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Association between abdominal obesity indices and falls among older community-dwellers in Guangzhou, China: a prospective cohort study

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Abstract

Background Central obesity was considered as a risk factor for falls among the older population. Waist circumference (WC), lipid accumulation product (LAP), visceral adiposity index (VAI), and the Chinese visceral adiposity index (CVAI) are considered as surrogate markers for abdominal fat deposition in increasing studies. Nevertheless, the longitudinal relationship between these indices and falls among the older population remains indistinct. This study aimed to explore the association between abdominal obesity indices and falls among older community-dwellers.

Methods Our study included 3501 individuals aged ≥ 65 years from the Guangzhou Falls and Health Status Tracking Cohort at baseline in 2021 and then prospectively followed up in 2022. The outcome of interest was the occurrence of falls. The Kaplan-Meier curves and multivariable Cox regression analysis were used to explore the associations between abdominal obesity indices and falls. Moreover, the restricted cubic spline analysis (RCS) was conducted to test the non-linear relationships between abdominal obesity indices and hazards of falls incident.

Results After a median follow-up period of 551 days, a total of 1022 participants experienced falls. The cumulative incidence rate of falls was observed to be higher among individuals with central obesity and those falling within the fourth quartile (Q4) of LAP, VAI, and CVAI. Participants with central obesity and those in Q4 of LAP, VAI, and CVAI were associated with higher risk of falls, with hazard ratios (HRs) of 1.422 (HR 95%CI: 1.255–1.611), 1.346 (1.176–1.541), 1.270 (1.108–1.457), 1.322 (1.154–1.514), respectively. Each 1-SD increment in WC, LAP, VAI, and CVAI was a significant increased risk of falls among participants. Subgroup analysis further revealed these results were basically stable and appeared to be significantly stronger among those females, aged 65–69 years, and with body mass index (BMI) ≥ 28 kg/m^2. Additionally, RCS curves showed an overall upward trend in the risk of falls as the abdominal indices increased.

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Conclusions Abdominal obesity indices, as WC, LAP, VAI, and CVAI were significantly associated with falls among older community-dwellers. Reduction of abdominal obesity indices might be suggested as the strategy of falls prevention.

Keywords Abdominal obesity indices, Cohort study, Falls, Older population

Background

The World Health Organization (WHO) estimates that the number of people aged 60 years and older will mushroom to 1.4 billion by 2030 and 2.1 billion by 2050, and this increase will accelerate in the coming decades, particularly within developing countries [1]. Based on the National Bureau of Statistics in China, there are approximate 2.17 million individuals aged 65 years and older, constituting 15.4% of the total population in 2023 [2]. Falls are defined as an event which results in a person coming to rest inadvertently on the ground or floor or other lower level, and can occur on one level of from a height [3]. Studies have reported older people are considered as a high risk group of falls, and falls incidence rises sharply with advancing age [4]. Previous studies showed that the prevalence of falls among older people varied from 8.59 to 39.7% [5–10]. A recent study showed the prevalence of falls among older community-dwellers was 22.49% in China [11].

Falls often trigger a downward spiral in health like head injuries and hip fractures [12], activity restriction [13], reduces life-quality, and also brings inestimable economic and healthcare burden to family and society. A estimation from WHO reveals that more than 684,000 deaths related to falls and an estimated 172 million suffer from short-term or long-term disabilities [3]. And falls are investigated as the second leading reason of unintentional injury deaths and the number one cause of injury-related mortality among people aged 65 years and older [3, 14]. Data from the Guangzhou Injury Monitoring System presents falls-related injury was consistently the first place from year 2014 to 2018 [15]. Falls among the older population have become a worldwide public health issue, and this issue is particularly pronounced in China, a nation with a large population of older individuals. Therefore, it is urgent to identify the risk factors associated with falls and to implement feasible and effective strategies for preventing falls among older population in China.

Previous studies demonstrated that obesity was a risk factor for falls, especially in the older population [16, 17]. Overweight or obesity is a general definition of body fat condition, and is frequently measured by body mass index (BMI). However, BMI, which measures both fat mass and lean mass [18], has deficiencies in distinguishing muscle from fat mass [19]. In recent years, instead of focusing on overall adiposity, adipose tissue distribution was applied in predicting health issues [20–22]. Moreover, increasing evidences have shown that central adiposity was a stronger predictor of falls than BMI among the older individuals with obesity [23–25]. It was known that abdominal adiposity could be accurately detected by radiological imaging techniques, including dual-energy X-ray absorptiometry (DEXA), magnetic resonance imaging (MRI), computed tomography (CT), and dual bioelectrical impedance analysis (BIA) [26, 27]. However radiological measurements might not be widely accepted by the public or applied for routine clinical practices on account of complex operations, high costs, and radiation exposure hazards [28, 29].

As credible surrogate-indicators, abdominal obesity indices, including waist circumference (WC), lipid accumulation product (LAP), the visceral adiposity index (VAI), and Chinese visceral adiposity index (CVAI), have been established to evaluate abdominal adiposity, which were feasible, easily accessible and reliable. These indices combine anthropometric and lipid parameters and were calculated by structural formulas, which were believed superior to traditional anthropometric parameters, and could discriminate between subcutaneous and visceral adipose tissue [30]. As surrogate-indicators of abdominal obesity, these indices have been studied in many health areas and were proved to have impacts on health outcome predicting [30, 31]. However, to the best of our knowledge, the relationship between novel abdominal obesity indices (LAP, VAI, CVAI) and falls is unclear.

