital status, smoking, drinking, hypertension, diabetes, heart disease, and stroke, the odds of incident falls remained significantly higher in Q4 and were 1.18 times those in Q1 (OR = 1.18, 95% CI: 1.04–1.35, *P* = 0.011), whereas the associations for Q2 and Q3 did not reach statistical significance. When WWI quartiles were entered as an ordinal variable, the odds of incident falls showed a significant increasing trend with higher WWI (*P* for trend = 0.0018; Table 2).

Table 2
Logistic regression analysis of baseline WWI and incident falls

Variable	Model 1, OR(95% CI)	Model 2, OR(95% CI)	Model 3, OR(95% CI)	P value (Model 3)
Q1	1 [Ref]	1 [Ref]	1 [Ref]	—
Q2	1.02(0.91, 1.14)	0.95(0.85, 1.07)	0.95(0.85, 1.07)	0.405
Q3	1.32(1.17, 1.48)	1.12(1.00, 1.26)	1.12(0.99, 1.26)	0.066
Q4	1.66(1.48, 1.86)	1.20(1.06, 1.37)	1.18(1.04, 1.35)	0.011
P for trend	—	—	—	0.0018

Q1 was the reference group. Model 1 was unadjusted. Model 2 was adjusted for age and sex. Model 3 was additionally adjusted for residence, educational level, marital status, smoking, drinking, hypertension, diabetes, heart disease, and stroke. P for trend was obtained by entering WWI quartiles into Model 3 as an ordinal categorical variable.

Dose-response analysis

A three-knot restricted cubic spline was used to examine the dose-response relationship between WWI and incident falls. The overall association was statistically significant (*P* = 0.0004), whereas the test for nonlinearity was not statistically significant (*P* = 0.0835). No clear evidence of a nonlinear association was observed, suggesting that the relationship between WWI and incident falls was predominantly linear (Fig. 2).

Subgroup analyses

Subgroup analyses showed that each 1-standard-deviation increase in WWI was associated with higher odds of incident falls in most prespecified subgroups. No significant interactions were observed across strata of age, sex, smoking, drinking, marital status, educational level, residence, or BMI (all *P* for

interaction > 0.05), indicating insufficient evidence that the association between WWI and incident falls differed according to age, sex, BMI, or the other subgrouping factors (Fig. 3).

Sensitivity analyses

Sensitivity analyses were conducted to evaluate the stability of the main findings under different sample restrictions. After excluding participants who had already experienced a fall by the 2013 follow-up, the odds of incident falls remained significantly higher in Q3 and Q4 than in Q1. After excluding participants with hypertension, diabetes, heart disease, or stroke at baseline, the effect estimates across quartiles were attenuated, but the direction of the association did not materially change. Finally, when the analysis was restricted to participants with complete fall information in 2013, 2015, 2018, and 2020, the odds of incident falls remained significantly higher in Q4 (OR = 1.23, 95% CI: 1.05–1.43). Overall, the sensitivity analyses supported the main findings.

ROC curve analysis

ROC curve analysis showed that the AUC for WWI in discriminating incident falls was 0.560 (95% CI: 0.548–0.571), which was higher than the AUCs for BMI (0.491, 95% CI: 0.479–0.503), WC (0.499, 95% CI: 0.487–0.511), and WHtR (0.531, 95% CI: 0.519–0.543). Paired DeLong tests showed that the differences in AUC between WWI and BMI, WC, and WHtR were 0.0686, 0.0609, and 0.0288, respectively, and all differences were statistically significant after Holm correction (all adjusted $P < 0.001$). Among the four adiposity-related indicators compared in this study, WWI showed relatively greater discriminative ability (Fig. 4 and Table 3).

