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Impact of Older Age Adiposity on Incident Diabetes: A Community-Based Cohort Study in China

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Background: Obesity classifications vary globally and the impact of older age adiposity on incident diabetes has not been well-studied.
Methods: We examined a random sample of 2,809 participants aged ≥60 years in China, who were free of diabetes at baseline and were followed up for up to 10 years to document diabetes (n=178). The incidence of diabetes was assessed in relation to different cut-off points of body mass index (BMI) and waist circumference (WC) in multiple adjusted Cox regression models.
Results: The diabetic risk in the cohort increased linearly with the continuous and quartile variables of BMI and WC. The BMI-World Health Organization (WHO) and BMI-China criteria analysis did not show such a linear relationship, however, the BMI-Asian/Hong Kong criteria did; adjusted hazards ratio (HR) was 0.42 (95% confidence interval [CI], 0.20 to 0.90) in BMI <20 kg/m^2, 1.46 (95% CI, 0.99 to 2.14) in 23–≤26 kg/m^2, and 1.63 (95% CI, 1.09 to 2.45) in ≥26 kg/m^2. The WC-China criteria revealed a slightly better prediction of diabetes (adjusted HRs were 1.79 [95% CI, 1.21 to 2.66] and 1.87 [95% CI, 1.22 to 2.88] in central obese action levels 1 and 2) than the WC-WHO. The combination of the BMI-Asian/Hong Kong with WC-China demonstrated the strongest prediction. There were no gender differences in the impact of adiposity on diabetes.
Conclusion: In older Chinese, BMI-Asian/Hong Kong criteria is a better predictor of diabetes than other BMI criterion. Its combination with WC-China improved the prediction of adiposity to diabetes, which would help manage bodyweight in older age to reduce the risk of diabetes.

Keywords: Body mass index; Diabetes mellitus; Waist circumference

INTRODUCTION

Diabetes mellitus (DM) is one of the leading causes of morbidity and mortality in the world. The global disability-adjusted life years of diabetes is 67.9 million [1]. DM causes huge economic problems; the cost of it worldwide was estimated to be

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US $1.31 trillion in 2015 [2]. In 2019, an estimated total of 463 million people suffered from diabetes globally, of which around 135.6 million were among adults aged 65 to 79 years, showing a typically increasing prevalence with age [3].

China has the largest number of adults aged ≥18 years old with diabetes (n=116 million), accounting for approximately 12.8% of adult population [4,5]. This figure of adults with diabetes in China is set to rise to 147 million by 2045 [5]. With an exponentially rising ageing demographic, China has the largest proportion of population aged 65 years and older in the world, exacerbating the escalating burden of diabetes [6]. In an older population, the main form of diabetes is type 2, which accounts for more than 90% of the diabetic population. Previous studies [7,8] showed the risk of type 2 diabetes mellitus (T2DM) significantly increased with being overweight or obese. Body mass index (BMI) and waist circumference (WC) are commonly used measurements for general and central adiposity respectively, while the cut-off points of BMI and WC measuring overweight and obesity vary among different populations according to age, gender, and ethnicity [9]. In China, most studies have used the Chinese BMI criteria to define overweight and obesity associated with health outcomes [10-12].

The knowledge of the impact of adiposity on the incidence of DM is predominately derived from studies conducted in high income countries (HICs) and in young and middle-aged populations [13-15]. The findings of the HICs studies are not generalisable to those in low- and middle-income countries (LMICs), since the populations have different adiposity profiles and patterns of disease risk factors [16,17]. China, the largest LMIC, has an ageing population (an 18% population growth of people aged ≥60 years [18]). The older Chinese population exhibits unique characteristics; with low levels of overweight/obesity in early adulthood due to economic deprivation and high levels of physical activity (manual work), while in older adulthood, increasing adiposity due to ageing, high dietary nutrition over the decades, and decreased physical activity. However, few studies have examined the associations of BMI and WC measured in older age with incident DM. In previous studies, it was quite common that the Chinese BMI cut-off points were associated with DM in the Chinese population. However, these studies [19] were mainly cross-sectional or focused on young and middle-aged populations. There has been a lack of cohort studies examining the increased risk of incident DM in relation to older age adiposity in China. Furthermore, few studies have used different cut-off points of BMI or WC to identify the most powerful predictive values for DM and investigated the combined impact of BMI and WC on the risk of developing diabetes in older people in China [20]. It is also unclear whether there are any gender disparities in the impact of older age adiposity on the incidence of DM.