We therefore conducted a prospective cohort study, and aimed to explore the association between abdominal obesity indices (WC, LAP, VAI, CVAI) and falls among older community-dwellers in China.

Methods

Study design and participants

The Guangzhou Falls and Health Status Tracking Cohort (GFHSTC) is a longitudinal, population-based study in which participants were recruited from community healthcare centers in eleven counties of Guangzhou, China. Briefly, the GFHSTC study was designed to explore the associations between demographic information, lifestyle factors, chronic diseases, auxiliary examinations on health outcomes. This study depends on the GFHSTC. Ethical approval for this study protocol was granted by the Ethic Committee of Guangzhou Center for Disease Control and Prevention (GZCDC-ECHR-2023P0061).

Self-designed questionnaires were adopted in the present study, which was constituted by baseline information, health examination and follow-up healthcare interview (Supplementary material 1). Pre-survey was carried out among 100 participants, which demonstrated that the self-designed questionnaires were feasible and could meet the research needs.

A total of 4950 eligible residents aged≥65 years old from 11 counties of Guangzhou were recruited in this study in 2021, with an average 450 participants from each district. The baseline survey and health examination were conducted. And a falls and health follow-up survey was completed in 2022. The recruited participants were followed up until 2022. Finally, 3501 participants were enrolled in the analysis. The other 1449 individuals were excluded owing to response missing (n=965), survey refusing (n=426) and data missing (n=58) during the whole follow-up period (Fig. 1).

Baseline data collection and definitions

Baseline questionnaires (Supplementary material 1) were used to collect information on demographic characteristics (age, gender, ethnicity, marital status, education and location), lifestyle factors (cigarette smoking, alcohol drinking and physical exercise), medical history (hypertension, diabetes, coronary heart disease and COPD) by well-trained clinic staff following standard procedures. Age was grouped by 65–69, 70–74, 75–79, and ≥80. Marital status was categorized as married and single (unmarried, divorced and widowed). Education status was classified as primary school or below, secondary school, and college or further. The participant's location was categorized as urban or rural. Smoking, drinking and physical exercise were categorized by current status (yes or no). Medical status was diagnosed by clinic examination or self-report at baseline interview.

Moreover, anthropometric measurements (WC, height and weight) were performed at base line by trained physicians or nurses, following standardized protocols. Body height and weight were recorded to the nearest 0.1 cm and 0.1 kg while participants were wearing light indoor clothing without shoes. WC was measured at the umbilical level with participant in standing position. After a 10 min rest, blood pressure (BP) of participants was measured two times using a digital sphygmomanometer, and the mean of the two readings was used for analysis. After an overnight fast, the participants' venous blood were collected for laboratory examinations. Total cholesterol (TC), high-density lipoprotein cholesterol (HDL-C), low-density lipoprotein cholesterol (LDL-C), triglycerides (TG), fasting blood glucose (FBG) were measured following standard protocols in the laboratory of the community healthcare center.

BMI, LAP [32], VAI [33], and CVAI [34] was calculated as the following formulas:

$$BMI = weight\,(kg)\,/height^2\,(m)$$

$$VAI\,(male) = \left[\frac{WC\,(cm)}{39.68 + 1.88 \times BMI\,(kg/m^2)}\right] \times \left[\frac{TG(mmol/L}{1.03}\right] \times \left[\frac{1.31}{HDL\,(mmol/L)}\right]$$

$$VAI\,(female) = \left[\frac{WC\,(cm)}{36.58 + 1.89 \times BMI\,(kg/m^2)}\right] \times \left[\frac{TG(mmol/L}{0.81}\right] \times \left[\frac{1.52}{HDL\,(mmol/L)}\right]$$

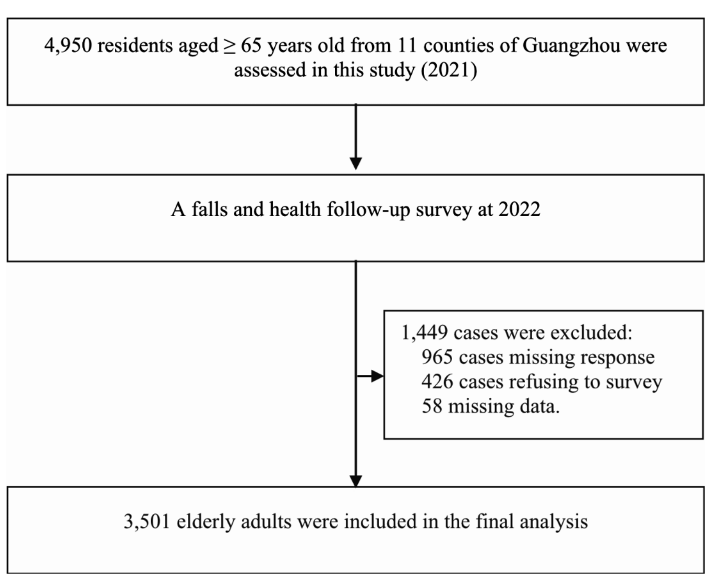

Fig. 1 Flowchart of study population

$$LAP\,(male) = [WC\,(cm) - 65] \times TG\,(mmol/L)$$

$$LAP\,(female) = [WC\,(cm) - 58] \times TG\,(mmol/L)$$

$$CVAI\,(male) = -267.93 + 0.68 \times age\,(years) + 0.03 \times BMI\,\left(kg/m^2\right) + 4.00 \times WC\,(cm) + 22.00 \times LgTG\,(mmol/L) - 16.32 \times HDL\,(mmol/L)$$

$$CVAI\,(female) = -187.32 + 1.71 \times age\,(years) + 4.32 \times BMI\,\left(kg/m^2\right) + 1.12 \times WC\,(cm) + 39.76 \times LgTG\,(mmol/L) - 11.66 \times HDL\,(mmol/L)$$

Followup and outcomes assessment

This study tracked participants from the baseline of January 2021 to December 2022. Participants were followed up annually through one-to-one healthcare interview and comprehensive health examination by professional staff in community healthcare centers. The primary outcome of this study is the occurrence of falls among older community-dwellers. Falls were defined as an event which results in a person inadvertently and unexpectably coming to rest on the ground or floor or other lower level, from a height [4]. Outcomes were collected through healthcare interview in 2022, by asking participants the following two questions: "Have you ever fallen during the follow-up period (year 2021–2022)?" and "When did you fall?" (Supplementary material 1).