Table 3
Paired DeLong tests comparing the AUC of WWI with other adiposity-related indicators

Comparison	AUC of WWI	AUC of comparator	ΔAUC	Z value	P value	Holm-adjusted P value
WWI vs BMI	0.560	0.491	0.069	9.64	< 0.001	< 0.001
WWI vs WC	0.560	0.499	0.061	11.30	< 0.001	< 0.001
WWI vs WHtR	0.560	0.531	0.029	7.31	< 0.001	< 0.001

Discussion

Using longitudinal data from CHARLS, this study investigated the association between baseline WWI and the risk of incident falls among middle-aged and older adults. After full adjustment for potential confounders, including demographic characteristics, lifestyle factors, and chronic diseases, higher WWI was significantly associated with an increased risk of incident falls. The trend test indicated that the risk of incident falls generally increased with higher WWI, whereas RCS analysis showed no clear departure from linearity. Subgroup analyses identified no significant differences in the association across age, sex,

BMI, or the other prespecified groups, and sensitivity analyses further supported the robustness of the findings. ROC analysis showed that, among the four adiposity-related indicators compared in this study, WWI had relatively greater discriminative ability.

Conventional adiposity indicators emphasize different aspects of obesity but have certain informational limitations in fall risk assessment. BMI assesses overall body size using body weight and height but cannot distinguish adipose tissue from lean tissue. With ageing, fat mass may increase while muscle mass decreases; consequently, individuals with similar BMI values may have markedly different body composition and functional status[26]. WC reflects abdominal fat distribution, but as an absolute circumference measure, it is influenced by sex, age, population characteristics, and measurement methods and does not directly provide information on muscle mass or muscle strength[24, 27]. WHtR adjusts WC for height and can partly reduce the influence of height differences, but it remains a ratio based on WC and height and does not directly incorporate body weight, muscle mass, or muscle function[24]. Although BMI, WC, and WHtR reflect different features of overall and central obesity, they may not fully identify the abnormal body composition characterized by coexisting fat accumulation and muscle loss in middle-aged and older adults[24]. In contrast, WWI adjusts WC by the square root of body weight, which may partly reduce the influence of overall body weight on the evaluation of WC. A higher WWI generally indicates a relatively larger WC at a similar or lower body weight and may simultaneously reflect central fat accumulation and reduced lean tissue. Previous studies have shown that WWI is positively associated with fat mass and inversely associated with muscle mass, bone mass, and muscle strength[18]. WWI has also shown good discriminative ability for screening sarcopenic obesity among community-dwelling older adults[28]. A prospective cohort study further showed that WWI was inversely associated with ASM/BMI and handgrip strength, and that older adults in the highest baseline WWI quartile had approximately 2.03 times the risk of developing sarcopenia compared with those in the lowest quartile[29].

These findings suggest that the potential value of WWI extends beyond a different mathematical transformation of WC; WWI may indirectly reflect the coexistence of increased adiposity and reduced muscle mass using simple anthropometric measurements. This feature is consistent with the mechanisms underlying falls among middle-aged and older adults. Fall risk is determined not only by body weight or adiposity, but is also closely related to muscle strength, balance, gait stability, and lower-extremity support. Previous studies have shown that obesity is associated with poorer physical performance, lower balance confidence, and falls[30]. Sarcopenic obesity and dynapenic abdominal obesity involve both abnormal fat accumulation and impaired muscle function and are generally more strongly associated with single falls, recurrent falls, slower gait speed, and functional impairment than obesity alone[12, 31–33]. Therefore, higher WWI may reflect the coexistence of central fat accumulation, reduced muscle mass or strength, and diminished overall functional reserve. This state may increase the mechanical burden during physical activity while weakening postural control and lower-extremity stability, thereby providing a possible explanation for the positive association between WWI and incident falls observed in the present study.

A previous cross-sectional study among older Chinese adults found that BMI and WHtR were not significantly associated with falls after full adjustment for confounders, and the direction of the association between WC and falls was inconsistent with findings from some previous studies. In contrast, WWI was positively associated not only with the occurrence of falls, but also with outcomes of different severity, including single falls, recurrent falls, and fall-related injuries[24]. In the present study, incident falls were constructed during follow-up among middle-aged and older adults who reported no falls at baseline. The highest WWI quartile had higher odds of incident falls than the lowest quartile, and the trend test showed that the odds generally increased with higher WWI. Compared with previous cross-sectional evidence, the longitudinal design of the present study further supports the association between baseline WWI and subsequent falls.

