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Body mass index, waist circumference, hip circumference, abdominal volume index, and cognitive function in older Chinese people: a nationwide study

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Abstract

Background Numerous studies have indicated an obesity paradox in observational research on aging health, where being normal weight or underweight adversely affects cognitive function, while moderate obesity may offer protective benefits. This study aims to investigate the association between body mass index (BMI), waist circumference (WC), hip circumference (HC), waist-to-height ratio (WHtR), waist-to-hip ratio (WHR), abdominal volume index (AVI), and the joint effect of BMI and HC on cognitive impairment in older Chinese people.

Methods A total of 10,579 participants aged 65 years and older from the 2018 Chinese Longitudinal Healthy Longevity Survey (CLHLS) were included in this cross-sectional study. BMI, WC, HC, WHtR, WHR, and AVI were calculated from height, weight, WC, and HC measurements, where weight, WC, and HC were obtained by direct measurement. Mini-Mental State Examination was used to assess cognitive impairment. Odds ratios (ORs) and 95% confidence intervals (95% CIs) were estimated using binary logistic regression. Non-linear correlations were investigated using restricted cubic spline curves.

Results In multivariate logistic regression models fully adjusted for confounding variables, our analyses showed significant negative associations of WC [OR 0.93 (95%CI 0.88–0.98), $P=.012$], HC [OR 0.92 (95%CI 0.87–0.97), $P=.004$], lower WHR (Q2) [OR 0.85 (95%CI 0.72-1.00), $P=.044$], and AVI [OR 0.93 (95%CI 0.88–0.98), $P=.011$] with cognitive impairment. Nonlinear curve analysis showed that the risk of cognitive impairment was lowest when the BMI was about 25.5 kg/m^2, suggesting that the optimal BMI for older Chinese people to maintain good cognitive ability may be in the overweight range. In addition, there was a non-linear "N" shaped relationship between HC and cognitive impairment, with HC having the highest risk of cognitive impairment at about 82 cm and the lowest risk at about 101 cm. The joint effects analysis indicated that the lowest risk was observed among those with normal or higher BMI but higher HC compared with participants with normal BMI levels and lower HC levels.

Conclusion In older Chinese people, a low-waisted and high-hip circumference body figure is favorable for cognitive function in older people. It also found a significant association between AVI and cognitive impairment. The joint

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analysis of BMI and HC suggests that maintaining a normal or higher BMI with a higher HC may be more conducive to maintaining good cognitive function.

Keywords Body mass index, Waist circumference, Hip circumference, Abdominal volume index, Cognitive impairment

Introduction

Cognitive decline is a major public health challenge that can lead to mild cognitive impairment or dementia worldwide [1]. Dementia has become one of the leading causes of death among older people globally, not only imposing a heavy burden on families and society in terms of long-term care, but also failing to ensure their quality of life [2]. The World Health Organization (WHO) estimates that 55 million older people worldwide are living with dementia, with China in particular accounting for 15 million, and the number will continue to rise [3]. Maintaining cognitive functioning is a core component of successful aging and is essential to improving the quality of life of older people and reducing social burdens [4].

Globally, obesity has emerged as a key health issue and has spread rapidly in recent decades. Obesity is thought to significantly increase the risk of poor health in older people [5–8], so weight management in older people is in the spotlight. However, different studies have reached inconsistent conclusions. Several studies have shown that obese older people can improve cardiovascular-metabolic function and quality of life through conscious weight loss [9]. In contrast, other studies have found that loss of muscle mass during weight loss negatively impacts cardiovascular health [10]. In addition, weight loss has been linked to cognitive impairment, depression, and other physical and mental problems in older people [11–13]. New research shows that older people who are overweight or mildly obese have the lowest mortality risk [14]. Therefore, guidelines for weight management in older people should be carefully designed and implemented. Body mass index (BMI) and waist circumference (WC) are the most commonly used measures of obesity. There are inevitable major changes in the human body's composition with aging, including a progressive loss of muscle [15]. Therefore, different indicators should be used when assessing obesity in older people based on their unique circumstances. BMI is commonly used to assess general obesity and nutritional status [14]. However, BMI alone does not reflect changes in body fat and muscle mass as we age [16]. WC is used to assess central obesity and reflects the size of abdominal adipose tissue [17]. The Abdominal Volume Index (AVI) is one of the best metrics for assessing the accumulation of abdominal fat, allowing for a better assessment of abdominal fat accumulation and a more accurate assessment of body fat percentage [18]. Hip circumference (HC) as an indicator of lower body fat is often overlooked because of its role as a key component of the original concept of waist-to-hip ratio (WHR) [19, 20]. Many studies have investigated HC independently and found that HC is strongly associated with many adverse health outcomes [19, 21–30].

The effect of obesity on the risk of cognitive impairment or dementia remains controversial [31]. Previous studies have shown that obesity leads to cognitive impairment and dementia in middle age [32, 33]. On the contrary, studies have shown that being overweight and obese may be helpful to older people [33] and that BMI shows a protective effect on cognitive function in older people [32, 34–36], supporting the concept of the "obesity paradox" [37, 38], which suggests that obesity confers a disease benefit or survival advantage over normal weight or underweight [39]. As for HC, it has been reported that narrow hips will increase the risk of diabetes [40], and diabetes is considered to be one of the main causes of cognitive decline in older people [41]. In addition, although the relationship between diabetes and cognitive decline has been widely recognized, there are relatively few studies on HC and cognitive function in the older people, especially the research on the potential impact of HC on cognitive health is still insufficient. In contrast, a large number of studies have focused on the association between BMI and cognitive function, however, there is a lack of research on how the combined effects of BMI and HC affect cognitive function in older people.

Currently, there are fewer studies on the relationship between multiple obesity indicators (BMI, WC, HC, waist-to-height ratio [WHtR], WHR, and AVI) and cognitive impairment by conducting them in older Chinese people. We hypothesized that these obesity indicators may be differentially associated with cognitive impairment in older people. Therefore, this study aimed to assess the potential associations between traditional and novel obesity indicators (BMI, WC, HC, WHtR, WHR, and AVI) and cognitive impairment using data from the Chinese Longitudinal Healthy Longevity Survey (CLHLS), and to further explore the association between BMI and HC joint effects on cognitive impairment.

Methods

Study design and population

CLHLS is conducted by the Chinese Center for Disease Control and Prevention and directed by the Center for Healthy Aging and Development at Peking University and the Center for the Study of Healthy Aging at Duke University [42]. Established in 1998, the CLHLS used a questionnaire to collect data, targeting older people aged 65 years and older, and utilized multistage whole population sampling to recruit participants from 23 of China's 31 provinces, covering 85% of China's total population. Meanwhile, trained interviewers collected data through face-to-face surveys to ensure a good response rate. The CLHLS study was approved by the Biomedical Ethics Committee of Peking University, Beijing, China (IRB00001052-13074).

