



OPEN Association between central obesity and ADL impairment among the middle-aged and elderly population in China based on CHARLS

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To explore the associations of central obesity indicators including waist circumference (WC), waist-to-height ratio (WHtR), and weight-adjusted waist index (WWI) with the impairment of basic activities of daily living (BADL) and instrumental activities of daily living (IADL) among middle-aged and elderly population in China. This prospective study used baseline data from 2011 and follow-up data, involving 6440 and 9646 participants, respectively. Binary logistic regression analysis was used to assess the relationships. Restricted cubic spline (RCS) curve was also used to analyze the correlation trends. Stratified analyses were performed to identify potential differences. Receiver operating characteristic curves were plotted to evaluate the predictive value of each indicator. WC (OR = 1.01, 95% CI: 1.01–1.02), WHtR (OR = 1.21, 95% CI = 1.09–1.33), and WWI (OR = 1.10, 95% CI: 1.02–1.19) were significantly associated with BADL impairment. Only WWI (OR = 1.16, 95% CI: 1.09–1.23) was associated with IADL impairment. WC, WHtR and WWI were linearly associated with BADL impairment while WWI was linearly associated with IADL impairment. The risk association between WWI and BADL was stronger in drinking individuals and males. In the participants with a BMI less than 24 kg/m² and who had received a high school education or above, the increase in WWI was accompanied by a more significant risk of IADL impairment. The predictive ability of WWI is higher than that of WC and WHtR, with AUC values of 0.597 and 0.615. WWI, as a comprehensive indicator of central obesity, may be useful in comprehensively identifying the risk of early daily living activity impairment among middle-aged and elderly population.

Keywords The activities of daily living, Waist circumference, Waist-to-height ratio, Weight-adjusted waist index, Central obesity

Abbreviations

ADL	Activities of daily living
AUC	Area under the curve
BADL	Basic activities of daily living
BMI	Body mass index
CHARLS	China Health and Retirement Longitudinal Study
95%CI	95% Confidence interval
CVD	Cardiovascular disease
DM	Diabetes mellitus
IADL	Instrumental activities of daily living
OR	Odds ratio
RCS	Restricted cubic spline
ROC	Receiver operating characteristic
WC	Waist circumference
WHtR	Waist-to-height ratio

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WWI Weight-adjusted waist index

The increasing aging of the global population has emerged as an irrefutable trend, bringing ongoing difficulties to public health systems globally. The issue of China's aging population has gained greater visibility in light of its tremendous economic growth. The projected increase in the percentage of adults aged 60 and beyond in China will double from 15% in 2015 to 30% by 2050¹. In middle-aged and elderly individuals, the process of aging is frequently accompanied by reduction in physical abilities and the emergence of health problems, including diminished muscular strength, reduced joint flexibility, cognitive alterations, and metabolic diseases. These disorders can impede people's capacity to carry out activities of daily living (ADL), which are frequently employed to evaluate functional limitations². ADL assessments include evaluations of both basic activities of daily living (BADL) and instrumental activities of daily living (IADL). BADL denotes the ability to perform basic self-care activities, including feeding, hygiene, and mobility, without external assistance. IADL encompass increasingly intricate tasks essential for self-sufficient functioning within the community, including shopping, housework, and medication administration³. Impairments in BADL or IADL are often considered critical indicators of functional disability in the elderly, leading to a decrease in quality of life and an increase in healthcare costs⁴. Previous studies have highlighted the potential impact of ADL on health and quality of life, linking high ADL risk to diseases such as depressive symptoms⁵, sleep disorders⁶, and hypertension⁷. The identification of high-risk populations and the development of potential intervention strategies can be facilitated by the investigation of factors that are associated with an increased risk of functional impairment.

Obesity has become a significant risk factor leading to chronic diseases and a reduced quality of living. Excessive body weight increases physical burden, making daily activities slow and strenuous⁸. Central obesity particularly leads to various chronic diseases, including metabolic disorders and hypertension, further limiting physical capacity and endurance in daily activities, resulting in functional impairments⁹. In recent years, waist circumference (WC) has been proposed as a more reliable indicator of obesity-related disease risk¹⁰, as WC measurement more accurately reflects abdominal fat distribution and visceral obesity, with less influence from overall muscle mass¹¹. However, WC fails to include variations in height, which might potentially lead to biased risk assessment among individuals of various heights¹². In order to address this issue, some researchers have introduced the waist-to-height ratio (WHtR) and demonstrated its superior performance over WC in predicting cardiovascular disease (CVD) and diabetes mellitus (DM)¹². The weight-adjusted waist index (WWI) is a newly introduced anthropometric measure, obtained by standardizing WC by weight. WWI reflects both fat and muscle mass composition, with higher WWI scores indicating higher levels of obesity¹³. WWI has been shown to effectively predict the risk of cardiometabolic diseases and mortality¹³. Recent studies have also found significant associations between WWI and type 2 DM¹⁴, cognitive impairment¹⁵, frailty¹⁶, and hypertension¹⁷.

However, there has been no prospective study conducted to evaluate the associations between central obesity indicators (WC, WHtR, and WWI) and BADL or IADL impairment in middle-aged and elderly populations (aged ≥ 45 years). Therefore, this study focuses on middle-aged and elderly populations, utilizing data from the China Health and Retirement Longitudinal Study (CHARLS) to comprehensively evaluate the stable associations of WC, WHtR, and WWI with BADL or IADL, thereby providing evidence to support central obesity management strategies for preventing ADL impairment.

Methods

Study population

CHARLS is a nationwide survey sponsored by the National School of Development at Peking University and conducted by the Peking University Institute of Social Science Survey. This study aims to collect comprehensive data on Chinese adults aged 45 and older, covering a wide range of aspects such as health status, healthcare utilization, personal experience, economic conditions, and family structure. The survey was conducted in 2011, 2013, 2015, 2018, and 2020 across 28 provinces (autonomous regions and municipalities), 150 counties, and 450 communities (villages). All participants provided informed consent prior to inclusion in the study. This research was approved by the Biomedical Ethics Review Committee of Peking University (IRB00001052-11015)¹⁸. In this study, the analyzed data were obtained from the 2011 to 2020 CHARLS data set. Participants were excluded if they met the following criteria: (1) age below 45; (2) missing BADL or IADL data; (3) missing data on weight, WC, or height; (4) missing demographic data; (5) participants with WC extreme values ($WC < 40$ cm or $WC > 150$ cm)¹⁹. The prospective study used baseline data from 2011 and follow-up data from 2013, 2015, 2018, and 2020, including 6440 and 9646 participants, respectively.

BADL/IADL impairment assessment

In this study, physical function was assessed using the ADL scale, which includes both BADL and IADL components. Each item on the scale has four response options: "no difficulty," "some difficulty but can still perform," "difficulty and needs help," and "unable to perform"²⁰. The ADL scale has been extensively utilized in both domestic and international research and has consistently shown strong reliability and validity in evaluating functional impairment. BADL comprises six aspects of personal care, including dressing, bathing, eating, getting out of bed, toileting, and incontinence. IADL consists of six tasks: housekeeping, cooking, shopping, medication management, using the telephone, and managing finances. Based on previous research findings, a dichotomous approach was adopted for the analysis: inability to independently perform any BADL or IADL task was defined as BADL or IADL impairment²¹.