In this study, we examined a community-based cohort of older people in China to investigate the associations of different BMI and WC cut-off points individually and in combination with the incidence of DM, and to identify if there were any gender differences.

METHODS

Study population and data collection

Studied populations were derived from the Anhui cohort study in China. The methods of the baseline investigations [21] and the follow-up in the cohort study [22,23] have been fully described before. In brief, we randomly selected 1,810 people aged ≥65 years who had lived for at least 5 years in Yiming sub-district of Hefei city in 2001 and 1,709 aged ≥60 years from all 16 villages in Tangdian District of Yingshang County in 2003. A total of 3,336 individuals participated in this study (urban participants n=1,736), with an overall response rate of 94.8%. Informed consent was obtained from each participant. In the case of those who were unable to provide informed consent due to disability or limited level of education, their next of kin or care givers were invited to provide approval for participation. The participants were interviewed at home by a trained survey team from the Anhui Medical University.

The main materials used in the interviews were a general health and risk factors questionnaire, and a Geriatric Mental Status (GMS)—a comprehensive semi-structured mental state interview. In the general health and risk factors record, we collected data relating to sociodemographic information, lifestyles, social networks and support, psychosocial aspects, cardiovascular disease and other disease risk factors [22]. We documented chronic diseases in the general health and risk factors questionnaire. Diabetes was defined based on a recorded doctor-diagnosis in the questionnaire interview for those who answered “Yes” to the question, “Have you ever been told by a doctor that you have diabetes?” [23]. The GMS questionnaire data was read by the Automated Geriatric Examination for Computer Assisted Taxonomy (AGECAT) to diagnose depression and dementia cases for each participant [19]. According to standard procedures, we measured the participants’ blood pressure, body weight, height, and WC. The body weight of each participant was recorded to the nearest 0.1 kg by digital scales with light clothing on, whilst height was measured without shoes to the nearest 0.5 cm by a portable audiometer. The WC was measured to the nearest 0.1 centimetre by using a plastic tape placed at the mid-way between the lowest rib and the iliac crest. We calculated BMI for each participant by dividing measured body weight with the square of height (kg/m²).

Follow-up of cohort

One year after the baseline survey, we re-interviewed 2,608 participants (wave 2) using the same protocol as at baseline. From 2007 to 2009, we successfully re-examined 1,757 surviving cohort members (wave 3), and in 2010 to 2011, we carried out a wave 4 survey and re-interviewed 944 participants. At each wave interview of the follow-up, we documented diabetes based on doctor-diagnosis recorded in the questionnaire.

The vital status of the cohort members was monitored until December 2011. At each survey wave, we conducted home visits to obtain information about participants' survival status through multiple sources including resident committees, family members, neighbours, and friends. In the urban cohort, we also reviewed electronic registration databases from the Centre for Disease Control and Police Registration in Hefei city to identify mortality and causes of deaths. In total we identified 671 deaths during the follow-up of the cohort. For those that were deceased, we used a standard verbal autopsy questionnaire to interview their next of kin responsible or reviewed their death certificate to determine the date and causes of death, including diabetes diagnosis [23].

Data analysis

Of the 3,336 participants, 191 had baseline diabetes and 336 were lost to follow-up. After excluding them, 2,809 participants remained for analysis. Over 10 years follow-up 178 participants were identified to have developed diabetes. We described baseline characteristics of participants using mean ± standard deviation (SD) and percentage (%) and examined differences in their distributions between diabetic and non-diabetic participants in the follow-up using a one-way analysis of variance (ANOVA) for continuous variables and a chi-square test for categorical variables.