To explore the associations of BMI, WC, HC, WHtR, WHR, and AVI with cognitive impairment, we used the most recent cross-sectional data from the 2018 CLHLS. In 2018, a total of 15,874 participants completed the CLHLS. Of these, 103 participants aged less than 65 years were excluded. Further excluded were 361 participants with dementia, 4038 participants with missing MMSE information, 551 participants with missing anthropometric measurements (weight, height, WC, and HC), 239 participants with outliers in anthropometric measurements (weight, height, WC, and HC), and 3 participants with extreme values of BMI (BMI < 10 kg/m^2, BMI > 50 kg/ m^2) [12]. Anthropometric outliers are detected using the Z-Score method, a standard deviation-based method that standardizes the data and detects observations that are far from the mean. If any of the data points are outside the range of three standard deviations, these points can be considered outliers. We used multiple interpolation to fill in missing data [43, 44]. Age, sex, occupation, education, marital status, drinker, smoker, diabetes, hypertension, basic activities of daily living (BADL) and instrumental activities of daily living (IADL) variables were included in the estimation model. The missing data analysis process used the mice function of the R package mice with the method set to random forest. A chi-square test on the data before and after interpolation showed no significant difference in the baseline data before and after interpolation (Supplementary Table S1). Details of how participants were selected are shown in Fig. 1. At the same time, we provide the baseline characteristics of the excluded participants in Supplementary Table S2.

Measures

Assessment of cognitive impairment

Cognitive impairment is defined by the Chinese version of the Brief Mental State Examination (MMSE) [45], which was translated from the international standard of the MMSE questionnaire. The Chinese version of the MMSE contains 24 items in six dimensions (5 orientation items, 3 registration items, 1 naming item, 5 attention and calculation items, 3 recall items, and 7 language items). The Chinese version of the MMSE is scored from 0 to 30, with higher scores on the MMSE assessment indicating better cognitive ability. This MMSE has been validated in a population of older people in China, where scores below 24 are defined as cognitive impairment [12, 46].

BMI, WC, HC, WHtR, WHR and AVI

For the survey, height (cm) and weight (kg) were measured with a tape measure and a scale without shoes or heavy clothing. When WC was measured, the participant was asked to exhale calmly, and the interviewer placed the tape measure directly against the skin and waited for the elderly person to record near the end of their exhalation. HC is measured at the point of maximum gluteal muscle prominence and the anterior plane pubic symphysis [47, 48].

BMI was calculated with the following formula:

$$\text{BMI} = \text{Weight (kg)}/\text{Height}^2\ \text{(m)}$$

WHtR was calculated with the following formula:

$$\text{WHtR} = \text{WC (cm)}/\text{Height (cm)}$$

WHR was calculated with the following formula:

$$\text{WHR} = \text{WC (cm)}/\text{HC (cm)}$$

AVI was calculated with the following formula:

$$\text{AVI} = \left[2 \times \text{WC}^2\ \text{(cm)} + 0.7 \times (\text{WC (cm)} - \text{HC (cm)})^2\right]/1000$$

BMI was classified into four types according to the Chinese guideline [49], which were underweight (BMI < 18.5 kg/m^2), normal weight (18.5 kg/m^2 ≤ BMI < 24.0 kg/m^2), overweight (24.0 kg/m^2 ≤ BMI < 28 kg/m^2) and obesity (BMI ≥ 28 kg/m^2). Central obesity was defined as ≥ 85 cm in men and ≥ 80 cm in women and vice versa as Noncentral obesity according to the criteria of the available studies [29, 30]. HC, WHtR, WHR and AVI were quartered.

Covariates

This study adjusted for many covariates including age, sex, type of residence, marital status, education, occupation, current smoking status, current smoking status,

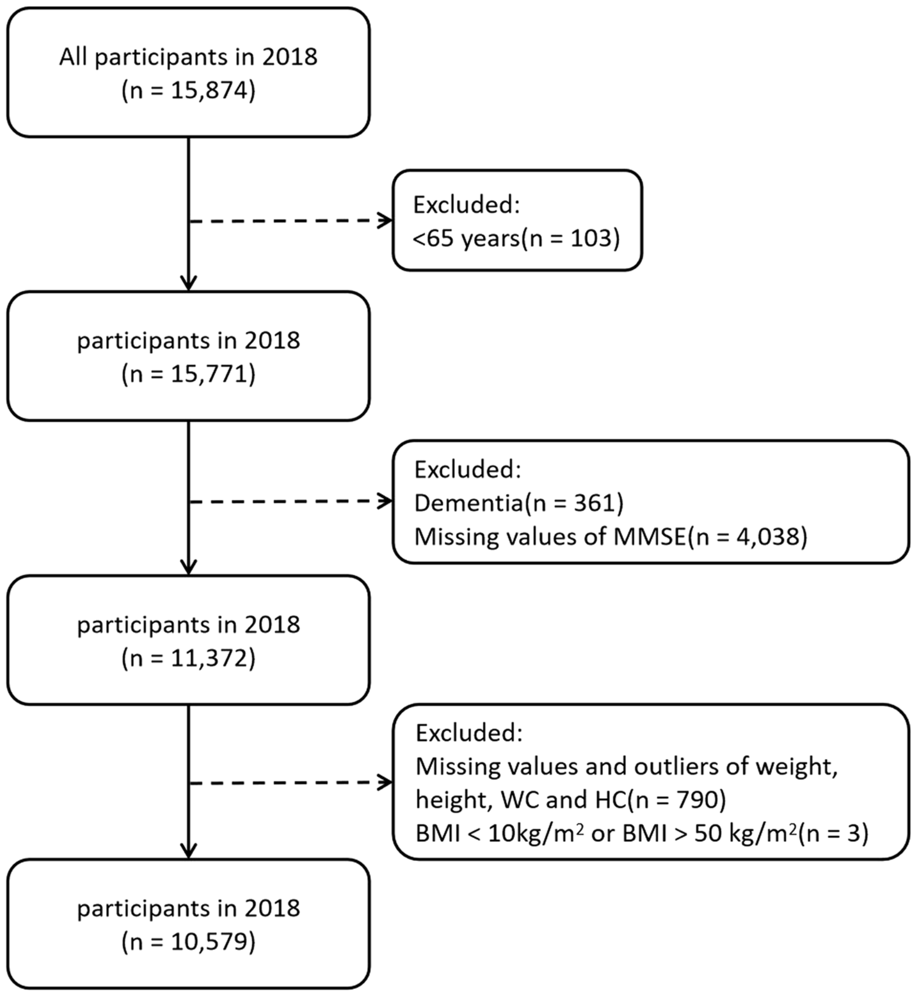

Fig. 1 Flow diagram of how to select participants

hypertension, diabetes mellitus, BADL, and IADL. Gender was categorized as male and female. The type of residence was categorized as urban and rural. Marital status was categorized as married and other. Education was categorized as formal education (≥ 1 year of education) and no formal education (< 1 year of education). The occupation (occupation before the age of 60) was categorized as professional work (skilled professionals, government, management) and non-professional work (agriculture, fishing, services, industry, domestic work). Participants were defined as smokers/drinkers if current smokers/drinkers, regardless of frequency and quantity. Hypertension/diabetes was defined as whether they self-reported having hypertension/diabetes [50, 51].