In the present study, the AUC of WWI for incident falls was 0.560, which was generally consistent with the range of 0.55–0.58 reported previously[24]. Paired DeLong tests showed that the AUC of WWI was higher than those of BMI, WC, and WHtR, and the differences remained statistically significant after Holm correction, indicating that WWI showed the best discriminative performance for incident falls among the four adiposity-related indicators compared in this study. This relative advantage may be related to the ability of WWI to capture, to some extent, information on both abdominal adiposity and fat-muscle imbalance. Taken together, these findings indicate that, compared with BMI, WC, and WHtR, WWI showed the best discriminative performance for identifying middle-aged and older adults at high risk of falls and may serve as a primary simple indicator for early identification and risk stratification. For individuals with high WWI, additional assessment of handgrip strength, gait speed, balance, chronic disease status, and medication use may be warranted.

Regarding the consistency of the analytical results, the quartile analysis indicated that the association was mainly concentrated at higher WWI levels, whereas RCS analysis showed no clear evidence of nonlinearity. None of the interaction tests in the prespecified subgroup analyses reached statistical significance, indicating insufficient evidence that the association between WWI and incident falls differed substantially according to age, sex, smoking, drinking, marital status, educational level, residence, or BMI. The direction of the association remained generally consistent after excluding early fallers, excluding participants with major chronic diseases at baseline, and restricting the analysis to participants with complete follow-up, further supporting the robustness of the main findings.

This study has several limitations. First, although a longitudinal design was used and multiple potential confounders were adjusted for, residual confounding cannot be completely excluded in an observational study, and causal inference cannot be made. Second, falls were mainly assessed by self-report and may therefore be subject to recall bias. Third, because of database limitations, information on gait, balance, fear of falling, and medication use was unavailable, preventing a more complete explanation of the mechanisms underlying the association between WWI and falls. Future studies should incorporate objective measures of body composition, muscle strength, gait, and balance to further clarify the potential mechanisms linking WWI to falls and to evaluate its value in comprehensive fall risk prediction models.

Conclusions

Higher baseline WWI was significantly associated with an increased risk of incident falls among middle-aged and older adults. Compared with BMI, WC, and WHtR, WWI demonstrated the best discriminative performance in the early identification of middle-aged and older adults at high risk of falls and may serve as a primary simple indicator for early identification and risk stratification.

Abbreviations

AUC
Area under the curve
BMI
Body mass index
CHARLS
China Health and Retirement Longitudinal Study
CI
Confidence interval
IQR
Interquartile range
OR
Odds ratio
RCS
Restricted cubic spline
ROC
Receiver operating characteristic
WC
Waist circumference
WHtR
Waist-to-height ratio
WWI
Weight-adjusted waist index

Declarations

Ethics approval and consent to participate

This study was a secondary analysis of de-identified data from CHARLS. The CHARLS study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board of Peking University (Approval No. IRB00001052-11015). Written informed consent was obtained from all participants. Clinical trial number: not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Author Contribution

SD contributed to conceptualization, methodology, software, formal analysis, visualization, and writing—original draft. YL contributed to supervision and writing—review and editing. JW contributed to data curation. All authors read and approved the final manuscript.

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Data Availability

The datasets analysed during the current study are available from the China Health and Retirement Longitudinal Study (CHARLS) repository after registration and approval in accordance with the CHARLS data-use procedures: https://charls.charlsdata.com/index/en.html.