Measurement of WC, WHtR and WWI

Following the acquisition of informed consent, proficient experts carried out meticulous assessments for each participant, encompassing measures of height (in meters), weight (in kilograms), and waist circumference (in

Variable	BADL			IADL		
	No (n = 4944)	Yes (n = 1496)	P	No (n = 5677)	Yes (n = 3969)	P
Age (year)	58.11 ± 8.30	64.75 ± 10.09	< 0.0001	55.62 ± 7.47	62.14 ± 9.50	< 0.0001
Sex			0.02			< 0.0001
Female	3008(60.84)	961(64.24)		2681(47.23)	2396(60.37)	
Male	1936(39.16)	535(35.76)		2996(52.77)	1573(39.63)	
Marital status			< 0.0001			< 0.0001
Married	4491(90.84)	1213(81.08)		5343(94.12)	3394(85.51)	
Non married	453(9.16)	283(18.92)		334(5.88)	575(14.49)	
Education			< 0.0001			< 0.0001
Illiterate	2475(50.06)	933(62.37)		1817(32.01)	2468(62.18)	
Primary school or middle school	2076(41.99)	493(32.95)		2982(52.53)	1327(33.43)	
High school or above	393(7.95)	70(4.68)		878(15.47)	174(4.38)	
Residence place			0.25			< 0.0001
Rural	3374(68.24)	1045(69.85)		3448(60.74)	2834(71.40)	
Urban	1570(31.76)	451(30.15)		2229(39.26)	1135(28.60)	
Smoke			0.27			< 0.0001
No	3632(73.46)	1121(74.93)		3793(66.81)	2872(72.36)	
Yes	1312(26.54)	375(25.07)		1884(33.19)	1097(27.64)	
Drink			< 0.0001			< 0.0001
No	3520(71.20)	1144(76.47)		3535(62.27)	2867(72.23)	
Yes	1424(28.80)	352(23.53)		2142(37.73)	1102(27.77)	
Hypertension			< 0.0001			< 0.0001
No	3067(62.03)	692(46.26)		3797(66.88)	2157(54.35)	
Yes	1877(37.97)	804(53.74)		1880(33.12)	1812(45.65)	
Dyslipidemia			< 0.01			0.18
No	3348(67.72)	955(63.84)		3907(68.82)	2680(67.52)	
Yes	1596(32.28)	541(36.16)		1770(31.18)	1289(32.48)	
DM			< 0.0001			< 0.0001
No	4375(88.49)	1247(83.36)		5083(89.54)	3447(86.85)	
Yes	569(11.51)	249(16.64)		594(10.46)	522(13.15)	
WC (cm)	85.39 ± 10.16	86.71 ± 10.98	< 0.0001	85.29 ± 9.70	85.01 ± 10.37	0.19
Weight (kg)	58.64 ± 11.44	57.35 ± 12.46	< 0.001	60.79 ± 11.13	56.78 ± 11.60	< 0.0001
BMI (kg/m ²)	23.66 ± 3.96	23.68 ± 4.33	0.85	23.77 ± 3.68	23.22 ± 4.09	< 0.0001
WWI (cm/√kg)	11.21 ± 0.88	11.53 ± 0.98	< 0.0001	10.98 ± 0.80	11.35 ± 0.94	< 0.0001
WHtR	0.54 ± 0.07	0.56 ± 0.07	< 0.0001	0.53 ± 0.06	0.55 ± 0.07	< 0.0001

Table 1. Baseline characteristics of participants. DM, diabetes mellitus; WC, waist circumference; BMI, body mass index; WWI, Index; WHtR, waist-to-height ratio.

centimeters). Participants' height was measured in an upright position and without wearing shoes, using accurate tools. The weight was measured precisely, with participants taking off their shoes and heavy coats to eliminate any extra weight and ensure accuracy. WC was measured with participants standing and removing heavy clothing. A tape measure was positioned at the level of the umbilicus, and the measurement was recorded at the conclusion of exhalation to ensure accuracy. In order to conduct a more thorough analysis of the correlation between central obesity and ADL impairment, some crucial indicators were computed. WHtR was calculated by dividing WC by height, incorporating body shape into the assessment of central obesity. Finally, the WWI was derived by dividing WC by the square root of weight, reflecting excessive body fat buildup and the loss of muscular mass.

Covariates

Self-reported questionnaires were used to gather covariate data, which included sociodemographic factors such as age, sex, educational level, marital status, residence, smoking, and drinking. Specifically, educational level was divided into three categories: primary school or below, middle/high school, and college or above. Marital status was classified as married or unmarried. Residence was categorized as urban or rural. Smoking status was classified as no or yes based on current smoking status, while drinking was divided into no or yes based on current alcohol status. Age was categorized into two groups, 45–64 years and 65 years or older in the subgroup analysis and BMI was divided into two groups based on whether it is greater than or equal to 24 kg/m².

Character	Crude model		Model 1		Model 2		Model 3	
	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P
WC	1.01(1.01,1.02)	<0.0001	1.01(1.01,1.02)	<0.0001	1.02(1.01,1.02)	<0.0001	1.01(1.01,1.02)	<0.001
Quartile 1	Reference		Reference		Reference		Reference	
Quartile 2	1.05(0.89,1.24)	0.55	1.11(0.93,1.33)	0.24	1.13(0.94,1.34)	0.19	1.08(0.91,1.30)	0.38
Quartile 3	1.1(0.93,1.30)	0.27	1.15(0.96,1.37)	0.13	1.19(1.00,1.43)	0.05	1.11(0.92,1.33)	0.28
Quartile 4	1.39(1.18,1.64)	<0.0001	1.49(1.25,1.77)	<0.0001	1.58(1.32,1.88)	<0.0001	1.36(1.13,1.64)	0.001
P for trend		<0.0001		<0.0001		<0.0001		0.002
WC SD	1.14(1.07,1.20)	<0.0001	1.16(1.09,1.23)	<0.0001	1.19(1.12,1.26)	<0.0001	1.13(1.06,1.20)	<0.001
WC IQR	1.2(1.10,1.30)	<0.0001	1.23(1.13,1.35)	<0.0001	1.28(1.17,1.40)	<0.0001	1.19(1.08,1.30)	<0.001
WHtR	1.38(1.27,1.50)	<0.0001	1.27(1.16,1.39)	<0.0001	1.3(1.19,1.43)	<0.0001	1.21(1.09,1.33)	<0.001
Quartile 1	Reference		Reference		Reference		Reference	
Quartile 2	1.14(0.96,1.35)	0.14	1.15(0.96,1.38)	0.12	1.18(0.98,1.41)	0.08	1.12(0.93,1.35)	0.22
Quartile 3	1.3(1.10,1.54)	0.003	1.28(1.07,1.54)	0.01	1.33(1.11,1.60)	0.002	1.21(1.00,1.46)	0.05
Quartile 4	1.64(1.39,1.93)	<0.0001	1.44(1.20,1.73)	<0.0001	1.51(1.26,1.82)	<0.0001	1.3(1.07,1.58)	0.01
P for trend		<0.0001		<0.0001		<0.0001		0.01
WHtR SD	1.25(1.18,1.32)	<0.0001	1.18(1.10,1.25)	<0.0001	1.2(1.12,1.28)	<0.0001	1.14(1.06,1.22)	<0.001
WHtR IQR	1.36(1.26,1.47)	<0.0001	1.25(1.15,1.37)	<0.0001	1.29(1.18,1.41)	<0.0001	1.2(1.09,1.32)	<0.001
WWI	1.47(1.38,1.57)	<0.0001	1.14(1.06,1.22)	<0.001	1.14(1.06,1.23)	<0.001	1.1(1.02,1.19)	0.01
Quartile 1	Reference		Reference		Reference		Reference	
Quartile 2	1.23(1.03,1.47)	0.03	1.12(0.93,1.35)	0.23	1.14(0.95,1.38)	0.17	1.08(0.89,1.30)	0.45
Quartile 3	1.58(1.32,1.87)	<0.0001	1.26(1.04,1.51)	0.02	1.28(1.06,1.55)	0.01	1.18(0.98,1.43)	0.08
Quartile 4	2.36(2.00,2.79)	<0.0001	1.36(1.12,1.65)	0.002	1.39(1.14,1.68)	0.001	1.26(1.03,1.53)	0.02
P for trend		<0.0001		0.001		<0.001		0.02
WWI SD	1.42(1.34,1.51)	<0.0001	1.12(1.05,1.20)	<0.001	1.13(1.06,1.21)	<0.001	1.1(1.02,1.17)	0.01
WWI IQR	1.53(1.43,1.65)	<0.0001	1.15(1.06,1.25)	<0.001	1.16(1.07,1.26)	<0.001	1.12(1.03,1.21)	0.01