The BADL were measured on six subscales: (1) bathing; (2) dressing; (3) toileting; (4) indoor activities; (5) bowel control; and (6) eating. Each item is rated on a scale from 1 to 3 (1 for complete independence; 2 for partial dependence; and 3 for complete dependence). The IADL were assessed through eight questions: (1) Can you visit your neighbors by yourself? (2) Can you do your own shopping? (3) Can you cook for yourself if necessary? (4) Can you do your own laundry if necessary? (5) Can you walk alone for one kilometer at a time? (6) Can you lift 5 kg, such as a heavy bag of groceries? (7) Can you squat down and stand up three times in a row? (8) Can you take public transportation alone? Each item is rated on a three-point scale ranging from 1 (fully independent) to 3 (fully dependent). The higher the respondent's score on the BADL/IADL assessment, the higher the level of functional dependency [52, 53]. Need help was defined when "partial and full dependence" was selected for at least one of the BADL assessments, and Dependence was defined when "partial and full dependence" was selected for at least one of the IADL assessments.

Statistical analysis

Data management and statistical analysis were performed using R software (version 4.3.1). Continuous variables were tested for normality using the Kolmogorov-Smirnov test and reported as mean ± standard deviation (SD) if they conformed to a normal distribution or median (Q1, Q3) if they did not. Categorical variables were reported as n (%). Wilcoxon rank-sum test and chi-square test were used to compare baseline characteristics between the two groups. Odds ratios (ORs) and 95% confidence intervals (95% CIs) were calculated using multivariate binary logistic regression models to assess the association of BMI, WC, HC, WHtR, WHR and AVI with cognitive impairment. To control for the effect of potential confounders on the findings, we developed three models for each BMI, WC, HC, WHtR, WHR and AVI to adjust for potential confounders in this study. Model 1: unadjusted; Model 2: adjusted for gender and age; Model 3: Model 2 was further adjusted for type of residence, marital status, education, occupation, current smoking status, current smoking status, hypertension, diabetes, BADL, and IADL. Restricted cubic spline (RCS) regression was used to analyze the nonlinear relationship between BMI, WC, HC, and AVI and cognitive impairment. RCS analysis was performed using the lrm function of the R package "rms" with the node set to 4-knot. These nodes were automatically placed at the 5%, 35%, 65%, and 95% quantiles based on the distribution of the respective variables. This method of node selection adequately captures the nonlinear relationship between variables and cognitive functioning while avoiding model overfitting, and this method of node setting has been widely used in previous studies [54, 55]. Fully adjusted models were also used in subgroup analyses to investigate whether the associations between BMI, WC, HC, and AVI and cognitive impairment varied by age (65–79, ≥80 years), sex, marital status, type of residence, marital status, education, occupation, current smoking status, current smoking status, hypertension, diabetes, BADL, and IADL. Sensitivity analyses were performed to test the stability of the results by including 206 dementia patients with complete information. All statistical tests were two-sided, with $P < .05$ considered statistically significant.

Results

Participant characteristics

A total of 10,594 participants with a median age of 82 (74, 91) years were enrolled in this study, of which 5629 (53.1%) participants were female. The median (Q1, Q3) of BMI, WC, HC, WHtR, WHR and AVI of the participants were 22.23 (19.78, 24.91) kg/m^2, 85 (78, 92) cm, 92 (86, 98) cm, 0.55 (0.50, 0.59), 0.92 (0.88, 0.97) and 14.49 (12.24, 16.95) liters (L), respectively. Cognitive impairment was defined as an MMSE score of less than 24. The results showed that 2325 (21.9%) participants had cognitive impairment (Table 1). Among the older Chinese people in this study, the prevalence of cognitive impairment was 35.9% in the underweight group, 14.0% in the overweight group, and 15.4% in the obese group. Additionally, the prevalence of cognitive impairment in those with central obesity, defined by the WC threshold, was 19.7% (Supplementary Table S3). Compared to participants with normal cognitive function (Table 1), participants with cognitive impairment tended to be older, female, with no formal education, performing nonprofessional work, live in rural, of other marital status, nonsmokers, non-drinkers, not hypertensive and diabetic, BADL/IADL assessments reflecting dependence, underweight, no abdominal obesity, low HC and low AVI persons (All $P < .05$).

Associations of BMI, WC, HC, WHtR, WHR and AVI with cognitive impairment

Table 2 demonstrates the association between BMI, WC, HC, WHtR, WHR and AVI and cognitive impairment. Analyzed according to continuous variables, WC, HC and AVI were associated with cognitive impairment. After adjusting for potential confounders (Model 3), the adjusted ORs for WC, HC, and AVI were 0.93 (95% CI: 0.88–0.98, $P = .012$), 0.92 (95% CI: 0.87–0.97, $P = .004$), and 0.93 (95% CI: 0.88–0.98, $P = .011$), respectively. When analyzed by categorical variables, the associations of BMI, HC, WHR, and AVI with cognitive impairment were statistically significant after adjusting for covariates. The adjusted OR for HC (Q4) compared with HC (Q1) was 0.71 (95% CI: 0.60–0.84, $P < .001$). The adjusted OR for WHR (Q2) compared with WHR (Q1) was 0.85 (95% CI: 0.72-1.00, $P = .044$). The adjusted OR for AVI (Q4) compared with AVI (Q1) was 0.81 (95% CI: 0.69–0.95, $P = .010$). In addition, an adjusted OR of 1.16 (95% CI: 1.00-1.34, $P = .045$) was also found in our study for underweight participants compared with normal BMI, suggesting that underweight older people have a higher risk of developing cognitive impairment, which is consistent with previous studies [12].