We computed person-years at risk to the end of follow up, date of DM diagnosis, date of death, or date of loss to follow-up. We used multivariate adjusted Cox regression models to examine baseline adiposity associated with incident diabetes, calculating hazard ratio (HR) and 95% confidence interval (CI). We examined the continuous BMI and WC, and then their quartiles (Q) associated with incident DM. Following these, we investigated the cut-off points of BMI and WC for overweight and obesity measurements associated with DM. We used three sets of BMI criteria for analysis to compare their predictive values to diabetes; (1) BMI-World Health Organization (WHO) (the criteria recommended for the world population by the WHO) [24], (2) BMI-China (recommended for the Chinese population [25]), and (3) BMI-Asian/Hong Kong (recommended for the Asia and Hong Kong Chinese populations [26]), and two sets of WC cut-off points for analysis; (1) WHO recommended its action level cut-off point [27], and (2) the Chinese Medical Association recommended criteria central obesity for Chinese adults [11,12]. These cut-off points are shown in Supplementary Table 1. We further included the combination of BMI cut-off points with WC central obesity criteria for analysis (the most predictive cut-off point criteria from both BMI and WC would be selected). Finally, we stratified the data by gender for analysis to test differences between men and women in the association of adiposity with the incidence of DM. We computed a ratio of two HRs and tested the differences in the HRs using the methods in our previous studies [22]. All analyses were performed using SPSS version 26.0 (IBM Co., Armonk, NY, USA).

Disclosure

Ethical approval for this cohort study was obtained from the Research Ethics Committee, Anhui Medical University, China (Ref. none, granted in 2001 and 2007) and the Research Ethics Committee, University of Wolverhampton (Ref. A1- Favourable, granted in 2010).

RESULTS

The mean age of the 2,809 participants at baseline was 71.8 ± 6.9 years, 51.7% were women, 50.4% lived in rural areas, and 52.6% were illiterate. Their average BMI was 23.5 ± 3.4 kg/m² and WC 83.99 ± 11.3 cm. According to the Chinese BMI criteria, 52.4% of participants were within normal weight, while 5.4% were underweight, 32.8% overweight and 9.4% obese. The distribution of the participants' baseline characteristics is shown in Table 1. Participants who were overweight/obese were more likely to be younger, live in urban areas, have higher

Table 1. Distribution of socio-demographic and characteristics of participants: the Anhui cohort study

Variable	All participants (n=2,809)	Underweight <18.5 kg/m^2 (n=151)	Normal weight 18.5–<24 kg/m^2 (n=1,472)	Overweight 24–<28 kg/m^2 (n=922)	Obese ≥28 kg/m^2 (n=264)	P value[a]
Age, yr	71.8±6.9	74.2±8.2	72.0±7.2	71.0±6.2	71.3±6.5	<0.001
Sex						
Men	1,356 (48.3)	82 (54.3)	736 (50.0)	482 (52.3)	153 (58.0)	0.095
Women	1,453 (51.7)	69 (45.7)	736 (50.0)	440 (47.7)	111 (42.0)	
Socio-economic status						
Urban-rural						
Urban	1,394 (49.6)	86 (57.0)	664 (45.1)	505 (54.8)	139 (52.7)	<0.001
Rural	1,415 (50.4)	65 (43.0)	808 (54.9)	417 (45.2)	125 (47.3)	
Educational level						
≥High secondary school	626 (22.3)	83 (55.0)	819 (55.6)	444 (48.2)	132 (50.0)	0.005
Secondary school	362 (12.9)	21 (13.9)	177 (12.0)	105 (11.4)	40 (15.2)	
Primary school	343 (12.2)	18 (11.9)	165 (11.2)	139 (15.1)	40 (15.2)	
Illiterate	1,478 (52.6)	29 (19.2)	311 (21.1)	234 (25.4)	52 (19.7)	
Income satisfactory						
Very satisfactory	279 (9.9)	13 (8.6)	132 (9.0)	103 (11.2)	31 (11.7)	0.001
Satisfactory	1,335 (47.5)	70 (46.4)	658 (44.7)	463 (50.2)	144 (54.5)	
Average	939 (33.4)	51 (33.8)	526 (35.7)	285 (30.9)	77 (29.2)	
Poor	256 (9.1)	17 (11.3)	156 (10.6)	71 (7.7)	12 (4.5)	
Lifestyles						
Smoking						
Never smoker	1,429 (50.9)	70 (46.4)	722 (49.0)	491 (53.3)	146 (55.3)	0.002
Former smoker	171 (6.1)	12 (7.9)	88 (6.0)	56 (6.1)	15 (5.7)	
Current smoker	777 (27.7)	44 (29.1)	457 (31.0)	225 (24.4)	51 (19.3)	
Not known[a]	432 (15.4)	25 (16.6)	205 (13.9)	150 (16.3)	52 (19.7)	
Alcohol consumption in the last 2 years						
None	2,269 (80.8)	134 (88.7)	1,156 (78.5)	758 (82.2)	221 (83.7)	0.003
Occasionally/often/daily	540 (19.2)	17 (11.3)	316 (21.5)	164 (17.8)	43 (16.3)	
Walking or group touring						
Yes	1,202 (42.8)	78 (51.7)	696 (47.3)	329 (35.7)	99 (37.5)	<0.001
No	1,607 (57.2)	73 (48.3)	776 (52.7)	593 (64.3)	165 (62.5)	
Waist circumference, cm	83.99±11.3	74.51±8.9	80.55±9.0	87.55±10.9	96.10±11.8	<0.001
Social network and support						
Marital status						
Married	2,031 (72.3)	93 (61.6)	1,040 (70.7)	701 (76.0)	197 (74.6)	0.005
Never married	105 (3.7)	8 (5.3)	62 (4.2)	28 (3.0)	7 (2.7)	
Widowed/divorced	673 (24.0)	50 (33.1)	370 (25.1)	193 (20.9)	60 (22.7)	
Living with						
None	301 (10.7)	18 (11.9)	168 (11.4)	89 (9.7)	26 (9.8)	0.518
Others	2,508 (89.3)	133 (88.1)	1,304 (88.6)	833 (90.3)	238 (90.2)	