Table 2. Binary logistic regression analysis of the relationship between WC, WHtR, WWI and BADL impairment. WC, waist circumference; WHtR, waist-to-height ratio; WWI, weight-adjusted waist Index. SD, standard deviation; IQR, interquartile range; OR, odds ratio; 95%CI, 95% confidence interval. Model 1: age, sex were adjusted; Model 2: age, sex, smoking, drinking, residence place, marital status, education were adjusted; Model 3: age, sex, smoke, drink, residence place, marital status, education, hypertension, dyslipidemia, DM were adjusted.

Health status assessment

Hypertension diagnosis was based on physician diagnosis. The diagnostic criteria for DM included any of the following: fasting blood glucose ≥ 7 mmol/L, random blood glucose ≥ 11.1 mmol/L, glycated hemoglobin $\geq 6\%$, or physician-confirmed diagnosis²². Dyslipidemia was diagnosed based on any of the following criteria: total cholesterol ≥ 6.2 mmol/L, low-density lipoprotein cholesterol ≥ 4.1 mmol/L, triglycerides ≥ 2.3 mmol/L, high-density lipoprotein cholesterol < 1 mmol/L, or physician-confirmed diagnosis²³.

Statistical strategy

Participants were divided into two groups based on the presence or absence of BADL or IADL impairment respectively. Mean \pm standard deviation was used to represent continuous variables, whereas percentages were used to express categorical variables. Between-group differences were assessed using T-tests for continuous variables and Chi-square tests for categorical variables. In order to examine the relationships between WC, WHtR, WWI and BADL/IADL impairment, multivariable logistic regression models were used to calculate odds ratio (OR) and 95% confidence interval (95%CI). To control for potential covariates, models were adjusted sequentially: Model 1 adjusted for age, sex, and BMI; Model 2 further adjusted for smoking, drinking, residence, marital status, and educational level; Model 3 additionally adjusted for hypertension, dyslipidemia, and DM. Subsequently, the results of the models before and after adjustment were visualized. Restricted cubic spline (RCS) was performed to find the trend of change, and subgroup analyses were conducted based on sex, marital status, residence, smoking, drinking, hypertension, dyslipidemia, DM, BMI, and age using logistic regression. Bonferroni correction was performed in subgroup analysis with significant interaction effects. Finally, receiver operating characteristic (ROC) curves were plotted to evaluate the diagnostic value of each indicator. In the continuous models, RCS, and subgroup analysis, WHtR was multiplied by a factor of 10 to facilitate the interpretation of OR. Statistical significance was set at $P < 0.05$, and all statistical analyses were conducted using R version 4.4.1.

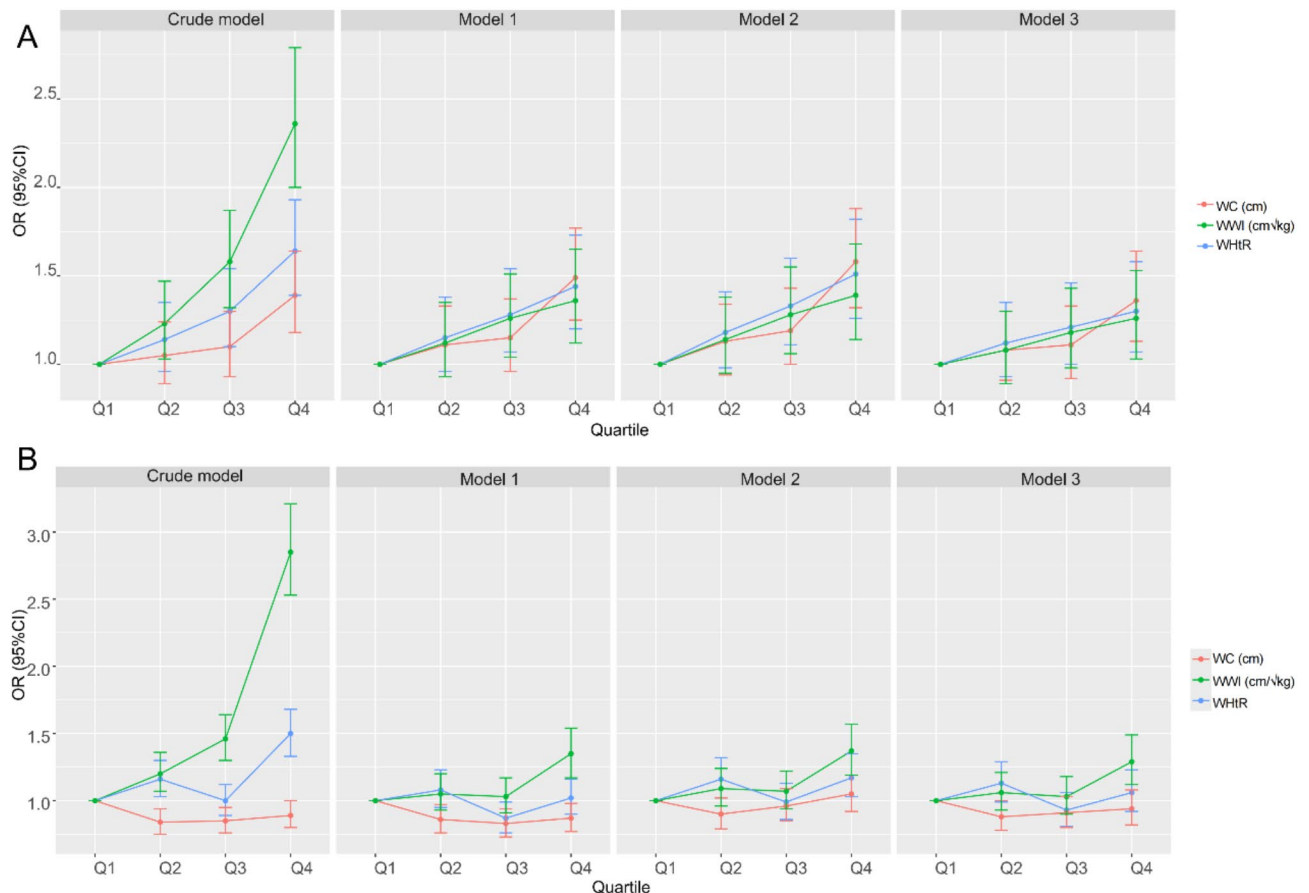


Fig. 1. Logistic regression trend plot of the relationship between WC, WHtR, WWI and ADL impairment. A, Binary logistic regression trend plot of the relationship between WC, WHtR, WWI and BADL impairment. B, Binary logistic regression trend plot of the relationship between WC, WHtR, WWI and IADL impairment. OR, odds ratio; 95%CI, 95% confidence interval; Q1, quartile 1; Q2, quartile 2; Q3, quartile 3; Q4, quartile 4.