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Figures

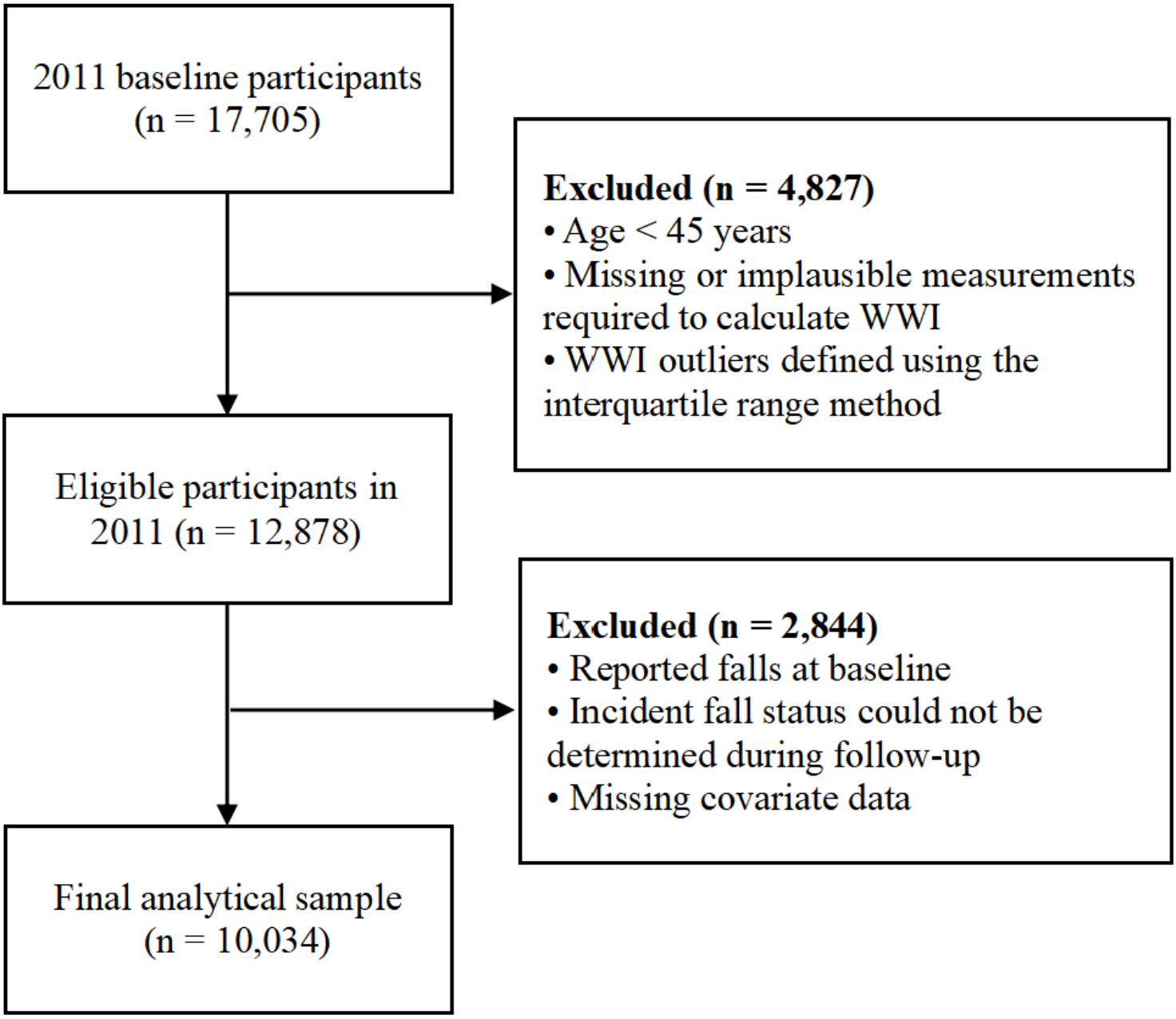


Figure 1

Flow chart of participant selection.