(*Continued to the next page*)

Table 1. Continued

Variable	All participants (*n*=2,809)	Underweight <18.5 kg/m^2 (*n*=151)	Normal weight 18.5–<24 kg/m^2 (*n*=1,472)	Overweight 24–<28 kg/m^2 (*n*=922)	Obese ≥28 kg/m^2 (*n*=264)	*P* value[a]
Frequency of visiting children or other relatives						
Daily	1,650 (58.7)	8 (5.3)	56 (3.8)	26 (2.8)	9 (3.4)	0.186
At least weekly	731 (26.0)	19 (12.6)	187 (12.7)	98 (10.6)	25 (9.5)	
At least monthly or less often	329 (11.7)	49 (32.5)	364 (24.7)	249 (27.0)	69 (26.1)	
Never	99 (3.5)	75 (49.7)	865 (58.8)	549 (59.5)	161 (61.0)	
Help available when needed						
No	179 (6.4)	15 (9.9)	108 (7.3)	45 (4.9)	11 (4.2)	0.011
Yes	2,630 (93.6)	136 (90.1)	1,364 (92.7)	877 (95.1)	253 (95.8)	
Psychosocial-factors						
Have trusted friends						
No	670 (23.9)	37 (24.5)	411 (27.9)	180 (19.5)	42 (15.9)	<0.001
Yes	2,139 (76.1)	114 (75.5)	1,061 (72.1)	742 (80.5)	222 (84.1)	
Feeling lonely						
No	2,582 (91.9)	127 (84.1)	1,350 (91.7)	867 (94.0)	238 (90.2)	0.001
Yes	222 (7.9)	22 (14.6)	121 (8.2)	54 (5.9)	25 (9.5)	
Unknown[a]	5 (0.2)	2 (1.3)	1 (0.1)	1 (0.1)	1 (0.4)	
Worrying						
No	2,110 (75.1)	106 (70.2)	1,060 (72.0)	726 (78.7)	218 (82.6)	<0.001
Yes	693 (24.7)	42 (27.8)	411 (27.9)	195 (21.1)	45 (17.0)	
Unknown[a]	6 (0.2)	3 (2.0)	1 (0.1)	1 (0.1)	1 (0.4)	
Relationship with neighbours						
Good	2,076 (73.9)	109 (72.2)	1,052 (71.5)	705 (76.5)	210 (79.5)	0.007
OK/poor	733 (26.1)	42 (27.8)	420 (28.5)	217 (23.5)	54 (20.5)	
Cardiovascular risk factors						
Hypertension status						
No hypertension (<140×90)	1,182 (42.1)	87 (57.6)	696 (47.3)	335 (36.3)	64 (24.2)	<0.001
Undetected	908 (32.3)	40 (26.5)	492 (33.4)	291 (31.6)	85 (32.2)	
Untreated	160 (5.7)	8 (5.3)	72 (4.9)	63 (6.8)	17 (6.4)	
Uncontrolled	433 (15.4)	13 (8.6)	161 (10.9)	184 (20.0)	75 (28.4)	
Controlled	126 (4.5)	3 (2.0)	51 (3.5)	49 (5.3)	23 (8.7)	
Hypercholesterolemia						
No	2,610 (92.9)	145 (96.0)	1,393 (94.6)	834 (90.5)	238 (90.2)	<0.001
Yes	177 (6.3)	4 (2.6)	67 (4.6)	85 (9.2)	21 (8.0)	
Unknown[a]	22 (0.8)	2 (1.3)	12 (0.8)	3 (0.3)	5 (1.9)	
Comorbidities						
Heart disease						
No	2,407 (85.7)	129 (85.4)	1,282 (87.1)	775 (84.1)	221 (83.7)	0.090
Yes	388 (13.8)	20 (13.2)	181 (12.3)	146 (15.8)	41 (15.5)	
Unknown[a]	14 (0.5)	2 (1.3)	9 (0.6)	1 (0.1)	2 (0.8)	
Stroke						
No	2,689 (95.7)	144 (95.4)	1,419 (96.4)	875 (94.9)	251 (95.1)	0.273
Yes	114 (4.1)	6 (4.0)	51 (3.5)	47 (5.1)	10 (3.8)	
Unknown[a]	6 (0.2)	1 (0.7)	2 (0.1)	0	3 (1.1)	