Result

Baseline characteristics

Table 1 presents the distribution of participants in the prospective study and the baseline comparison. The results indicated that 1,496 participants experienced BADL impairment during the follow-up period. Compared to participants without BADL impairment, those with BADL impairment were generally older, female, unmarried, had lower educational attainment, were more likely to have hypertension, dyslipidemia, DM and had higher WC, WHtR, and WWI. Additionally, 3,969 participants experienced IADL impairment. Compared to those without IADL impairment, participants with IADL impairment were generally older, female, unmarried, had lower educational attainment, lived in rural areas, did not smoke and drink, and had a higher likelihood of hypertension and DM. Although their weight and BMI were lower, their WHtR and WWI values were higher compared to those without IADL impairment.

Association of WC, WHtR, WWI with ADL impairment in the prospective study

Table 2 shows the associations between WC, WHtR, WWI and the incidence of BADL impairment in the prospective study, based on logistic regression models. In the unadjusted model, WC (OR=1.01, 95%CI: 1.01–1.02), WHtR (OR=1.38, 95%CI: 1.27–1.50), and WWI (OR=1.47, 95%CI: 1.38–1.57) were significantly associated with a higher risk of BADL impairment. After adjusting for variables, WC (OR=1.01, 95%CI: 1.01–1.02), WHtR (OR=1.21, 95%CI: 1.09–1.33), and WWI (OR=1.10, 95%CI: 1.02–1.19) remained significantly associated with BADL impairment risk. Additionally, when converting continuous variables into categorical variables, participants in the highest quartiles of WC (OR=1.36, 95%CI: 1.13–1.64), WHtR (OR=1.30, 95%CI: 1.07–1.58), and WWI (OR=1.26, 95%CI: 1.03–1.53) exhibited a higher risk of BADL impairment compared to those in the lowest quartiles (Fig. 1A). Analyses based on standard deviations and interquartile ranges further confirmed a significant positive association between WC, WHtR, WWI and BADL impairment.

Table 3 presents the relationships between WC, WHtR, WWI and IADL impairment in the prospective study. According to the unadjusted model, WHtR (OR=1.29, 95%CI: 1.21–1.37) and WWI (OR=1.65, 95%CI: 1.57–1.74) were significantly associated with a higher risk of IADL impairment, while WC was not. After adjusting for covariates, only WWI (OR=1.16, 95%CI: 1.09–1.23) remained associated with IADL impairment. Further

Character	Crude model		Model 1		Model 2		Model 3	
	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P	OR (95%CI)	P
WC	1(0.99,1.00)	0.18	1(0.99,1.00)	0.15	1(1.00,1.01)	0.08	1(1.00,1.01)	0.91
Quartile 1	Reference		Reference		Reference		Reference	
Quartile 2	0.84(0.75,0.94)	0.003	0.86(0.76,0.97)	0.02	0.9(0.79,1.02)	0.11	0.88(0.78,1.00)	0.06
Quartile 3	0.85(0.76,0.95)	0.004	0.83(0.73,0.94)	0.003	0.96(0.85,1.09)	0.54	0.91(0.80,1.03)	0.14
Quartile 4	0.89(0.80,1.00)	0.05	0.87(0.77,0.98)	0.03	1.05(0.92,1.19)	0.50	0.94(0.82,1.08)	0.39
P for trend		0.06		0.02		0.39		0.44
WC SD	0.97(0.93,1.01)	0.18	0.97(0.93,1.01)	0.15	1.04(0.99,1.09)	0.08	1(0.95,1.05)	0.91
WC IQR	0.96(0.91,1.02)	0.18	0.96(0.90,1.02)	0.15	1.06(0.99,1.13)	0.08	1(0.94,1.08)	0.91
WHtR	1.29(1.21,1.37)	<0.0001	1.03(0.95,1.10)	0.49	1.11(1.03,1.20)	0.01	1.05(0.97,1.14)	0.21
Quartile 1	Reference		Reference		Reference		Reference	
Quartile 2	1.16(1.03,1.30)	0.01	1.08(0.95,1.23)	0.22	1.16(1.02,1.32)	0.02	1.13(0.99,1.29)	0.07
Quartile 3	1(0.89,1.12)	0.95	0.87(0.76,0.99)	0.03	0.99(0.86,1.13)	0.85	0.93(0.81,1.06)	0.29
Quartile 4	1.5(1.33,1.68)	<0.0001	1.02(0.90,1.16)	0.75	1.17(1.03,1.35)	0.02	1.06(0.92,1.23)	0.40
P for trend		<0.0001		0.45		0.14		0.97
WHtR SD	1.18(1.13,1.23)	<0.0001	1.02(0.97,1.07)	0.49	1.07(1.02,1.12)	0.01	1.03(0.98,1.09)	0.21
WHtR IQR	1.26(1.19,1.33)	<0.0001	1.02(0.96,1.09)	0.49	1.1(1.03,1.18)	0.01	1.05(0.98,1.12)	0.21
WWI	1.65(1.57,1.74)	<0.0001	1.17(1.11,1.24)	<0.0001	1.18(1.11,1.25)	<0.0001	1.16(1.09,1.23)	<0.0001
Quartile 1	Reference		Reference		Reference		Reference	
Quartile 2	1.2(1.07,1.36)	0.002	1.05(0.93,1.20)	0.43	1.09(0.96,1.24)	0.20	1.06(0.93,1.21)	0.37
Quartile 3	1.46(1.30,1.64)	<0.0001	1.03(0.91,1.17)	0.63	1.07(0.94,1.22)	0.32	1.03(0.90,1.18)	0.68
Quartile 4	2.85(2.53,3.21)	<0.0001	1.35(1.17,1.54)	<0.0001	1.37(1.19,1.57)	<0.0001	1.29(1.12,1.49)	<0.001
P for trend		<0.0001		<0.001		<0.0001		0.002
WWI SD	1.55(1.49,1.62)	<0.0001	1.15(1.09,1.21)	<0.0001	1.16(1.10,1.22)	<0.0001	1.14(1.08,1.20)	<0.0001
WWI IQR	1.73(1.64,1.83)	<0.0001	1.19(1.12,1.27)	<0.0001	1.2(1.12,1.28)	<0.0001	1.17(1.10,1.25)	<0.0001

Table 3. Binary logistic regression analysis of the relationship between WC, WHtR, WWI and IADL impairment. WC, waist circumference; WHtR, waist-to-height ratio; WWI, weight-adjusted waist Index. SD, standard deviation; IQR, interquartile range; OR, odds ratio; 95%CI, 95% confidence interval. Model 1: age, sex were adjusted; Model 2: age, sex, smoking, drinking, residence place, marital status, education were adjusted; Model 3: age, sex, smoke, drink, residence place, marital status, education, hypertension, dyslipidemia, DM were adjusted.

analysis by quartiles indicated that participants in the highest quartile of WWI (OR = 1.29, 95%CI: 1.12–1.49) had a significantly increased risk of IADL impairment compared to those in the lowest quartile (Fig. 1B). Standard deviation and interquartile range analysis demonstrated that WC and WHtR were not significantly associated with IADL impairment, while WWI maintained a positive correlation with IADL impairment.