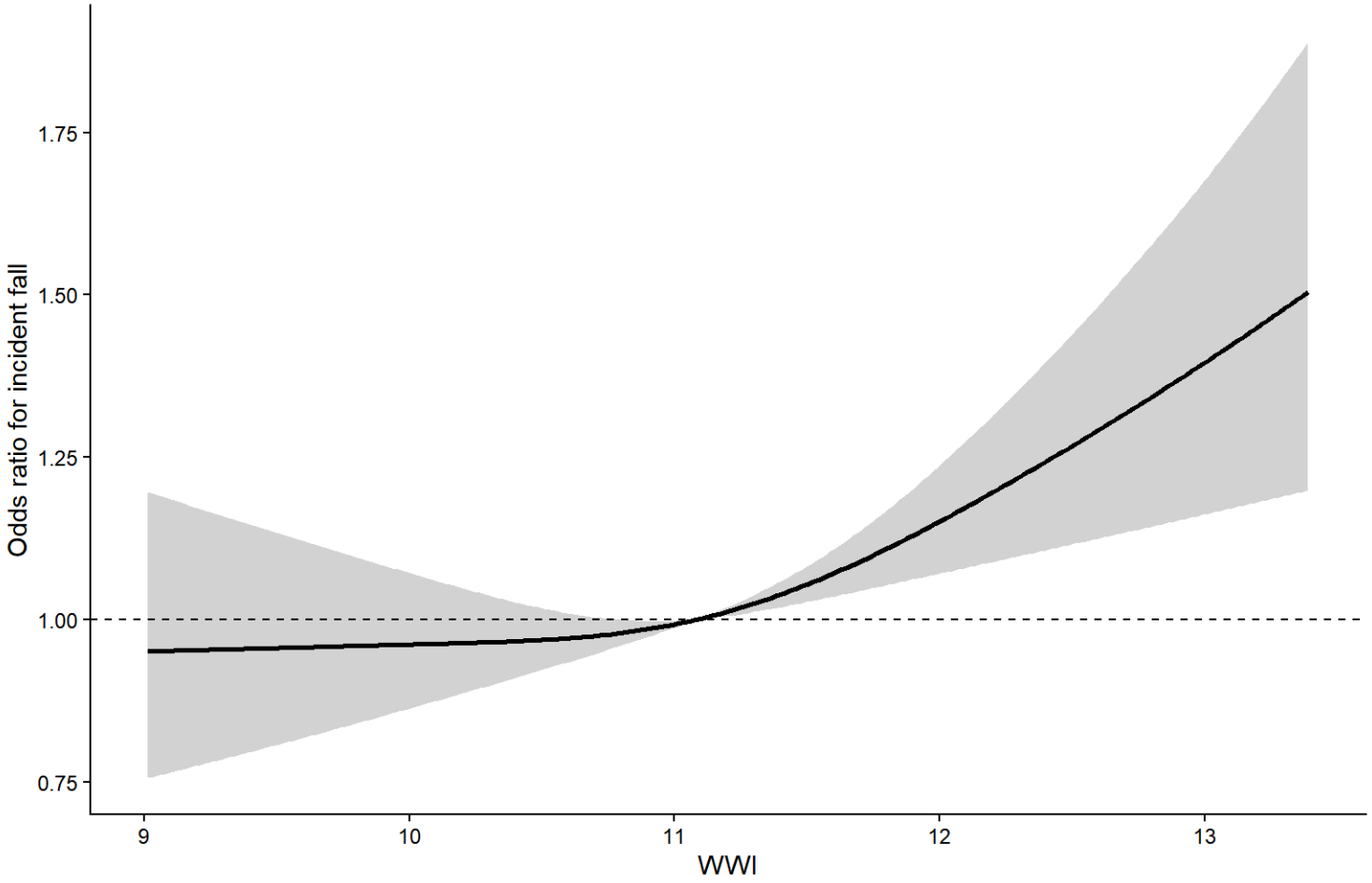


Figure 2

Dose-response relationship between WWI and incident falls. The solid line represents the odds ratio, and the shaded area represents the 95% confidence interval.