Sensitivity analysis

Based on the 10,594 participants, we further included 206 dementia patients with complete information for sensitivity analysis to test the stability of the results. As shown in Supplementary Table S4, in the fully adjusted model (Model 3), the results of the sensitivity analysis were largely similar to the primary results, only BMI (continuous variable) (OR [95% CI]: 0.93 [0.88, 0.99]; $P = .018$) and central obesity (WC, categorical variable) (OR [95% CI]: 0.89 [0.79, 0.99]; $P = .035$) were different

Table 1 Baseline characteristics of participants grouped by cognitive impairment

Characteristic	Overall ($n = 10594$)	Normal cognitive function ($n = 8269$)	Cognitive impairment ($n = 2325$)	*P*
Age, median (Q1, Q3) (year)	82 (74, 91)	79 (72, 87)	93 (86, 100)	< 0.001
Sex (%)				< 0.001
Female	5629 (53.1)	4007 (48.5)	1622 (69.8)	
Male	4965 (46.9)	4262 (51.5)	703 (30.2)	
Education (%)				< 0.001
Formal education	5874 (55.4)	5346 (64.7)	528 (22.7)	
No formal education	4720 (44.6)	2923 (35.3)	1797 (77.3)	
Occupation (%)				< 0.001
Nonprofessional work	9364 (88.4)	7134 (86.3)	2230 (95.9)	
Professional work	1230 (11.6)	1135 (13.7)	95 (4.1)	
Residence (%)				< 0.001
Rural	4633 (43.7)	3542 (42.8)	1091 (46.9)	
Urban	5961 (56.3)	4727 (57.2)	1234 (53.1)	
Marital status (%)				< 0.001
Married	5077 (47.9)	4586 (55.5)	491 (21.1)	
Other	5517 (52.1)	3683 (44.5)	1834 (78.9)	
Smoker (%)				< 0.001
No	8833 (83.4)	6778 (82)	2055 (88.4)	
Yes	1761 (16.6)	1491 (18)	270 (11.6)	
Drinker (%)				< 0.001
No	8939 (84.4)	6844 (82.8)	2095 (90.1)	
Yes	1655 (15.6)	1425 (17.2)	230 (9.9)	
Hypertension (%)				< 0.001
No	5951 (56.2)	4486 (54.3)	1465 (63)	
Yes	4643 (43.8)	3783 (45.7)	860 (37)	
Diabetes (%)				< 0.001
No	9556 (90.2)	7372 (89.2)	2184 (93.9)	
Yes	1038 (9.8)	897 (10.8)	141 (6.1)	
BADL (%)				< 0.001
Don't need help	9024 (85.2)	7528 (91)	1496 (64.3)	
Need help	1570 (14.8)	741 (9)	829 (35.7)	
IADL (%)				< 0.001
Independence	4369 (41.2)	4180 (50.6)	189 (8.1)	
Dependence	6225 (58.8)	4089 (49.4)	2136 (91.9)	
BMI, median (Q1, Q3) (kg/m^2)	22.23 (19.78, 24.91)	22.66 (20.13, 25.24)	20.92 (18.63, 23.46)	< 0.001
BMI (%)				< 0.001
Normal weight	5550 (52.4)	4282 (51.8)	1268 (54.5)	
Obesity	831 (7.8)	703 (8.5)	128 (5.5)	
Overweight	2668 (25.2)	2294 (27.7)	374 (16.1)	
Underweight	1545 (14.6)	990 (12)	555 (23.9)	
WC, median (Q1, Q3) (cm)	85 (78, 92)	86 (79, 93)	82 (75, 90)	< 0.001
WC (%)				< 0.001
Central obesity	6649 (62.8)	5339 (64.6)	1310 (56.3)	
Noncentral obesity	3945 (37.2)	2930 (35.4)	1015 (43.7)	
HC, median (Q1, Q3) (cm)	92 (86, 98)	93 (87, 99)	90 (84, 95)	< 0.001
HC (%)				< 0.001
Q1 (HC < 86 cm)	2398 (22.6)	1589 (19.2)	809 (34.8)	
Q2 (86 ≤ HC < 92 cm)	2583 (24.4)	1964 (23.8)	619 (26.6)	
Q3 (92 ≤ HC < 98 cm)	2547 (24)	2067 (25)	480 (20.6)	

Table 1 (continued)

Characteristic	Overall (*n* = 10594)	Normal cognitive function (*n* = 8269)	Cognitive impairment (*n* = 2325)	*P*
Q4 (HC ≥ 98 cm)	3066 (28.9)	2649 (32)	417 (17.9)	
WHtR, median (Q1, Q3)	0.55 (0.50, 0.59)	0.54 (0.50, 0.59)	0.55 (0.50, 0.60)	0.185
WHtR (%)				< 0.001
Q1 (WHtR < 0.50)	2492 (23.5)	1906 (23)	586 (25.2)	
Q2 (0.50 ≤ WHtR < 0.55)	2792 (26.4)	2238 (27.1)	554 (23.8)	
Q3 (0.55 ≤ WHtR < 0.59)	2660 (25.1)	2131 (25.8)	529 (22.8)	
Q4 (WHtR ≥ 0.59)	2650 (25)	1994 (24.1)	656 (28.2)	
WHR, median (Q1, Q3)	0.92 (0.88, 0.97)	0.92 (0.88, 0.97)	0.93 (0.88, 0.97)	0.082
WHR (%)				0.005
Q1 (WHR < 0.88)	2636 (24.9)	2066 (25)	570 (24.5)	
Q2 (0.88 ≤ WHR < 0.92)	2625 (24.8)	2108 (25.5)	517 (22.2)	
Q3 (0.92 ≤ WHR < 0.97)	2660 (25.1)	2040 (24.7)	620 (26.7)	
Q4 (WHR ≥ 0.97)	2673 (25.2)	2055 (24.9)	618 (26.6)	
AVI, median (Q1, Q3) (L)	14.49 (12.24, 16.95)	14.80 (12.57, 17.30)	13.57 (11.35, 16.20)	< 0.001
AVI (%)				< 0.001
Q1 (AVI < 12.2 L)	2620 (24.7)	1830 (22.1)	790 (34)	
Q2 (12.2 ≤ AVI < 14.5 L)	2656 (25.1)	2043 (24.7)	613 (26.4)	
Q3 (14.5 ≤ A VI < 16.9 L)	2655 (25.1)	2148 (26)	507 (21.8)	
Q4 (AVI ≥ 16.9 L)	2663 (25.1)	2248 (27.2)	415 (17.8)	

BADL Basic activities of daily living, *IADL* Instrumental activities of daily living, *BMI* Body mass index, *WC* Waist circumference, *HC* Hip circumference, *WHtR* Waist-to-height ratio, *WHR* Waist-to-hip ratio, *AVI* Abdominal volume index

from the primary results. Overall, sensitivity analysis demonstrated the stability and reliability of the results generated by logistical regression analysis.

Subgroup analysis

We also conducted subgroup analyses to explore whether the associations between BMI, WC, HC, and AVI and cognitive impairment remained stable across subgroups (including age, sex, type of residence, marital status, education, occupation, current smoking status, current smoking status, hypertension, diabetes mellitus, BADL, and IADL). As shown in Fig. 2, except for sex and occupation, the associations between BMI, WC, HC, and AVI and cognitive impairment were not significantly affected in other categorical variables including age (65–79 and ≥ 80 years), type of residence, marital status, education, smoking, drinking, diabetes, hypertension, BADL, and IADL (*P* for interaction > 0.05). Also, we found from the results of the study that BMI, HC and AVI had a stronger protective effect among females compared to males. BMI, WC and AVI had a stronger protective effect among nonprofessional work compared to professional work.