Statistical analysis

Statistical analyses were done with R (version 4.2.1) and SPSS (version 25.0, SPSS Inc., Chicago, IL, USA). Data were summarized as number(percentages), mean ± standard deviation (SD), or median (interquartile range) where appropriate. The Chi-square test was performed for categorical data, and the Student's t-test or Mann-Whitney U-test was for continuous data, when comparing the differences between the two groups. Kaplan-Meier curves were plotted to describe the cumulative incidence rates of falls by groups according to the incident of central obesity and the quartiles of abdominal obesity indices and the log-rank test were used for comparison. Referring to the two-category of WC, we determine the third quartile (the 75th percentile) as the cut point to categorize the data of LAP, VAI and CVAI in the statistical analysis. Cox proportional-hazards regression analysis was utilized to calculate the hazard ratios (HRs) of falls across the incident of central obesity and the quartiles of the LAP, VAI, and CVAI. Abdominal obesity indices were analyzed as categorical variables, and also continuous variables by estimating the risk of falls associated with one SD increase. Model 1 was a crude model without adjustment. Model 2 was adjusted for gender and age. And Model 3 adjusted for gender, age, ethnic groups, marital status, education, cigarette smoking, alcohol drinking, physical exercise, hypertension, diabetes, coronary heart disease, and chronic obstructive pulmonary disease additionally. Subgroup analysis were conducted based on gender, age, and BMI. Moreover, the restricted cubic spline (RCS) analysis was conducted to test the non-linear relationships between abdominal obesity indices and hazards of falls incidents. *P* value < 0.05 was considered statistical significance.

Results

Baseline characteristics

Overall, 3501 participants aged ≥ 65 years old were enrolled for current analysis, and the mean age was 71.43 ± 5.54 years at baseline. At a median follow-up of 551 days, 1022 (29.19%) participants experienced falls. The baseline characteristics of participants suffered falls at follow-up were presented in Table 1. In comparison to those without falls, participants who suffered falls tended to be female, older, single, primary school or below, rural living, less physical exercises, with hypertension or diabetes. Besides, they also had higher SBP, triglyceride, FBG, BMI, WC, LAP, VAI, CVAI, or lower HDL cholesterol (all *P* value < 0.05, Table 1). In addition, no statistical differences were found in the univariate analysis of ethnic groups, alcohol drinking, coronary heart disease, COPD, DBP, total cholesterol, and LDL cholesterol (all *P* value > 0.05).

Cumulative incidence of falls according to quartiles of abdominal obesity indices

Kaplan-Meier curves for incident falls among participants by quartiles of abdominal obesity indices were applied (Fig. 2). Participants with central obesity were correlated with a higher risk of falls. Moreover, in contrast to the individuals in Q1-Q3 of LAP, VAI, CVAI, those in Q4 had an elevated higher risk of falls (all log-rank tests *P* < 0.01).

Relationship between abdominal obesity indices and falls

The Cox regression models were employed to examine the correlations of abdominal obesity indices with the risk of falls among older community-dwellers (Table 2). Compared to the lower WC (Male:<90 cm; Female < 85 cm) and lower quartile groups (Q1 - Q3) of LAP, VAI, and CVAI, those exhibiting central obesity (Male:≥90 cm; Female ≥ 85 cm), and belonging to the higher quartile group (Q4), demonstrated a higher risk of falls. This finding was consistent across both the crude model (Model 1) and the adjusted models (Model 2, 3), with fully adjusted hazard ratios (HRs) of 1.422 (95%CI: 1.255–1.611), 1.346 (95%CI: 1.176–1.541), 1.270 (95%CI: 1.108–1.457), and 1.322 (95%CI: 1.154–1.514), respectively.

Table 1 Baseline characteristics of participants according to the falls status at follow-up