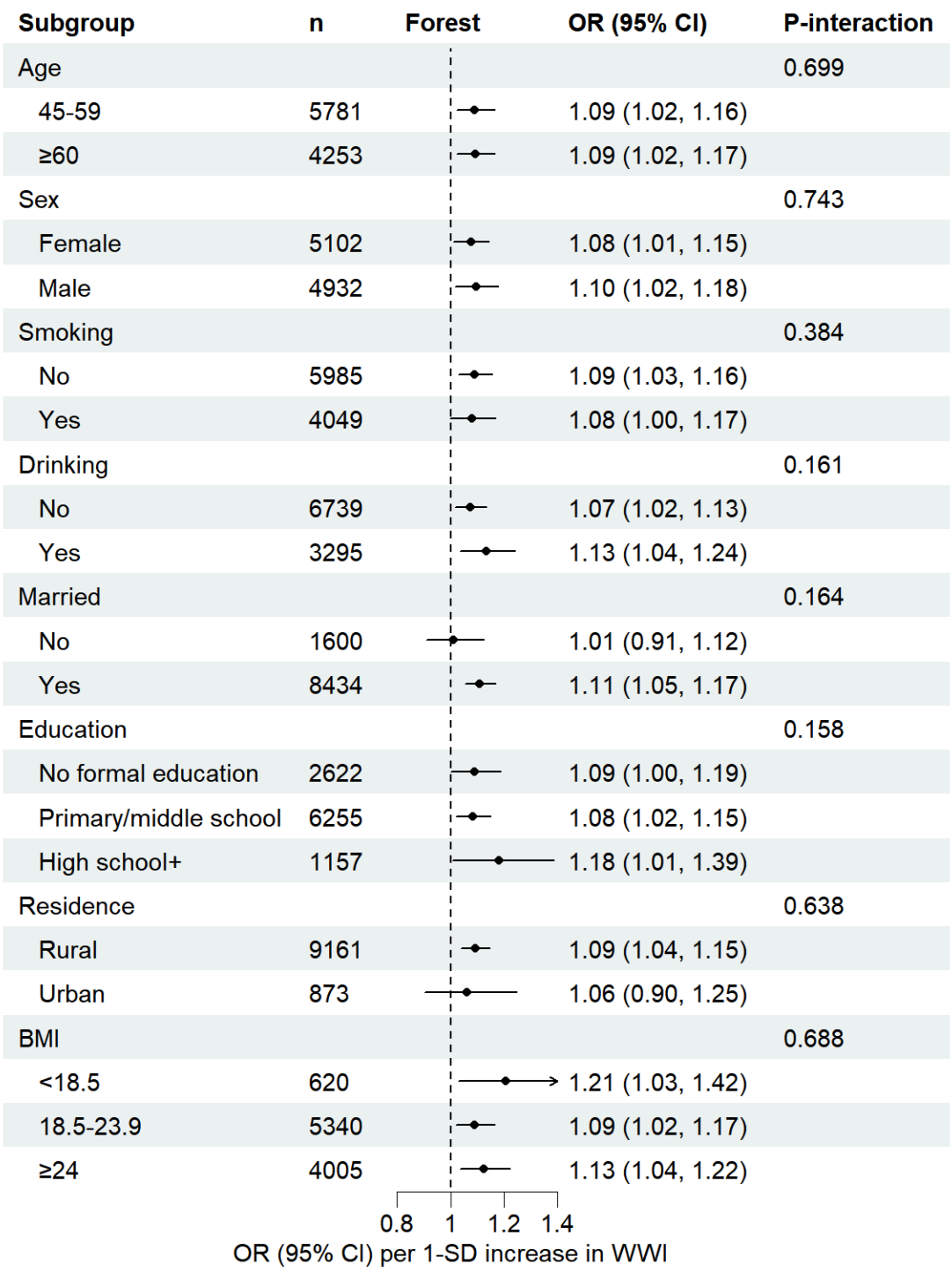


Figure 3

Subgroup analyses of the association between WWI and incident falls. ORs and 95% CIs are presented per 1-standard-deviation increase in WWI.