Smoothed curve fitting and threshold effect analysis

We further assessed the relationship between BMI, WC, HC, and AVI and cognitive impairment using RCS regression. The results showed evidence of nonlinearity for the association of BMI (*P* for overall (used to assess whether there is a significant association between the independent variable and the dependent variable) < 0.001, *P* for nonlinearity = 0.005) and HC (*P* for overall < 0.001, *P* for nonlinearity = 0.004) with the risk of cognitive impairment (Fig. 3A and C). There was a linear negative correlation between WC (*P* for overall < 0.024, *P* for nonlinearity = 0.896) and AVI (*P* for overall < 0.019, *P* for nonlinearity = 0.695) and cognitive impairment (Fig. 3B and D). In addition, given that WC and HC are likely to differ significantly between sexes, especially in older populations, further analyses stratified by gender were conducted to address the relationship between WC and HC and cognitive impairment. The results showed that there was a linear negative correlation between WC (*P* for overall = 0.015, *P* for nonlinearity = 0.825) and HC (*P* for overall < 0.001, *P* for nonlinearity = 0.134) and cognitive impairment in female, and there was no statistically significant association between WC and cognitive impairment in male (*P* for overall = 0.695, *P* for nonlinearity = 0.690), as well as nonlinearity for the association of HC with the risk of cognitive impairment in male (*P* for overall = 0.002, *P* for nonlinearity < 0.001) (Supplementary Figure S1A and 1B). As shown in Fig. 3, BMI has a "U" shape with an inflection point of 25.5 kg/m^2, while HC has a skewed "N" shape with a peak inflection point of 83 cm and a trough inflection point of 101 cm.

Table 2 Binomial logistic regression analysis of the relationship between BMI, WC, HC, WHtR, WHR and AVI and cognitive impairment

Characteristic		Model 1		Model 2		Model 3	
		OR (95% CI)	P	OR (95% CI)	P	OR (95% CI)	P
BMI	Per SD	0.66 (0.63–0.69)	< 0.001	0.92 (0.87–0.97)	0.003	0.95 (0.89-1.00)	0.057
	Normal weight	1.00 (reference)		1.00 (reference)		1.00 (reference)	
	Obesity	0.61 (0.50–0.75)	< 0.001	0.98 (0.79–1.22)	0.846	0.97 (0.77–1.22)	0.787
	Overweight	0.55 (0.49–0.62)	0.001	0.88 (0.76–1.01)	0.071	0.93 (0.80–1.08)	0.366
	Underweight	1.89 (1.68–2.14)	< 0.001	1.21 (1.05–1.38)	0.008	1.16 (1.00-1.34)	0.045
WC	Per SD	0.73 (0.70–0.77)	< 0.001	0.92 (0.87–0.97)	0.002	0.93 (0.88–0.98)	0.012
	Normal weight	1.00 (reference)		1.00 (reference)		1.00 (reference)	
	Central obesity	0.71 (0.65–0.78)	< 0.001	0.89 (0.80–0.99)	0.031	0.91 (0.81–1.02)	0.094
HC	Per SD	0.66 (0.63–0.69)	< 0.001	0.90 (0.85–0.95)	< 0.001	0.92 (0.87–0.97)	0.004
	Q1 (HC < 86 cm)	1.00 (reference)		1.00 (reference)		1.00 (reference)	
	Q2 (86 ≤ HC < 92 cm)	0.62 (0.55–0.70)	< 0.001	0.91 (0.79–1.05)	0.211	0.95 (0.82–1.11)	0.535
	Q3 (92 ≤ HC < 98 cm)	0.46 (0.40–0.52)	< 0.001	0.85 (0.73–0.99)	0.038	0.90 (0.77–1.06)	0.202
	Q4 (HC ≥ 98 cm)	0.31 (0.27–0.35)	< 0.001	0.68 (0.58–0.79)	< 0.001	0.71 (0.60–0.84)	< 0.001
WHtR	Per SD	1.04 (0.99–1.09)	0.098	1.01 (0.96–1.06)	0.801	1.00 (0.94–1.05)	0.889
	Q1 (WHtR < 0.50)	1.00 (reference)		1.00 (reference)		1.00 (reference)	
	Q2 (0.50 ≤ WHtR < 0.55)	0.81 (0.71–0.92)	0.001	0.87 (0.75–1.01)	0.075	0.93 (0.79–1.09)	0.344
	Q3 (0.55 ≤ WHtR < 0.59)	0.81 (0.71–0.92)	0.002	0.88 (0.76–1.03)	0.105	0.91 (0.77–1.06)	0.233
	Q4 (WHtR ≥ 0.59)	1.07 (0.94–1.22)	0.299	1.01 (0.87–1.18)	0.847	1.01 (0.86–1.18)	0.913
WHR	Per SD	1.04 (0.99–1.08)	0.137	1.00 (0.95–1.05)	0.991	0.99 (0.93–1.04)	0.618
	Q1 (WHR < 0.88)	1.00 (reference)		1.00 (reference)		1.00 (reference)	
	Q2 (0.88 ≤ WHR < 0.92)	0.89 (0.78–1.02)	0.084	0.91 (0.78–1.06)	0.232	0.85 (0.72-1.00)	0.044
	Q3 (0.92 ≤ WHR < 0.97)	1.10 (0.97–1.25)	0.142	1.06 (0.92–1.23)	0.420	0.99 (0.85–1.15)	0.870
	Q4 (WHR ≥ 0.97)	1.09 (0.96–1.24)	0.191	1.02 (0.88–1.18)	0.839	0.98 (0.84–1.14)	0.766
AVI	Per SD	0.73 (0.69–0.76)	< 0.001	0.92 (0.87–0.97)	0.002	0.93 (0.88–0.98)	0.011
	Q1 (AVI < 12.2 L)	1.00 (reference)		1.00 (reference)		1.00 (reference)	
	Q2 (12.2 ≤ AVI < 14.5 L)	0.70 (0.61–0.79)	< 0.001	0.94 (0.82–1.08)	0.383	0.97 (0.84–1.12)	0.669
	Q3 (14.5 ≤ A VI < 16.9 L)	0.55 (0.48–0.62)	< 0.001	0.87 (0.75–1.01)	0.066	0.89 (0.76–1.03)	0.121
	Q4 (AVI ≥ 16.9 L)	0.43 (0.37–0.49)	< 0.001	0.79 (0.68–0.92)	0.002	0.81 (0.69–0.95)	0.010

Model 1: No covariates were adjusted. Model 2: Age and sex were adjusted. Model 3: Age, sex, education, occupation, residence, marital status, smoker, drinker, hypertension, diabetes, BADL and IADL were adjusted

BADL Basic activities of daily living, *IADL* Instrumental activities of daily living, *OR* Odds ratio, *CI* Confidence interval, *BMI* Body mass index, *WC* Waist circumference, *HC* Hip circumference, *WHtR* Waist-to-height ratio, *WHR* Waist-to-hip ratio, *AVI* Abdominal volume index

BMI was negatively associated with cognitive impairment when BMI was 25.5 kg/m^2 or lower. In contrast, with a BMI of 25.5 kg/m^{2}or higher, there was no statistically significant relationship between BMI and cognitive impairment. HC was negatively associated with cognitive impairment in the range of 83–101 cm ($P < .001$). In contrast, there was no statistically significant association between HC and cognitive impairment at HC less than 83 cm or greater than 101 cm (Supplementary Table S5).