RCS analysis in the prospective study

As shown in Fig. 2, the RCS results suggest there was a linear relationship between WC, WHtR, WWI and BADL impairment risk. Similarly, Fig. 3 indicates a linear correlation between WWI and IADL impairment risk.

Subgroup analysis in the prospective study

Figure 4 presents the associations between WC, WHtR, WWI and the risk of BADL impairment across different subgroups, including sex, age, BMI, drinking, smoking, marital status, residence, DM, hypertension, and dyslipidemia. Most subgroups did not significantly affect these associations after adjusting for covariates. However, WWI showed a stronger association with the risk of BADL impairment among individuals who consumed alcohol and males.

Figure 5 displays the associations between WWI and the risk of IADL impairment in various subgroups after adjusting for covariates. The results showed that among the participants with a BMI less than 24 kg/m² and who had received a high school education or above, the increase in WWI was accompanied by a more significant risk of IADL impairment.

ROC curve of WC, WHtR and WWI on ADL impairment

ROC curve analysis is used to evaluate the diagnostic value of WC, WHtR and WWI in predicting ADL impairment. As shown in Fig. 6, the area under the curve (AUC) of the three indicators reflecting central obesity was greater than 0.5, indicating their potential in identifying ADL risk. It is worth noting that the predictive ability of WWI is higher than WC and WHtR, with AUC values of 0.597 and 0.615, respectively in BADL and IADL impairment.

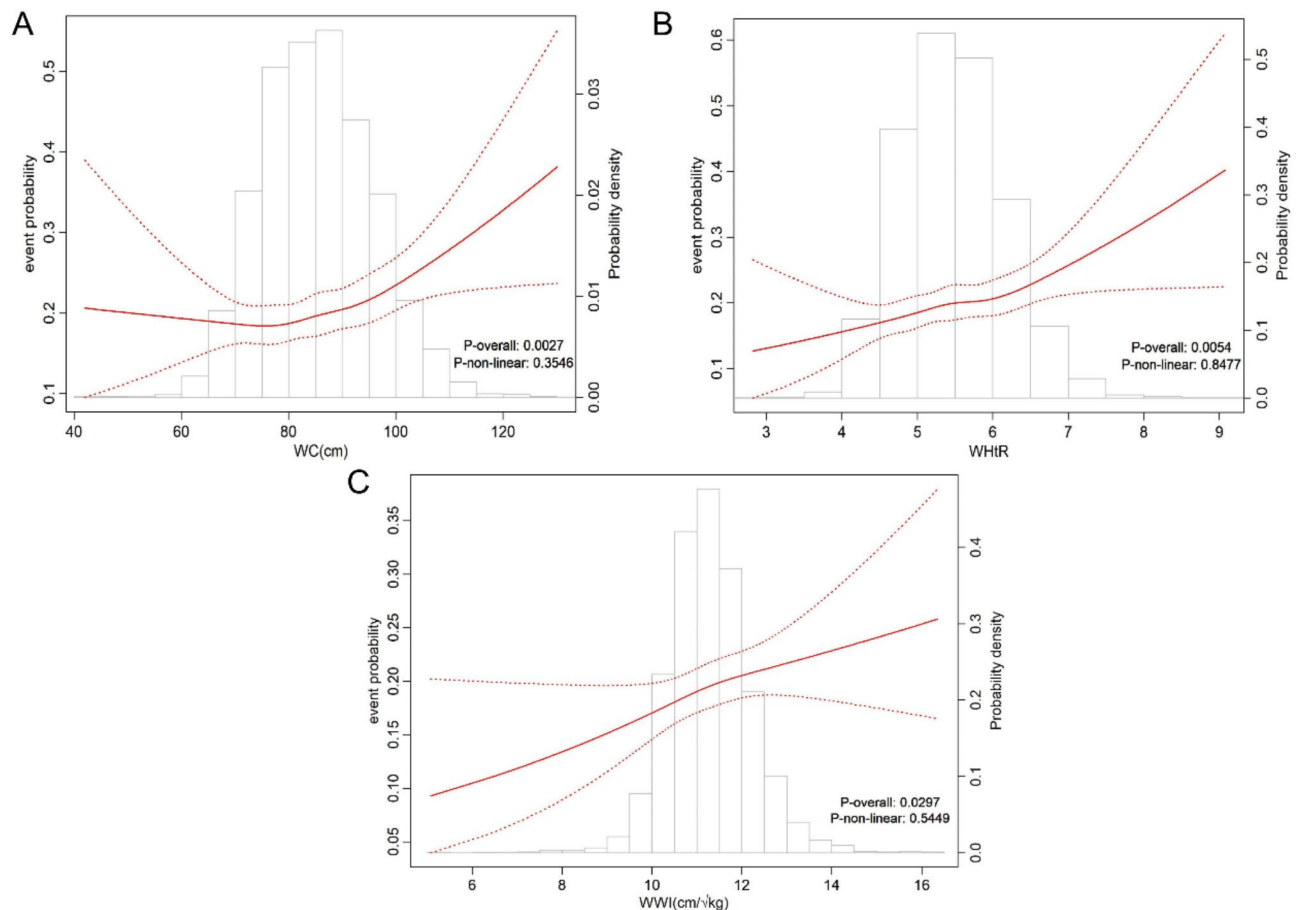


Fig. 2. RCS curves for WC, WHtR and WWI associated with BADL impairment after adjusting age, sex, smoking, drinking, residence place, marital status, education, hypertension, dyslipidemia, DM. A, RCS curve of WC related to BADL impairment; B, RCS curve of WHtR related to BADL impairment; C, RCS curve of WWI related to BADL impairment.

Discussion

This study investigated the relationship between central obesity indicators (WC, WHtR and WWI) and BADL and IADL impairment in a middle-aged and elderly Chinese population. The results showed that higher levels of WC, WHtR and WWI significantly increased the risk of BADL impairment and the increase of WWI effectively reflected the increased risk of IADL impairment. These findings emphasize that central obesity, particularly as measured by WWI, may significantly affect functional health in middle-aged and older populations. This implies that greater emphasis should be placed on the use of WWI in health screening and risk assessment.