(*Continued to the next page*)

Table 1. Continued

Variable	All participants (*n*=2,809)	Underweight <18.5 kg/m² (*n*=151)	Normal weight 18.5–<24 kg/m² (*n*=1,472)	Overweight 24–<28 kg/m² (*n*=922)	Obese ≥28 kg/m² (*n*=264)	*P* value[a]
GMS-AGECAT diagnosis						
"Well"	2,096 (74.6)	96 (63.6)	1,073 (72.9)	715 (77.5)	212 (80.3)	<0.001
Depression-subcase	94 (3.3)	2 (1.3)	49 (3.3)	39 (4.2)	4 (1.5)	
Depression-case	117 (4.2)	13 (8.6)	70 (4.8)	26 (2.8)	8 (3.0)	
Dementia-subcase	287 (10.2)	21 (13.9)	150 (10.2)	90 (9.8)	26 (9.8)	
Dementia-case	215 (7.7)	19 (12.6)	130 (8.8)	52 (5.6)	14 (5.3)	

Values are presented as mean±standard deviation or number (%).
SD, standard deviation; GMS, Geriatric Mental Status; AGECAT, Automated Geriatric Examination for Computer Assisted Taxonomy.
[a]*P* values in the chi-square test are calculated based on available data, not including "Unknown" data.

levels of education and satisfactory income, be married, have help available when needed, have trusted friends, have a good relationship with neighbours, have increased WC, and hypertension (mainly those uncontrolled) and hypercholesterolemia. They were less likely to smoke or drink alcohol, walk or have group touring, feel lonely, worry, and have depression or dementia. There were no significant differences in gender, living with others, frequency of children/relatives visiting, heart disease and stroke across the four groups of underweight, normal weight, overweight and obese. The details of these differences can be seen in Table 1.

Table 2 shows number, rate, and HR of incident diabetes among participants with different levels of BMI. We found that the continuous and quartile BMI were significantly and linearly associated with incident DM in different co-variables adjustment analysis (Table 2). The age-sex adjusted HR for DM in BMI Q2 versus Q1 was 1.48 (95% CI, 0.90 to 2.45), 1.92 (95% CI, 1.18 to 3.11) in Q3 and 2.53 (95% CI, 1.59 to 4.02) in Q4. With the increased adjustments for socioeconomic status, social networks and support (Model 2 in Table 2), and psychological symptoms and co-morbidities (Model 3 in Table 2), the HRs in Q3 and Q4 were reduced respectively, but the significant linear association with incident diabetes remained. Using the BMI-WHO cut-off points, we found that there were small numbers of participants who were classified as "underweight (<18.5 kg/m²)" or "obese (≥30 kg/m²)." The fully adjusted HRs (Model 3) in the BMI-WHO cut-off point were 0.51 (95% CI, 0.19 to 1.39) in underweight, 1.66 (95% CI, 1.21 to 2.28) in overweight and 1.34 (95% CI, 0.64 to 2.81) in obese when compared to normal weight. The data for BMI-China cut-off points showed that more participants were classified as "overweight" and "obese" with no change in "underweight" participants compared to those in the BMI-WHO categories. The linear association with the incidence of DM appeared to have strengthened. The matched HRs (Model 3) were 0.53 (95% CI, 0.19 to 1.46) for "BMI <18.5 kg/m²," 1.62 (95% CI, 1.16 to 2.25) for "24 to ≤28 kg/m²" and 1.47 (95% CI, 0.89 to 2.41) for "≥28 kg/m²." In the BMI-Asian/Hong-Kong criteria, there was a positive linear association with incidence of diabetes (Table 2).