Analyses of the joint effect of BMI and HC on cognitive impairment

To determine the joint effect of BMI and HC, we set up various combinations of BMI and HC to condition participants of different body figures and considered keeping a significant number of samples in each group, where BMI was divided into three groups including Normal BMI (18.5 ≤ BMI < 24.0 kg/m^2), Lower BMI (BMI < 18.5 kg/m^2) and Higher BMI (BMI ≥ 24.0 kg/m^2), and HC was categorized into two groups including Lower HC (HC < 92 cm) and Higher HC (HC ≥ 92 cm). The cutoff value of 92 cm for HC was chosen based both on the median of the population to ensure a balanced sample size across groups and the point of intersection with the reference line in the RCS analysis. Participants with normal BMI levels and higher HC [OR 0.83 (95%CI, 0.72–0.97)] and participants with higher BMI levels and higher HC [OR 0.79 (95%CI, 0.68–0.92)] had a lower risk of cognitive impairment compared with participants with normal BMI levels

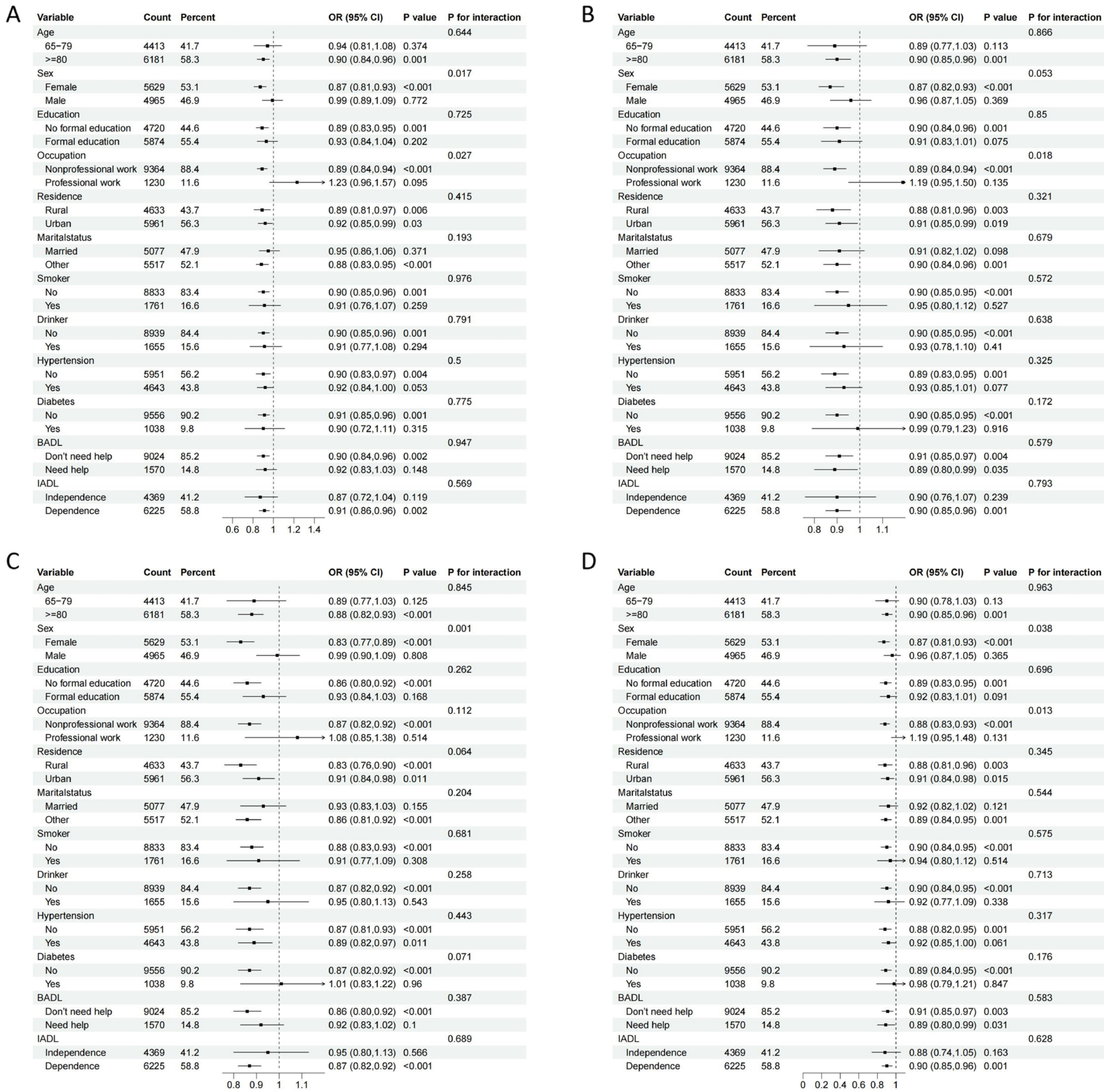

Fig. 2 Subgroup analysis of the associations between BMI, WC, HC, and AVI and cognitive impairment. Model 3-based associations between BMI (**A**), WC (**B**), HC (**C**), and AVI (**D**) and cognitive impairment. BADL, basic activities of daily living; IADL, instrumental activities of daily living; OR, odds ratio; CI, confidence interval; BMI, body mass index; WC, waist circumference; HC, hip circumference; WHtR, waist-to-height ratio; WHR, waist-to-hip ratio; AVI, abdominal volume index

and lower HC levels (Table 3). In addition, we also conducted a stratified analysis according to gender. We found that the results in male were consistent with the overall results, but in female, excepted for the participants with lower BMI and higher HC, the other combinations showed significant differences compared with participants with normal BMI and lower HC (Supplementary Table S6).