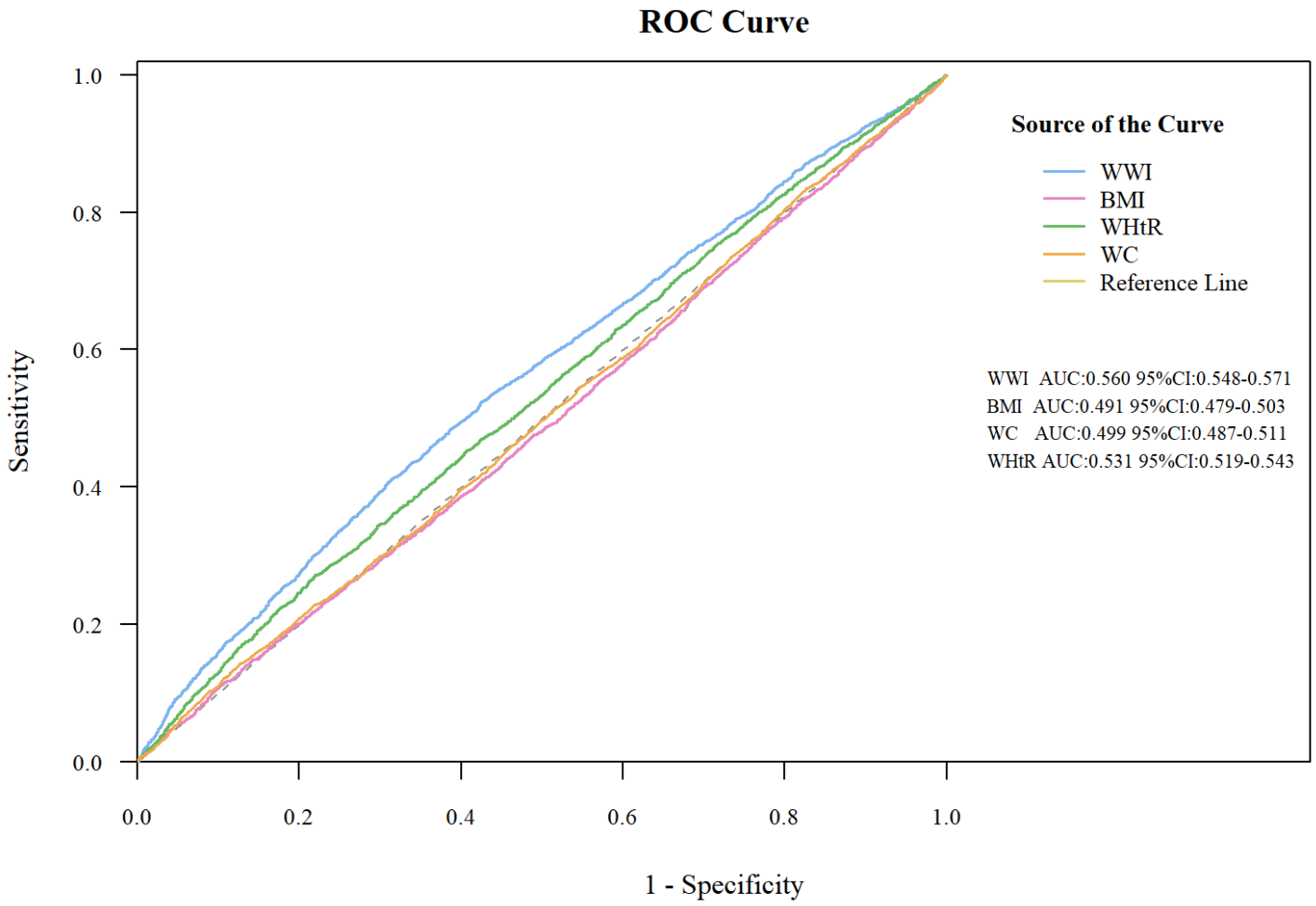


Figure 4

Receiver operating characteristic curves for WWI, BMI, WC, and WHtR in discriminating incident falls.