IADL and BADL are recognized as having a hierarchical longitudinal relationship²⁴. IADL reflects initial stages of impairment, encompassing cognitive and social skills, while BADL represents an individual's ability to perform basic daily activities, showing a more pronounced level of physical disability²⁵. The risk of ADL impairment increases with age among obese individuals⁸. However, the relationship between obesity and the risk of physical impairment is not a simple linear one, and the risk of obesity leading to physical impairment remains controversial²⁶. Some studies suggest that BMI may be a protective factor against ADL impairment²⁷, while BMI is not a reliable measure of the ratio of fat to muscle, resulting in conflicting findings²⁸. Thus, depending merely on BMI may be inadequate for evaluating the dangers linked to early central obesity and may fail to identify a segment of the potentially high-risk population²⁹. Although the overall obesity indicators among the elderly population in China are relatively stable, the risks associated with central obesity are increasing³⁰. Patterns of central obesity trajectories are closely related to changes in CVD risk, even among individuals who are not overweight, and this association is more pronounced in younger individuals³¹. Central obesity is believed to be associated with risks of dyslipidemia, insulin resistance, and metabolic abnormalities³². WC is commonly used to assess the degree of abdominal fat accumulation and central obesity, and the association between WC and ADL impairment has been confirmed among the elderly population in China³³. WHtR is the ratio of WC to height, which not only considers the absolute value of waist circumference but also accounts for the influence of height, thereby reducing the biases in obesity assessment due to body shape. Research has demonstrated that WHtR is particularly reliable in reflecting the degree of visceral fat³⁴, and higher WHtR is closely related to the risks of dyslipidemia, insulin resistance, and cardiovascular diseases³⁵. A survey of 1,453 adults in the UK National Diet and Nutrition Survey (2008–2012) showed that compared to a complex combination of BMI and

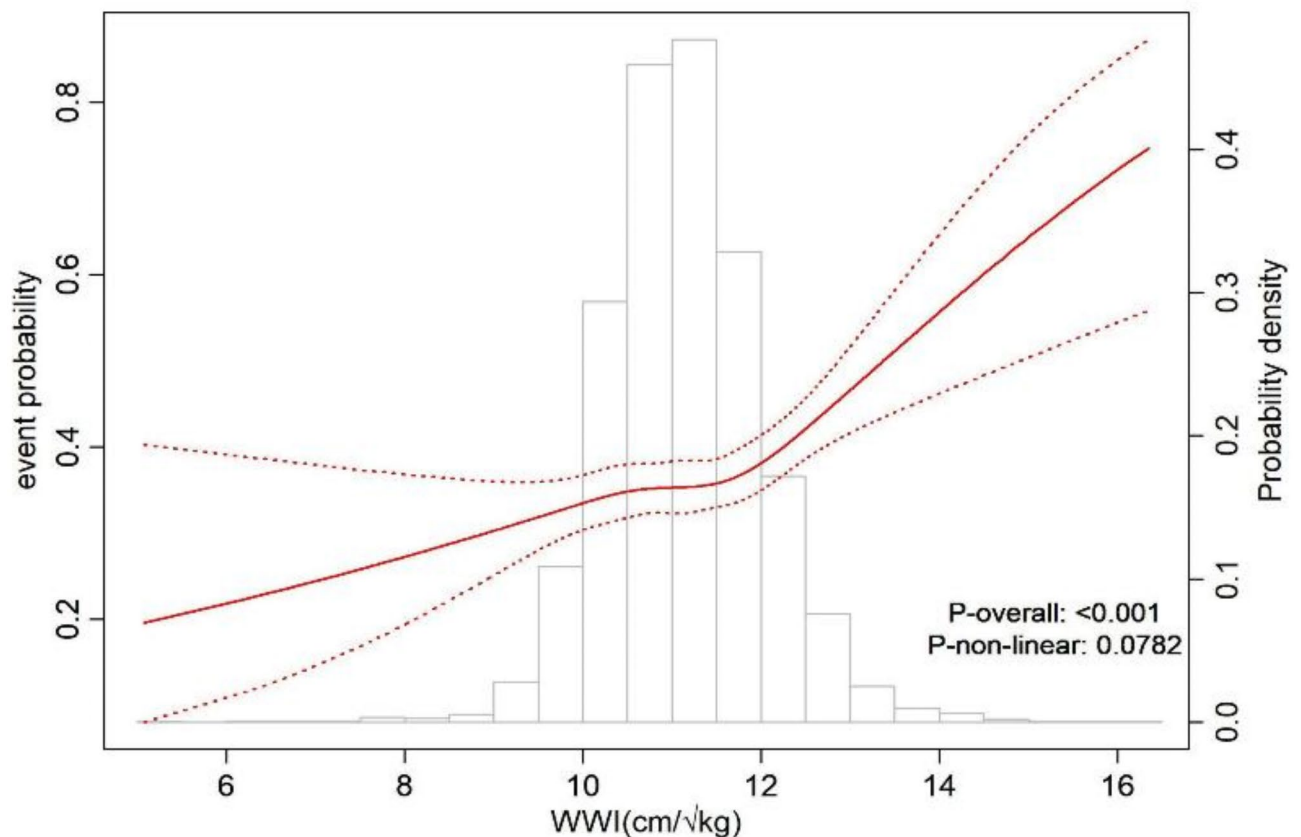


Fig. 3. RCS curves for WWI associated with IADL impairment after adjusting age, sex, smoking, drinking, residence place, marital status, education, hypertension, dyslipidemia, DM.

WC boundary values, a WHtR greater than 1/2 can identify more individuals at early health risk, while a WHtR greater than 0.6 is considered to be at high risk of obesity-related health issues³⁵. WHtR can serve as a simpler and more predictive indicator of early cardiovascular health risks related to central obesity²⁹.

IADL involves more complex cognitive and daily tasks, while BADL focuses on basic self-care abilities. The prospective study shows that WC and WHtR are only significantly associated with the risk of BADL impairment and not with IADL. This could be attributed to the fact that higher WC and WHtR may limit the range of motion and flexibility, making movements like bending and turning difficult, thereby affecting BADL activities such as dressing and personal hygiene. Additionally, excessive abdominal fat may increase the body's burden and exert continuous pressure on the musculoskeletal system, affecting basic mobility. Furthermore, the abdominal obesity and metabolic abnormalities represented by WC and WHtR have cumulative effects on physical function, especially since metabolic diseases have long-term negative impacts on BADL. In contrast, IADL impairment involves complex cognitive and interpersonal abilities, which are more likely to be influenced by factors such as cognitive reserve, social support, education level, or other non-metabolic factors. These complex factors may partially buffer the long-term impact of fat distribution on IADL, thus underestimating the influence of WC and WHtR on IADL³⁶.

WWI is an indicator that integrates weight and WC information, and higher WWI may indicate a higher body fat percentage. WWI enhances the association with WC while weakening the association with weight, thus more comprehensively reflecting fat distribution and muscle mass³⁷. As a novel indicator explaining central obesity, WWI is more reliable than WC and WHtR in predicting CVD and all-cause mortality in diabetic patients³⁸. Changes in fat and muscle mass are closely related to the decline in physical function, with fat content being positively correlated with impairment³⁹. The decrease in muscle mass is often accompanied by an increase in body fat, especially among middle-aged and elderly population, and the combined changes of these two may more directly reflect the risk of functional impairment⁴⁰. Research has demonstrated that dynapenic abdominal obesity is associated with an increased likelihood of ADL impairment in the elderly⁴¹. Moreover, through a stacked ensemble model, waist circumference has been determined to be a highly significant predictor of ADL impairment⁴². A cross-sectional study from the Chinese Longitudinal Healthy Longevity Survey showed that among the elderly population (aged over 65 years), BMI was not associated with ADL impairment, while WWI was positively correlated with fat content and negatively correlated with weight, indicating that it is an excellent indicator reflecting the risk of obesity-related ADL impairment⁴⁰.