Discussion

This study focused on the associations between obesity indicators (BMI, WC, HC, WHtR, WHR, and AVI) and cognitive impairment in older people in China, and further analyzed the joint effects of BMI and HC on cognitive impairment. Results found that WC, HC, lower WHR (Q2), and AVI were significantly associated with lower risk of cognitive impairment. BMI and

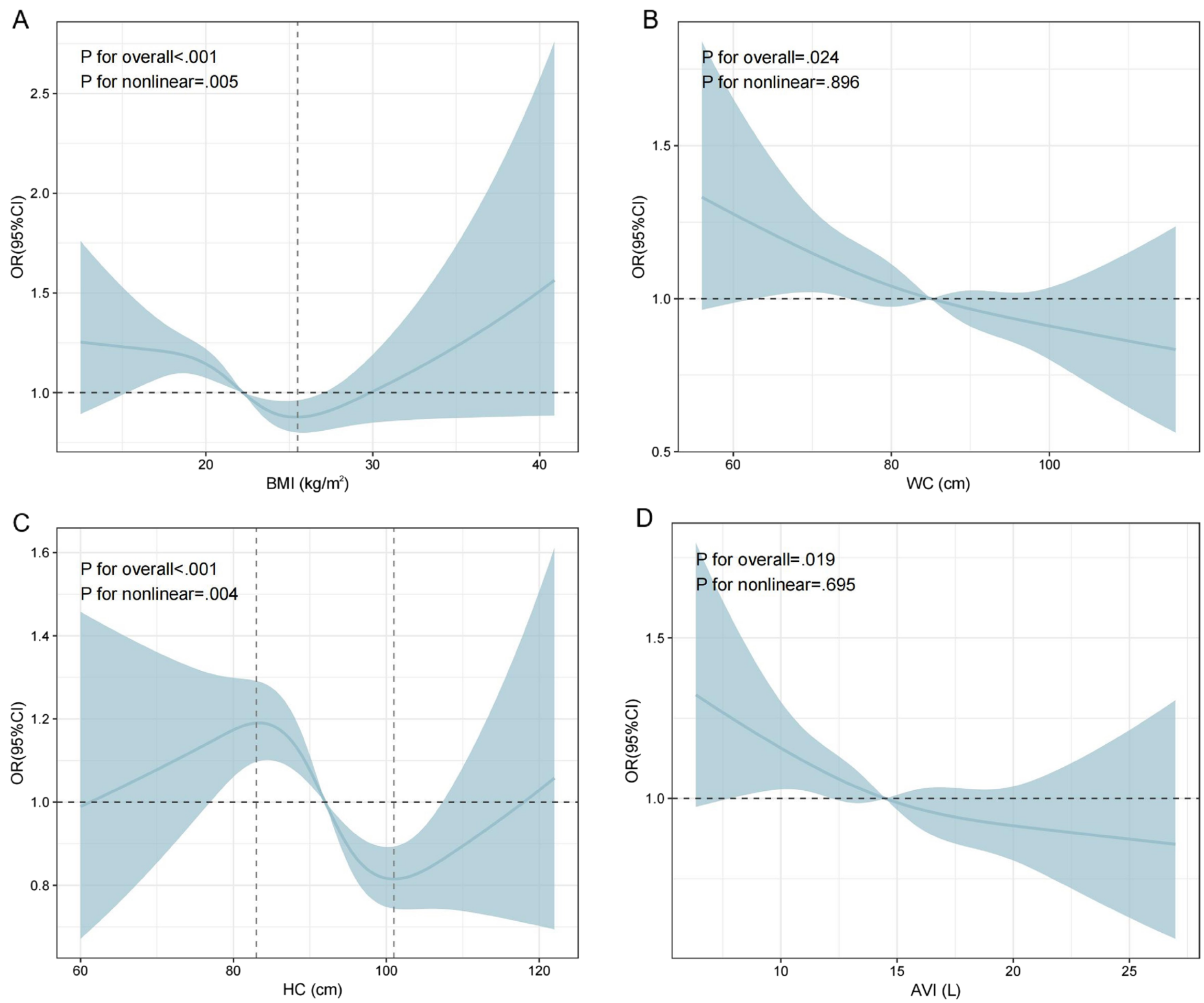

Fig. 3 RCS curves for BMI, WC, HC, and AVI associated with cognitive impairment. A 4-knot RCS regression was used to characterize the nonlinear associations of BMI (**A**), WC (**B**), HC (**C**), and AVI (**D**) with cognitive impairment, controlling for confounders of age and sex. RCS, restricted cubic spline; BMI, body mass index; WC, waist circumference; HC, hip circumference; AVI, abdominal volume index

overweight/obesity were associated with a lower risk of cognitive impairment before adjustment for confounders, but this association was not significant after adjustment. In addition, we found that central obesity, defined by the WC threshold, was not associated with cognitive impairment, but WC was negatively associated with cognitive impairment when expressed as a continuous variable. HC, lower WHR (Q2), and AVI were also negatively associated with cognitive impairment. Considering the joint effect of BMI and HC, the risk of cognitive impairment was lowest among individuals with normal BMI levels and higher HC, as well as those with higher BMI levels and higher HC.

In a study of Fuzhou, China, the prevalence of cognitive dysfunction in participants aged 70 years and older who were overweight (as defined by BMI) and centrally obese (as defined by WC) was 13.4% and 18.8%, respectively [56]. This result is consistent with our study. A

Table 3 Analyses of BMI and HC with cognitive impairment

Characteristic	Number of participants	OR (95% CI)[a]	*P*
Normal BMI + Lower HC	3068	1.00 (reference)	
Lower BMI + Lower HC	1333	1.12 (0.96–1.31)	0.152
Higher BMI + Lower HC	580	1.01 (0.79–1.28)	0.937
Normal BMI + Higher HC	2479	0.83 (0.72–0.97)	0.015
Lower BMI + Higher HC	191	1.07 (0.75–1.53)	0.715
Higher BMI + Higher HC	2943	0.79 (0.68–0.92)	0.002

[a] Data were adjusted for sex and age

survey of older people in Indonesia similarly showed that obese people were less likely to have cognitive impairment than normal weight people [57]. And a study of elderly Caucasian adults in Poland showed that obesity did e [58]. In addition, a study of older people in China found that the risk of cognitive impairment was significantly higher in underweight people than in normal weight people, while overweight/obese people were less likely to develop cognitive impairment [59]. In our study, unadjusted for confounders, overweight/obese participants demonstrated a reduced risk of cognitive impairment (OR < 1). In addition, our study similarly found that underweight has a negative impact on cognitive function in older people.

BMI is an important objective indicator for evaluating the nutritional status of older people. Previous studies have shown that older people with a BMI > 25 kg/m^2 are associated with good nutritional status and a low risk of cognitive impairment [60]. One other study reported that older people with a BMI ≥ 25 kg/m^2 had a lower risk of dementia, and that a decrease in BMI has been shown to be a marker of early dementia [61]. These studies all point to the existence of an "obesity paradox" in older people. A study analyzed 72 papers from 1999 to 2019 on the obesity paradox in older people. The results showed that most of the studies indicating the existence of an obesity paradox used BMI only as an indicator of obesity, ignoring the effects of body composition and fat distribution, and therefore inaccurately assessed the relationship between obesity and poor outcomes [62]. Significant changes in body composition and fat distribution occur with age. Older people typically experience a loss of muscle [15] and a redistribution of adipose tissue from the periphery to the center [63]. These changes may cause BMI to underestimate visceral fat accumulation, so relying on BMI alone may misclassify metabolic risk [64, 65]. Our study found that a BMI of 25.5 kg/m^2 possessed minimal risk of cognitive impairment and, in conjunction with previous studies, suggests that the traditional way of defining BMI may not be applicable as an indicator of obesity in older people. As a result, some researchers have suggested selecting different indicators of obesity or modifying anthropometric measures that define obesity for older people. In a growing number of studies, BMI-defined obesity criteria in older people are being reevaluated, including their impact on all-cause mortality, cardiovascular disease, and cognitive function [14, 60, 66]. Meanwhile, researchers have also developed different obesity indicators to better assess the impact of "true obesity" on adverse health outcomes among older people [67–70]. In our study, there was a linear negative correlation between AVI, which is sensitive to abdominal obesity, and cognitive impairment. This phenomenon may be attributed to leptin, an adipocytokine expressed in adipose tissue, which has been shown to enhance learning and memory in animal models by modulating hippocampal synaptic plasticity and amyloid processes [71]. Many previous studies have also demonstrated the potent neurotrophic and neuroprotective effects of leptin in a variety of animal studies, as well as its protective effects against the development or progression of Alzheimer's disease pathology [72–75].