Variables	Total ($n = 3,501$)	Without falls ($n = 2,479$)	With falls ($n = 1,022$)	*P*
Gender				**< 0.001**
Male	1691 (48.30)	1262 (50.91)	429 (41.98)	
Female	1810 (51.70)	1217 (49.09)	593 (58.02)	
Age, **years**	71.43 ± 5.54	71.09 ± 5.36	72.24 ± 5.86	**< 0.001**
Age groups, **years**				**< 0.001**
65–69	1714 (48.96)	1279 (51.59)	435 (42.56)	
70–74	1047 (29.91)	728 (29.37)	319 (31.21)	
75–79	442 (12.62)	285 (11.50)	157 (15.36)	
≥ 80	298 (8.51)	187 (7.54)	111 (10.86)	
Ethnic groups				0.999
Han	3497 (99.89)	2476 (99.88)	1021 (99.90)	
Else	4 (0.11)	3 (0.12)	1 (0.10)	
Marital status				**0.005**
Married	3180 (90.83)	2272 (91.65)	908 (88.85)	
Single [a]	321 (9.17)	207 (8.35)	114 (11.15)	
Education				**< 0.001**
Primary school or below	972 (27.76)	650 (26.22)	322 (31.51)	
Secondary school	1728 (49.36)	1241 (50.06)	487 (47.65)	
College or further	801 (22.88)	588 (23.72)	213 (20.84)	
Location				**< 0.001**
Urban	2702 (77.18)	1973 (79.59)	729 (71.33)	
Rural	799 (22.82)	506 (20.41)	293 (28.67)	
Cigarette smoking				**0.049**
Yes	453 (12.94)	339 (13.67)	114 (11.15)	
No	3048 (87.06)	2140 (86.33)	908 (88.85)	
Alcohol drinking				0.068
Yes	423 (12.08)	316 (12.75)	107 (10.47)	
No	3078 (87.92)	2163 (87.25)	915 (89.53)	
Physical exercise				**< 0.001**
Yes	2629 (75.09)	1923 (77.57)	706 (69.08)	
No	872 (24.91)	556 (22.43)	316 (30.92)	
Hypertension				**< 0.001**
Yes	2179 (62.24)	1487 (59.98)	692 (67.71)	
No	1322 (37.76)	992 (40.02)	330 (32.29)	
Diabetes				**< 0.001**
Yes	1325 (37.85)	856 (34.53)	469 (45.89)	
No	2176 (62.15)	1623 (65.47)	553 (54.11)	
Coronary heart disease				0.155
Yes	343 (9.80)	231 (9.32)	112 (10.96)	
No	3158 (90.20)	2248 (90.68)	910 (89.04)	
COPD				0.629
Yes	19 (0.54)	12 (0.48)	7 (0.68)	
No	3482 (99.46)	2467 (99.52)	1015 (99.32)	
SBP, **mmHg**	137.31 ± 16.86	136.89 ± 16.92	138.33 ± 16.67	**0.022**
DBP, **mmHg**	79.55 ± 9.88	79.58 ± 9.90	79.49 ± 9.83	0.797
Total cholesterol, **mmol/L**	5.28 ± 1.21	5.30 ± 1.19	5.22 ± 1.23	0.077
HDL cholesterol, **mmol/L**	1.42 ± 0.39	1.43 ± 0.38	1.39 ± 0.40	**0.009**
LDL cholesterol, **mmol/L**	3.16 ± 1.01	3.17 ± 1.01	3.15 ± 1.01	0.501
Triglyceride, **mmol/L**	1.44 (1.03, 2.04)	1.40 (1.00, 1.98)	1.56 (1.11, 2.23)	**< 0.001**
FBG, **mmol/L**	6.55 ± 2.44	6.41 ± 2.21	6.90 ± 2.89	**< 0.001**
Body mass index, **kg/m2**	24.26 ± 3.21	24.05 ± 3.17	24.77 ± 3.26	**< 0.001**
Waist circumference, **cm**	85.70 ± 8.70	85.03 ± 8.78	87.34 ± 8.26	**< 0.001**

Table 1 (continued)

Variables	Total (n = 3,501)	Without falls (n = 2,479)	With falls (n = 1,022)	P
LAP	34.40 (21.34, 54.72)	32.30 (19.80, 51.03)	39.22 (24.81, 62.39)	**< 0.001**
VAI	1.68 (1.05, 2.70)	1.58 (1.00, 2541)	1.97 (1.20, 3.00)	**< 0.001**
CVAI	125.32 (100.65, 151.44)	121.75 (96.35, 147.78)	133.07 (108.93, 161.50)	**< 0.001**

Note Data are summarized as n (%), Mean ± SD, or Median (IQR). SD: standard deviation, WC: waist circumference, LAP: lipid accumulation product, VAI: visceral adiposity index, CVAI: Chinese visceral adiposity index