Compared to WHtR and WC, WWI is not only an indicator of weight management but is also related to overall metabolic status, muscle mass, and long-term changes in cognitive function¹⁵. Long-term obesity

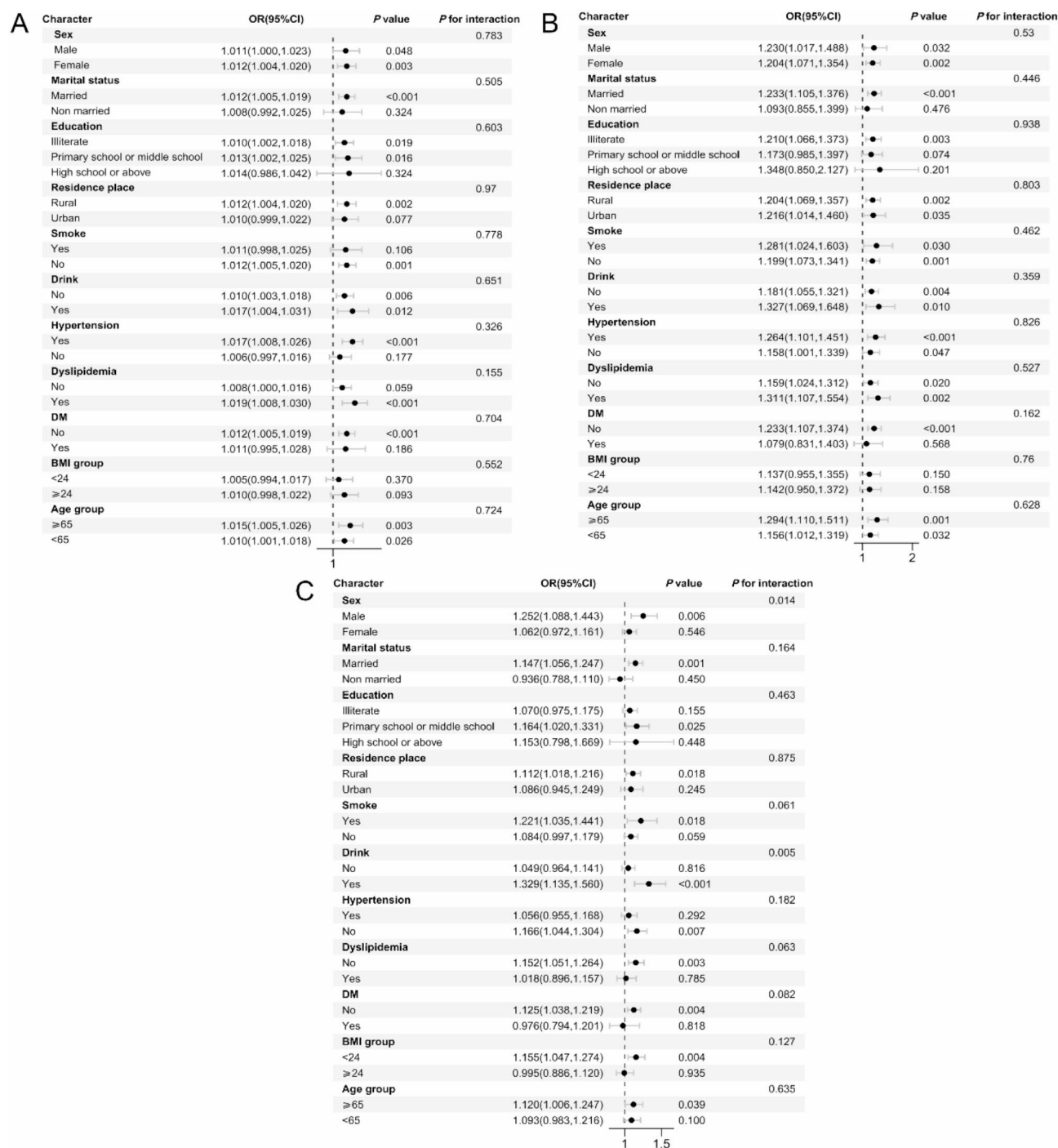


Fig. 4. Forest plot of the relationship between WC, WHtR, WWI and BADL impairment in different subgroups after adjusting age, sex, smoking, drinking, residence place, marital status, education, hypertension, dyslipidemia, DM. A, Forest plot of the relationship between WC and BADL impairment in different subgroups; B, Forest plot of the relationship between WHtR and BADL impairment in different subgroups; C, Forest plot of the relationship between WWI and BADL impairment in different subgroups. OR, odds ratio; 95%CI, 95% confidence interval.

can affect not only physical activity but also brain function over time through mechanisms such as chronic inflammation, metabolic disorders, and impaired blood flow, gradually leading to cognitive decline and thus a decrease in IADL⁴³. In the prospective studies, WWI shows a significant linear correlation with dysfunction in both BADL and IADL. This indicates that WWI, as a comprehensive indicator, has the potential to capture early signals of both basic instrumental activities impairments, making it advantageous in reflecting overall health status and predicting ADL functional decline at an earlier stage.