When analysing WC, we found that the continuous and quartile WC were significantly and linearly associated with the incidence of DM across different sets of adjustments for confounders (Table 3). The measurement for WC-WHO action levels also showed a linear association with incident diabetes, although the significance of the linear association was reduced slightly (Models 2 and 3 in Table 3). When adopting the WC-China cut-off points for central adiposity, which categorised more participants into central obesity action levels, a further linear association was identified with the incidence of diabetes; fully adjusted HR was 1.79 (95% CI, 1.21 to 2.66) in action level 1 and 1.87 (95% CI, 1.22 to 2.88) in action level 2 (Table 3). The data of WC-China action levels in combination with the BMI-Asian/Hong Kong demonstrated a stronger linear relationship with incident diabetes than the other two WC variables (Table 3).

Stratified data by gender demonstrated the patterns of the association of different cut-off points of BMI and WC with incident DM in men and women were similar to those in the total participants; all univariate analysis (Supplementary Table 2) revealed the risk of incident DM significantly increased with increased adiposity (except no significance in women with quartiles of BMI and WC). Table 4 showed fully adjusted HRs

Table 2. Number, rate, and hazard ratio of incident diabetes in older people with BMI: the Anhui cohort study

Variable	Total participants		DM		Model 1				Model 2				Model 3			
	Number	PYAR	Yes	Rate[a]	HR[b]	95% CI		P value	HR[c]	95% CI		P value	HR[d]	95% CI		P value
BMI, kg/m^2 (continuous)	2,809	15,062.87	178	11.82	1.09	1.05	1.13	<0.001	1.08	1.03	1.12	<0.001	1.07	1.03	1.12	0.001
BMI quartile[e]																
Q1	703	3,635.19	25	6.88	1.00				1.00				1.00			
Q2	700	3,972.12	39	9.82	1.48	0.90	2.45	0.124	1.61	0.97	2.67	0.066	1.60	0.96	2.67	0.070
Q3	703	3,686.98	49	13.29	1.92	1.18	3.11	0.008	1.95	1.20	3.18	0.007	1.92	1.17	3.14	0.010
Q4	703	3,768.58	65	17.25	2.53	1.59	4.02	<0.001	2.38	1.49	3.80	<0.001	2.26	1.40	3.66	0.001
BMI-WHO (cut-off point)																
<18.5	151	713.10	4	5.61	0.55	0.20	1.51	0.246	0.49	0.18	1.34	0.166	0.51	0.19	1.39	0.185
18.5–<24.9	1,816	9,908.86	94	9.49	1.00				1.00				1.00			
25–<29.9	750	3,967.77	72	18.15	1.88	1.39	2.56	<0.001	1.72	1.26	2.35	0.001	1.66	1.21	2.28	0.002
≥30	92	473.15	8	16.91	1.73	0.84	3.56	0.139	1.43	0.69	2.98	0.337	1.34	0.64	2.81	0.438
BMI-China (cut-off point)																
<18.5	151	713.10	4	5.61	0.59	0.21	1.60	0.297	0.52	0.19	1.43	0.202	0.53	0.19	1.46	0.218
18.5–<24	1,472	8,061.33	72	8.93	1.00				1.00				1.00			
24–<28	922	4,888.86	80	16.36	1.81	1.31	2.49	<0.001	1.68	1.22	2.31	0.002	1.62	1.16	2.25	0.004
≥28	264	1,399.59	22	15.72	1.72	1.07	2.78	0.026	1.53	0.95	2.49	0.083	1.47	0.89	2.41	0.130
BMI-Asian/HK (cut-off point)																
<20	392	1,983.02	8	4.03	0.43	0.20	0.90	0.026	0.41	0.19	0.88	0.021	0.42	0.20	0.90	0.026
20–<23	902	4,982.90	45	9.03	1.00				1.00				1.00			
23–<26	905	4,818.37	68	14.11	1.53	1.05	2.23	0.028	1.48	1.10	2.16	0.045	1.46	0.99	2.14	0.056
≥26	610	3,278.58	57	17.39	1.88	1.27	2.79	0.002	1.69	1.14	2.51	0.010	1.63	1.09	2.45	0.018