[a] Single: unmarried, divorced or widowed

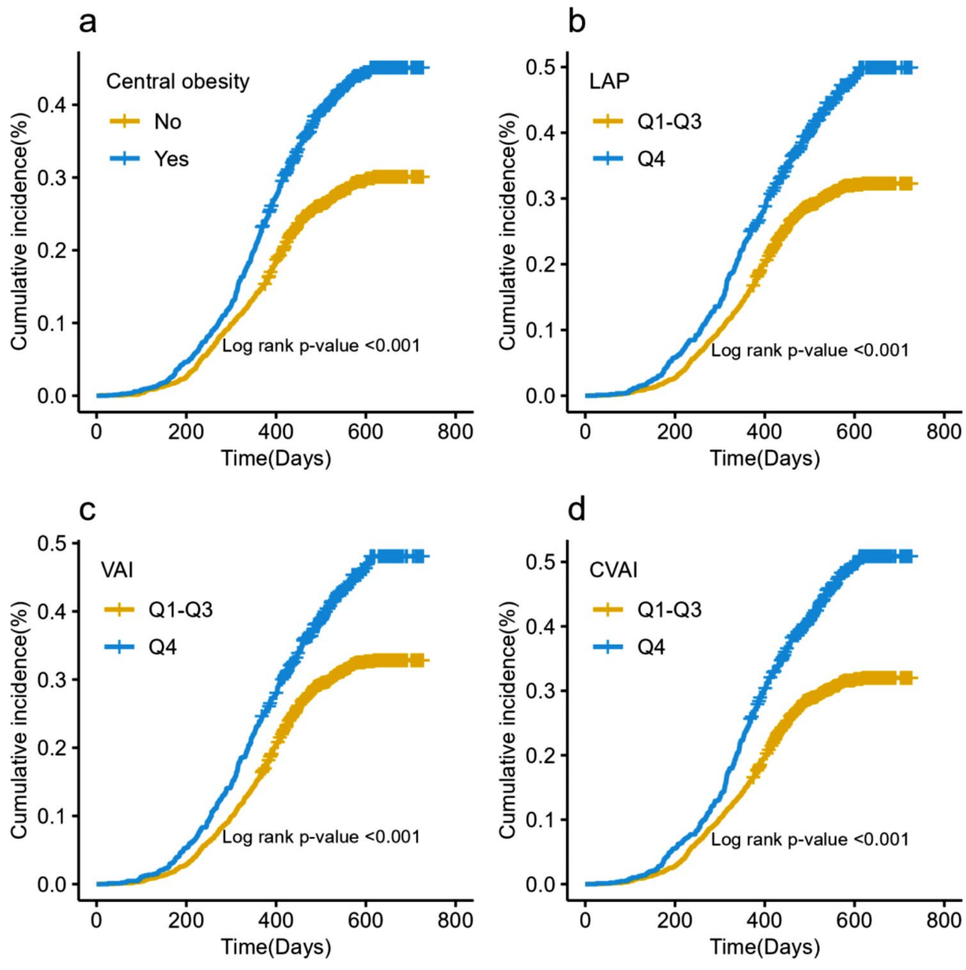

Fig. 2 Cumulative incidence of falls according to quartiles of abdominal obesity indices of participants. Note: **a**: WC: waist circumference, Center obesity: Yes: Male WC ≥ 90 cm, or female WC ≥ 85 cm; **b**: LAP: lipid accumulation product, Q1-Q3 (≤ 54.72), Q4 (>54.72); **c**: VAI: visceral adiposity index, Q1-Q3(≤ 2.70), Q4 (>2.70); **d**: CVAI: Chinese visceral adiposity index, Q1-Q3 (≤ 151.44), Q4 (>151.44)

When all abdominal obesity indices were applied as continuous variables in analysis, the positive association remained robust. After adjusting for all covariates (Model 3), each 1-SD increase in WC, LAP, VAI, and CVAI was related with a higher risk of falls among older community-dwellers, with adjusted HR being 1.265 (95%CI: 1.189–1.346), 1.182 (95%CI: 1.130–1.237), 1.150 (95%CI: 1.096–1.207), 1.013 (95% CI: 1.010–1.017), respectively.

Subgroup analysis of the relationship between abdominal obesity indices and the falls

Subgroup analysis further revealed these results were basically stable and reliable, and the majority of subgroups of WC, LAP, VAI, and CVAI showed significantly higher risk of falls (Fig. 3). The effects of WC, LAP, VAI, CVAI on falls were more pronounced in females, participants aged 65–69 years, and those with BMI≥28 kg/

Table 2 Associations between baseline abdominal obesity indices (both categorical and continuous variables) and falls of participants

Variables	Fallers/Total	Model 1, HR (95%CI)[a]	Model 2, HR (95%CI)[b]	Model 3, HR (95%CI)[c]
Continuous variables				
WC				
Per 1 SD increase	1022/3501	1.246 (1.172–1.324)***	1.299(1.221–1.381)***	1.265(1.189–1.346)***
LAP				
Per 1 SD increase	1022/3501	1.231(1.179–1.286)***	1.226(1.172–1.282)***	1.182(1.130–1.237)***
VAI				
Per 1 SD increase	1022/3501	1.188(1.138–1.242)***	1.177(1.124–1.233)***	1.150(1.096–1.207)***
CVAI				
Per 1 SD increase	1022/3501	1.017(1.014–1.020)**	1.015(1.012–11.018)**	1.013(1.010–1.017)**
Categorical variables				
Central obesity				
No(WC: Male:<90 cm; Female < 85 cm)	531/1528	Ref	Ref	Ref
Yes (WC: Male:≥90 cm; Female ≥ 85 cm)	491/1973	1.490(1.318–1.684)***	1.481(1.310–1.676)***	1.422(1.255–1.611)***
LAP Quartiles				
Q1-Q3 (≤ 54.72)	696/2610	Ref	Ref	Ref
Q4 (>54.72)	326/891	1.476(1.293–1.684)***	1.431(1.253–1.635)***	1.346(1.176–1.541)***
VAI Quartiles				
Q1-Q3(≤ 2.70)	700/2588	Ref	Ref	Ref
Q4 (>2.70)	322/913	1.405(1.230–1.606)***	1.339(1.169–1.534)***	1.270(1.108–1.457)***
CVAI Quartiles				
Q1-Q3 (≤ 151.44)	693/2621	Ref	Ref	Ref
Q4 (>151.44)	329/880	1.525(1.337–1.739)***	1.395(1.219–1.596)***	1.322(1.154–1.514)***

Note HR: hazard ratio, 95%CI: 95% confidence interval, SD: standard deviation, WC: waist circumference, LAP: lipid accumulation product, VAI: visceral adiposity index, CVAI: Chinese visceral adiposity index

[a] Model 1: Crude model

[b] Model 2: Adjusted for gender and age

[c] Model 3: Adjusted for gender, age, ethnic groups, marital status, education, cigarette smoking, alcohol drinking, physical exercise, hypertension, diabetes, coronary heart disease, and chronic obstructive pulmonary disease

*$P<0.05$; **$P<0.01$; ***$P<0.001$

m^2. Compared to the subgroup with BMI<28 kg/m^2, the obese group (BMI≥28 kg/m^2) showed a notably stronger association of each index with falls (Fig. 3).