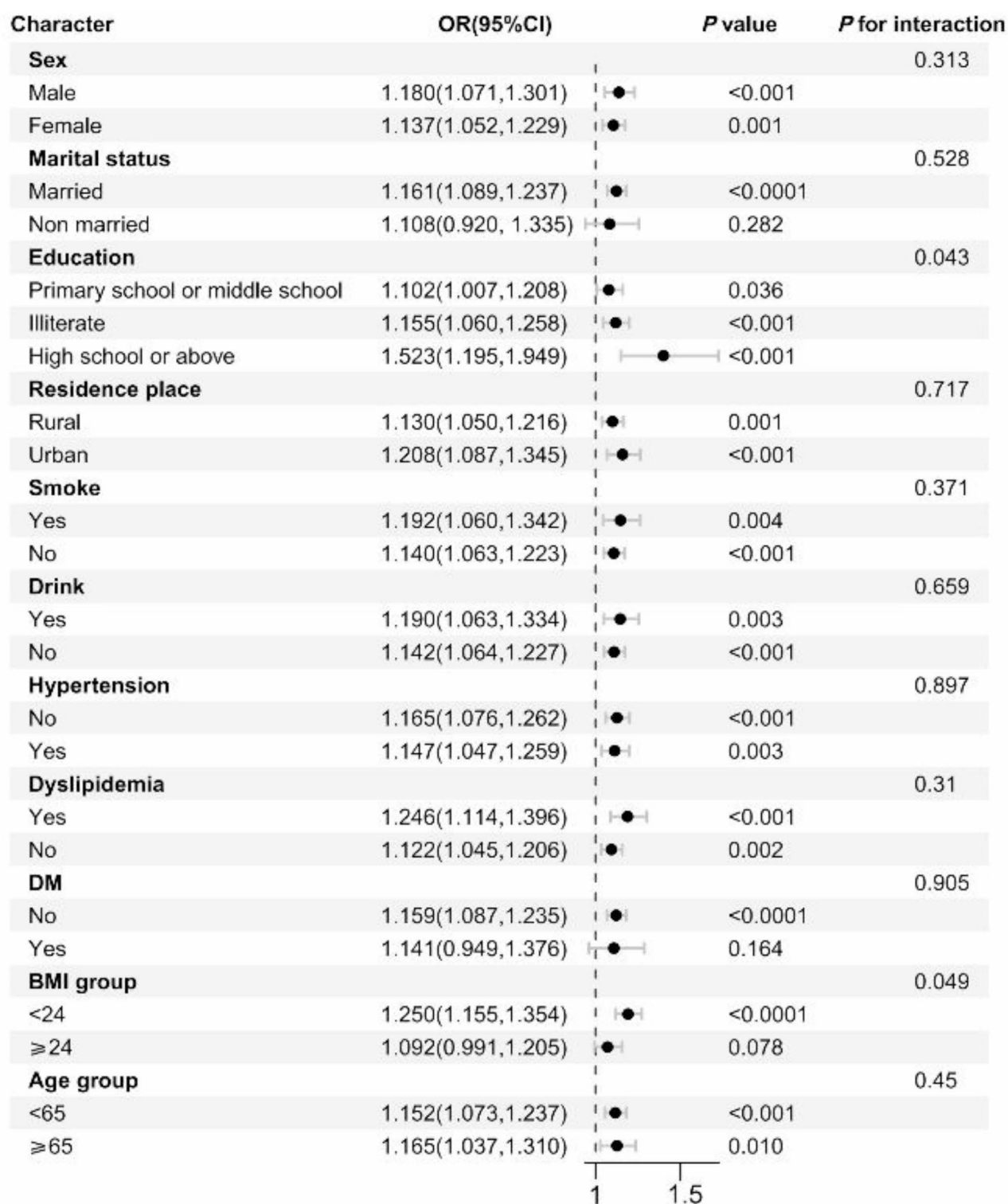


Fig. 5. Forest plot of the relationship between WWI and IADL impairment in different subgroups after adjusting age, sex, smoking, drinking, residence place, marital status, education, hypertension, dyslipidemia, DM. OR, odds ratio; 95%CI, 95% confidence interval.

The data in this study were measured by trained professionals, reducing the bias brought by self-reporting. Additionally, this study provides a relatively comprehensive analysis of the relationship between central obesity indicators (WC, WWI, and WHtR) and BADL and IADL, with a particular focus on the association between central obesity and ADL impairment in the middle-aged population. Compared to WC and WHtR, WWI not

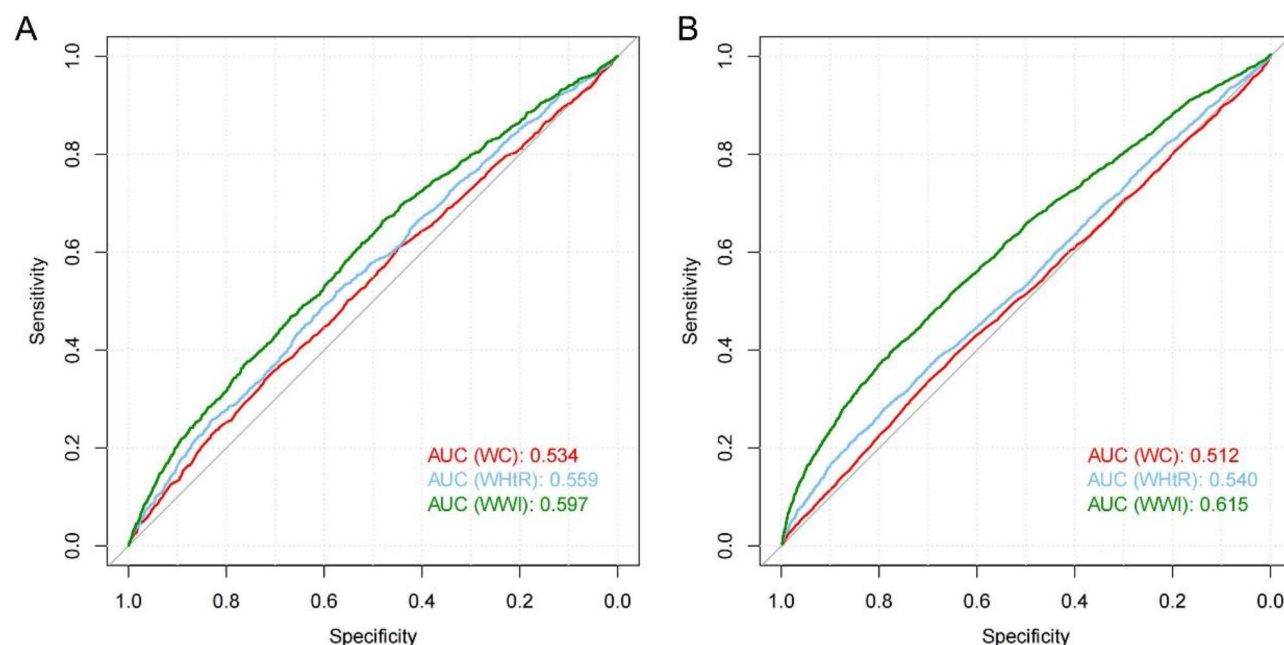


Fig. 6. ROC curve of WC, WHtR and WWI on ADL impairment. A, ROC curve of WC, WHtR and WWI on BADL impairment; B, ROC curve of WC, WHtR and WWI on IADL impairment.

only helps identify the risk of functional decline in middle-aged and elderly population but can also be used in daily health screening and risk assessment, indicating its potential application value in clinical evaluation.

Limitation

However, this study has some limitations. The study sample failed to capture the dynamic changes of the indicators, and there is a lack of control of confounding factors that may affect the results, such as physical activity, diet, mental state, and medication use. This may affect the accuracy of the analysis results.

Although the ROC analysis demonstrated that WWI has predictive ability for ADL impairment, this predictive power is relatively insufficient. This observation aligns with previous epidemiological studies⁴⁰. Notably, our findings establish WWI as a clinically accessible predictor that may serve as foundational element for composite risk models. Future research can further explore machine learning algorithms (such as random forest and gradient boosting tree) or hierarchical modeling strategies, and improve the prediction accuracy by optimizing feature selection and combination, such as incorporating age, lifestyle, physical activity, diet, psychological state and metabolic indicators. Through multidimensional analysis, we can better understand the mechanisms by which central obesity contributes to functional health decline and provide more precise and early health management strategies for middle-aged and elderly population.

Despite certain limitations in the findings of this study, it can still offer valuable references for policy - making and public health interventions. In the field of public health management, the potential role of indicators such as WC, WHtR, and WWI in assessing the activities of daily living ability of the population should be emphasized. It is recommended to incorporate these indicators into the routine health monitoring system. Moreover, efforts should be made to actively promote the implementation of weight management programs suitable for different groups at the grassroots level, so as to prevent and reduce the incidence of ADL impairments.

Conclusion

WC, WHtR, WWI are all associated with BADL impairment while only WWI is significantly associated with IADL impairment among middle-aged and elderly population in China. WWI, as a comprehensive indicators of central obesity, may be useful in comprehensively identifying the risk of early ADL impairment among middle-aged and elderly population.

Data availability

The data that support the findings of this study are available from China Health and Retirement Longitudinal Study (<http://charls.pku.edu.cn/>).

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Author contributions

YD and WZ conceived and designed the study. YD, XZ conducted data organization and analysis. YD, XZ analyzed the data and wrote the manuscript. YW and WZ polished the English. YH and YW revised the manuscript and contributed to the conception and design of this article. All authors reviewed the manuscript. All authors listed approved it for publication.

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Declarations

Ethics approval and consent to participate

This study adhered to the principles outlined in the Declaration of Helsinki. This research was approved by the Biomedical Ethics Review Committee of Peking University (IRB00001052-11015). All participants were informed for the protocol of study and signed informed consent form.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

Conflict of interest

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

Additional information

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