BMI male quartile ranges (Q1: 14.53 to 21.30 kg/m^2; Q2: 21.33 to 23.19 kg/m^2; Q3: 23.20 to 25.35 kg/m^2; Q4: 25.39 to 37.25 kg/m^2). BMI female quartile ranges (Q1: 14.27 to 21.16 kg/m^2; Q2: 21.17 to 23.44 kg/m^2; Q3: 23.46 to 25.77 kg/m^2; Q4: 25.78 to 41.05 kg/m^2).

BMI, body mass index; DM, diabetes mellitus; PYAR, person years at risk; HR, hazard ratio; CI, confidence interval; WHO, World Health Organization; HK, Hong Kong.

[a]Per 1,000 PYAR, [b]Adjusted for age (continuous), sex, [c]Adjusted for age (continuous), sex, urban-rural, education level, income, smoking, drinking alcohol, walking or group touring, marital status, help available when needed, have trusted friends and relationship with neighbours, [d]Adjusted for age (continuous), sex, urban-rural, education level, income, smoking, drinking alcohol, walking or group touring, marital status, help available when needed, have trusted friends, relationship with neighbours, feeling lonely, worrying, hypertension status group, hypercholesterolemia, and depression & dementia, [e]BMI quartile variable uses male and female data combined.

Table 3. Number, rate, and hazard ratio of incident diabetes in older people with WC and combination of WC and BMI: the Anhui cohort study

Variable	Total participants		DM		Model 1				Model 2				Model 3			
	Number	PYAR	Yes	Rate[a]	HR[b]	95% CI		*P* value	HR[c]	95% CI		*P* value	HR[d]	95% CI		*P* value
WC (continuous)	2,809	15,062.87	178	11.82	1.04	1.03	1.05	<0.001	1.03	1.01	1.04	<0.001	1.03	1.01	1.04	<0.001
WC-Quartiles[e]																
Q1	693	3,822.32	25	6.54	1.00				1.00				1.00			
Q2	743	4,063.25	31	7.63	1.15	0.68	1.96	0.594	1.09	0.64	1.85	0.756	1.07	0.63	1.83	0.803
Q3	648	3,458.95	54	15.61	2.39	1.49	3.84	<0.001	1.87	1.15	3.05	0.012	1.81	1.11	2.97	0.018
Q4	725	3,718.34	68	18.29	2.82	1.78	4.45	<0.001	1.93	1.18	3.14	0.009	1.83	1.12	3.01	0.017
WC-WHO action level																
No action	1,638	8,852.35	77	8.70	1.00				1.00				1.00			
Action level 1	576	3,087.07	43	13.93	1.79	1.22	2.65	0.003	1.43	0.96	2.13	0.082	1.37	0.91	2.05	0.133
Action level 2	595	3,123.46	58	18.57	2.53	1.75	3.67	<0.001	1.73	1.16	2.57	0.007	1.65	1.10	2.48	0.015
WC-China criteria[e]																
Level 0	1,272	7,018.53	46	6.55	1.00				1.00				1.00			
Level 1	883	4,674.63	70	14.97	2.30	1.59	3.35	<0.001	1.86	1.26	2.74	0.002	1.79	1.21	2.66	0.004
Level 2	654	3,369.71	62	18.40	2.89	1.97	4.24	<0.001	1.99	1.31	3.02	0.001	1.87	1.22	2.88	0.004
WC-China combined with BMI-Asian/HK[f]																
Group 1	820	4,458.27	28	6.28	1.00				1.00				1.00			
Group 2	1,040	5,632.60	63	11.18	1.78	1.14	2.79	0.011	1.54	0.98	2.43	0.060	1.49	0.95	2.35	0.086
Group 3	405	2,191.33	31	14.15	2.26	1.35	3.76	0.002	1.87	1.11	3.15	0.019	1.84	1.09	3.12	0.023
Group 4	544	2,780.66	56	20.14	3.22	2.04	5.07	0.000	2.23	1.38	3.61	0.001	2.08	1.27	3.41	0.004

WC male quartile range (Q1: 50.00 to 76.00 cm; Q2: 77.00 to 84.00 cm; Q3: 85.00 to 91.00 cm; Q4: 92.00 to 132.00 cm). WC female quartile range (Q1: 57.00 to 74.50 cm; Q2: 75.00 to 81.00 cm; Q3: 81.50 to 89.50 cm; Q4: 90.00 to 123.00 cm).