Restricted cubic splines analysis of the relationship between abdominal obesity indices and the falls

Multivariable-adjusted RCS analysis (Fig. 4) revealed a significant rising trend in the risk of falls as the WC, LAP, VAI, CVAI increased (all *P* value for overall and non-linear<0.05).

Discussions

Overweight and obesity have gradually become worldwide public health issues. Study showed China has a huge obese population, where over 15% adults were overall obese and over 35% suffered from abdominal obesity [35]. Previous studies illustrated that obesity and abdominal obesity had a positive correlation with falls [16, 17, 23, 36]. Abdominal obesity indices, as credible surrogate-indicators of abdominal adipose, has been proved to have significant impacts on health outcome predicting [30, 31]. Nevertheless, the predictive effects of abdominal obesity indices on falls are unclear, especially in the older population. In present cohort study, abdominal obesity indices, including WC, LAP, VAI, CVAI, were demonstrated to be positively associated with falls among the older community-dwellers. Our study adds to the existing evidences revealing significantly associations between abdominal obesity indices and falls among the older community-dwellers.

Our study found that central obesity (Male WC≥90 cm, Female WC≥85 cm) leads to a higher cumulative incidence rate of falls, and was associated with higher risk of falls when compared with normal WC, which were consistent with Cox regression analysis. Moreover, RCS analysis revealed that a significant dose-response relationship between WC and falls, indicating that the risk of falls increases concomitantly with a rise in WC. This finding was in accordance with previous research, revealing a positive association of WC with falls [37]. According to the existing evidences, the potential mechanism is that abdominal obesity is believed to increase pro-inflammatory cytokines such as interleukin-6 and tumour necrosis factor-alpha, which can stimulate bone osteoclastogenesis, resulting in the increase of bone resorption [38]. This mechanism suggests that abdominal obesity

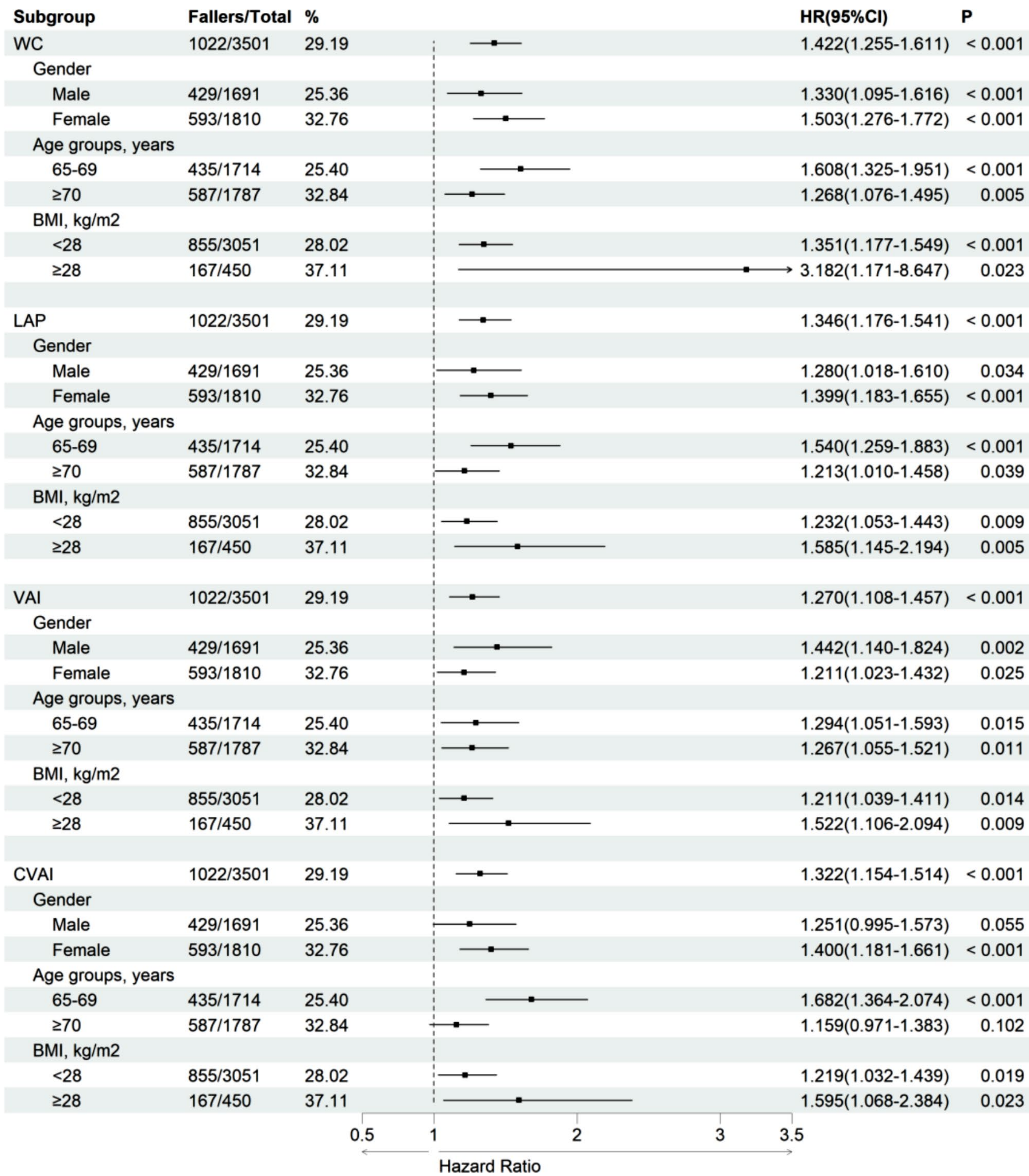

Fig. 3 Associations between abdominal obesity indices and falls of participants in different subgroups. Note: HR: hazard ratio, 95%CI: 95% confidence interval, WC: waist circumference. LAP: lipid accumulation product, VAI: visceral adiposity index, CVAI: Chinese visceral adiposity index. Each subgroup was adjusted for gender, age, ethnic groups, marital status, education, cigarette smoking, alcohol drinking, physical exercise, hypertension, diabetes, coronary heart disease, and chronic obstructive pulmonary disease. Hazard ratios show the risk of falls among participants with central obesity or those in Q4 of LAP, VAI and CVAI, compared with those without central obesity and those in Q1-Q3