Overweight or obesity in older people may stem from increased muscle mass or fat accumulation outside the abdomen. Previous studies have shown that increased leg fat in older people is associated with improved glucose metabolism, ultimately reducing the risk of cognitive impairment [76]. In the present study, we found that HC was negatively associated with cognitive impairment using logistic regression analysis, a result that supports the idea that HC contributes to reducing the risk of cognitive impairment in older people. This phenomenon may be explained by the protective effect that larger HC has against high blood glucose levels, thus slowing cognitive decline in older people [40, 77, 78]. In addition, we found no significant differences in cognitive impairment between older people with higher WHR (Q3) and highest WHR (Q4) compared to the lowest WHR (Q1), while older people with lower WHR (Q2) showed better cognitive functioning. This suggested that older people who maintained a reasonable waist and hip circumference had the lowest risk of developing cognitive impairment. A study of 30,697 participants aged 60 to 70 also found that older people with lower WHR had a lower risk of cognitive decline [79]. In the RCS regression analysis, we found a nonlinear relationship between HC and cognitive impairment in an "N" shape. By segmental analysis of HC, we found that elevated HC was protective against cognitive impairment when HC was between 83 and 101. However, the risk of cognitive impairment did not change significantly with HC below 83 cm or above 101 cm. Finally, our study examined the joint effect of BMI and HC on cognitive impairment in older people, suggesting that those with normal/higher BMI levels and higher HC had the lowest risk of cognitive impairment.

The results of this study showed that a BMI of 25.5 kg/m^2 and HC of 101 cm were the thresholds for the lowest risk of cognitive impairment, respectively. These cutoff values may be important in clinical practice, especially in the maintenance of cognitive function in older people. However, the use of single metrics may be biased, so we performed a joint analysis of BMI and HC. The study showed that older people with normal or high BMI had a lower risk of cognitive impairment in conditions of high HC (≥ 92 cm). Clinically, regular screening for body shape indicators such as BMI and HC, combined with assessment of other risk factors, can help to provide personalized health management recommendations for older people. The interaction between BMI and HC needs to be considered when weight management or body shape modification is undertaken to avoid an increased risk of cognitive impairment due to over-intervention. In addition, strict weight loss interventions may not be necessary for older people with higher HC and BMI, which is consistent with some of the literature supporting the protective effects of moderate overweight in older people [13, 14, 76, 79].

Strengths and limitations

This study has several strengths. First, weight, height, waist and hip circumference were measured by trained professionals, reducing misclassification bias in self-reported measurements. Second, we fully adjusted for covariates and conducted subgroup analyses to minimize the interference of potential confounders with the results. Third, this study is one of the few to simultaneously measure the associations between six obesity indicators (i.e., BMI, WC, HC, WHtR, WHR, and AVI) and cognitive impairment in a large sample, and found that lower WHR, AVI, and HC had a protective effect on cognitive impairment in older Chinese people. Fourth, the study used BMI and HC as continuous variables to explore their potential nonlinear associations with cognitive impairment, thereby identifying the optimal range of BMI and HC associated with lower cognitive impairment. Finally, we further investigated the joint effect of BMI and HC on cognitive impairment, and our results showed that people with normal or higher BMI but higher HC had the lowest risk of cognitive impairment, providing a valuable reference for rational body shape in older Chinese people.

This study also has some limitations. (1) This study used 2018 CLHLS cross-sectional data, so causality could not be determined. (2) Although there was a four-year interval between the last assessments, some of the participants were part of the follow-up group and may have experienced learning effects from the MMSE test, which could have affected the results of the assessment of cognitive function. (3) The respondents' cognitive impairment was assessed using the MMSE, which is not a clinical diagnostic tool, although it is highly correlated with cognitive impairment. (4) Self-reported health status or behavior due to personal memory deficits and subjective interpretations may introduce misclassification bias when adjusting for confounders. (5) Subjects excluded due to missing primary and dependent variables resulted in a reduced sample size, which may affect the accuracy of the analyzed results. (6) Due to the high missing rate of medication use data for diseases such as hypertension and diabetes in the original survey, if these variables are included in the analysis, the sample size may be significantly reduced, which may lead to selection bias and affect the reliability and representativeness of the results. Therefore, we did not include these potentially important confounders in our analysis. This may result in some of the confounders not being adequately controlled for, thus affecting the interpretation of the study results. (7) Because the apolipoprotein E (ApoE) genotype has a close association with cognitive function in older people, but the data limitations of this study do not make it possible to assess ApoE genotype.

Conclusion

This study suggests that WC, HC, lower WHR (Q2) and AVI are negatively associated with cognitive impairment in older Chinese people, whereas underweight is a risk factor for cognitive impairment. In addition, there was an "N" type nonlinear relationship between HC and cognitive impairment, with the highest and lowest risk HC values being approximately 83 and 101, respectively. The joint effects analysis showed that participants with higher or normal BMI but higher HC had the lowest risk of cognitive impairment, suggesting that both BMI and HC should be taken into account in the weight management of older Chinese people. Weight management programs for older people should focus on achieving and maintaining optimal weight and, in so doing, improving cognitive function.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12877-024-05521-0.

Supplementary Material 1.

Supplementary Material 2.

Authors' contributions

ZZL conceived the study and contributed to original draft; WJ and LH contributed to the data cleaning and the interpretation of the data; HJC designed the study, analyzed the data and revised the article critically for important intellectual content, and determined the final version to be submitted. All authors reviewed the manuscript.

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Data availability

This study was based on the datasets from the Chinese Longitudinal Healthy Longevity Survey (CLHLS). The CLHLS data can be publicly obtained through the National Archive of Computerized Data on Aging (NACDA) (https://www.icpsr.umich.edu/icpsrweb/NACDA/series/487). The analysis data used are available from the first author on reasonable request.

Declarations

Ethics approval and consent to participate
The data from CLHLS survey already obtained the ethical approval and informed consent and was approved by the Ethics Committee of Peking University (IRB00001052-13074). All participants or their surrogate respondents provided a written informed consent.

Competing interests
The authors declare no competing interests.

Content for publication
Not applicable.

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