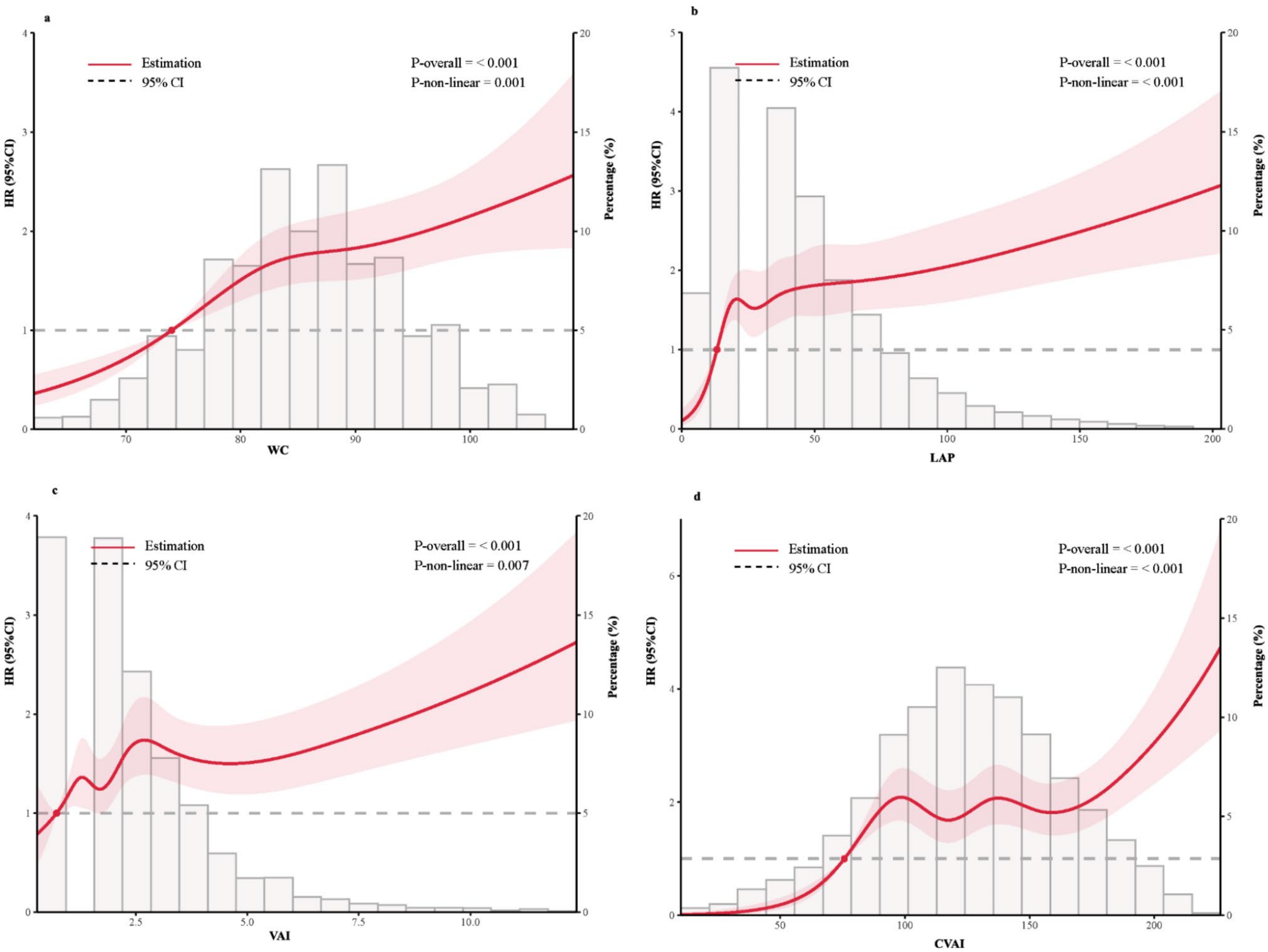

Fig. 4 Restricted cubic splines analysis of the relationship between abdominal obesity indices and the risk of falls among of participants Note: HR: hazard ratio, 95%CI: 95% confidence interval. **a**: WC: waist circumference, **b**: LAP: lipid accumulation product, **c**: VAI: visceral adiposity index, **d**: CVAI: Chinese visceral adiposity index. HR is adjusted as model 3: Adjusted for gender, age, ethnic groups, marital status, education, cigarette smoking, alcohol drinking, physical exercise, hypertension, diabetes, coronary heart disease, and chronic obstructive pulmonary disease

might lead to bone frailty, which tends to have negatives effect on gait steady. And in fact, it was demonstrated that large WC led to poor postural alignment, weak gait speed, and decreased joint flexibility in older population [39–41], and abdominal obesity reduced the muscle power, manoeuvering ability and the speed to completely recover footing during a fall [42]. All of the evidences above revealed people with large WC were more likely to fall, and they needed better motor balance capacity to avoid falls. Considering WC detection is feasible, easily accessible, free of machine or complex technique, it is meaningful to conduct WC test in daily clinical practice for falls prevention.

Our study also found that LAP, VAI, and CVAI were associated with elevated cumulative incidence rate of falls, and Cox regression models were also exhibited significantly correlations. Study has demonstrated CVAI as a reliable surrogate indicator in evaluating visceral fat mass among Chinese population [34]. In addition, LAP, VAI, and CVAI were valuable indicators and had significantly positive associations with high risk of cardiovascular (CV) events [30, 31]. And CV events, such as stroke, had been determined as risk factors for falls [43]. We speculate the potential explanation of the positive effect of LAP, VAI, and CVAI on falls might be the mediating impact of CV events. Moreover, RCS analysis revealed that a significant rising trend in the risk of falls as the LAP, VAI, CVAI increased. Our study revealed that abdominal obesity, as LAP, VAI and CVAI are worth more attention in risk management and prevention strategies making for falls among the older community-dwellers.

In the present study, we also found that the majority of subgroups of WC, LAP, VAI, and CVAI showed significantly higher risk of falls in subgroup analysis, which revealed these results were basically stable and reliable. Interestingly, the correlation between WC, LAP, VAI, CVAI and falls exhibited stronger in female, participants aged 65–69 years and those with BMI ≥ 28 kg/m2. When compared with men, females were more vulnerable to falls, which is accordant with previous surveys findings [44–46]. And female are more likely to suffer from osteoporosis as a result of the lack of estrogen after menopause, leading to rapid decline of muscle strength [10], subsequently increasing the risk of falls. Despite the fact that the incidence of falls among participants aged ≥ 70 years exceeded that of those aged 65–69 years (32.84% *VS* 25.40%), it was surprising to observe that the HR was significantly elevated in the subgroup aged 65–69 years, in contrast to the subgroup aged ≥ 70 years, in the subgroup analysis conducted. A potential explanation could be that individuals aged ≥ 70 years are more prone to having poorer physical conditions, which may contribute more significantly to falls than abdominal obesity indices do. Moreover, subgroup analysis showed the associations were significantly pronounced among individuals with BMI ≥ 28 kg/m^2. As previous finding claimed that older individuals with healthy BMI exhibited better balance and postural steady than those with obese BMI [47], we might suggest participants with BMI ≥ 28 kg/m^2 suffered from worse balance and postural steady, both of those were admitted risk factors of falls. Thus, it underlines the importance of WC evaluation for falls prevention, especially among female individuals with overall obesity.

Some strengths should be introduced in this study. To the best of our knowledge, it is the firstly prospective cohort study to examine the relationship between novel abdominal obesity indices (LAP, VAI, CVAI) and falls among older community-dwellers in China. Meanwhile, a total of 3501 participants were recruited from 11 counties, encompassing all the counties of Guangzhou, thereby ensuring a certain degree of representativeness. Finally, this study adjusted for underlying confounding factors where possible, as well as explored subgroup tests and RCS analysis to further examine the correlations between abdominal obesity indices and falls among older community-dwellers in China.

Several potential limitations in our study need to be mentioned. Firstly, we valued the abdominal obesity indices by formulates conducted by previous studies, instead of computed tomography (CT) and magnetic resonance imaging (MRI). Secondly, measurement bias and recall bias might be introduced. Thirdly, although we tried to control for the main characteristics that may modify the relationship between abdominal obesity indices and falls, some potential confounders still need to be considered, such as depression. Last but not least, although the study had a limited follow-up period, we solely focused on exploring the influence of baseline indices on falls, and did not assess the impact of changes in indices over the duration of the cohort period.

Conclusion

The present prospective cohort study showed that abdominal obesity indices, as WC, LAP, VAI, and CVAI, were associated with falls among older community-dwellers in Guangzhou, China. Subgroup and RCS analysis further confirmed these robust relations. The reduction of abdominal obesity indices may potentially mitigate the risk of falls and be proposed as a viable strategy for the prevention of falls among older community-dwellers.

Abbreviations

WC	Waist circumference
LAP	Lipid accumulation product
VAI	Visceral adiposity index
CVAI	Chinese visceral adiposity index
BMI	Body mass index
SD	Standard deviation
RCS	Restricted cubic spline analysis
HR	Hazard ratio
SD	Standard deviation
WHO	The World Health Organization
DEXA	Dual-energy X-ray absorptiometry
CT	Computed tomography
MRI	Magnetic resonance imaging
BIA	Bioelectrical impedance analysis
GFHSTC	The Guangzhou Falls and Health Status Tracking Cohort
COPD	Chronic obstructive pulmonary disease
BP	Blood pressure
SBP	Systolic blood pressure
DBP	Diastolic blood pressure
TC	Total cholesterol
HDL-C	High-density lipoprotein cholesterol
LDL-C	Low-density lipoprotein cholesterol
TG	Triglycerides
FBG	Fasting blood glucose
CV	Cardiovascular

Supplementary Information

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Supplementary Material 1

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Author contributions

WQL, JMC, MYS, SYS, YYF, CW and HL supervised the study data collection and quality control. WQL, LXY, and JYW conducted the literature review. WQL and LYL conducted the data analyses.JMC and WQL draft the manuscript, WQL and HL finalized the manuscript with inputs from all authors.

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Data availability

The datasets analysed during the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
This study was approved by the Ethic Committee of Guangzhou Center for Disease Control and Prevention (GZCDC-ECHR-2023P0061). All participants provided written informed consent.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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