WC, waist circumference; BMI, body mass index; DM, diabetes mellitus; PYAR, person years at risk; HR, hazard ratio; CI, confidence interval; WHO, World Health Organization; HK, Hong Kong.

[a]Per 1,000 PYAR, [b]Adjusted for age (continuous), sex, [c]Adjusted for age (continuous), sex, urban-rural, education level, income, smoking, drinking alcohol, walking or group touring, marital status, help available when needed, have trusted friends and relationship with neighbours, [d]Adjusted for age (continuous), sex, urban-rural, education level, income, smoking, drinking alcohol, walking or group touring, marital status, help available when needed, have trusted friends, relationship with neighbours, feeling lonely, worrying, hypertension status group, hypercholesterolemia, and depression & dementia, [e]WC quartiles uses male and female data combined, [f]WC-China—the waist cut measurements were combined with BMI-Asian/HK cut-off points. The groups were as follows: Group 1 (WC 0 and BMI 0 or WC 0 and BMI 1), Group 2 (WC 0 and BMI 2 or WC 1 and BMI 0 or WC 1 and BMI 1 or WC 1 and BMI 2), Group 3 (WC 0 and BMI 3 or WC 1 and BMI 3 or WC 2 and BMI 0 or WC2 and BMI 1), Group 4 (WC 2 and BMI 2 or WC2 and BMI 3).

Table 4. Adjusted HRs of incident diabetes across different measurements by BMI and WC in men and in women, and gender differences: the Anhui cohort study

Adiposity variable	Men				Women				Gender differences	
	HR[a]	95% CI		*P* value	HR[a]	95% CI		*P* value	RHR	*P* value
BMI (continuous)	1.09	1.02	1.17	0.011	1.06	1.01	1.12	0.032	1.03	0.524
BMI quartile[b]										
Q1	1.00				1.00				1.00	
Q2	1.79	0.82	3.87	0.142	1.54	0.78	3.07	0.214	1.16	0.776
Q3	2.16	1.32	4.51	0.030	1.79	0.91	3.51	0.092	1.21	0.686
Q4	2.82	1.38	5.75	0.004	1.95	1.01	3.77	0.047	1.45	0.456
BMI-WHO (cut-off point)										
<18.5	0.77	0.23	2.53	0.664	0.20	0.03	1.49	0.117	3.85	0.248
18.5–<24.9	1.00				1.00				1.00	
25–<29.9	1.80	1.14	2.85	0.012	1.49	0.96	2.33	0.076	1.21	0.562
≥30	1.10	0.26	4.68	0.898	1.48	0.61	3.58	0.388	0.74	0.732
BMI-China (cut-off point)										
<18.5	0.83	0.25	2.78	0.765	0.20	0.03	1.51	0.120	4.15	0.226
18.5–<24	1.00				1.00				1.00	
24–<28	1.72	1.07	2.79	0.026	1.51	0.96	2.39	0.077	1.14	0.700
≥28	1.92	0.91	4.05	0.089	1.17	0.59	2.31	0.661	1.64	0.338
BMI-Asian/HK (cut-off point)										
<20	0.63	0.23	1.71	0.366	0.22	0.07	0.74	0.015	2.86	0.182
20–<23	1.00				1.00				1.00	
23–<26	1.74	0.98	3.11	0.060	1.23	0.73	2.09	0.437	1.41	0.384
≥26	2.13	1.15	3.93	0.016	1.29	0.74	2.25	0.363	1.65	0.236
WC (continuous)	1.03	1.01	1.05	0.002	1.02	1.00	1.04	0.125	1.01	0.488
WC quartiles[b]										
Q1	1.00				1.00				1.00	
Q2	0.84	0.35	2.05	0.706	1.19	0.61	2.34	0.614	0.71	0.538
Q3	1.85	0.84	4.05	0.125	1.66	0.86	3.21	0.131	1.11	0.836
Q4	1.96	0.89	4.34	0.097	1.47	0.76	2.87	0.255	1.33	0.586
WC-WHO										
No action	1.00				1.00				1.00	
Action level 1	1.14	0.62	2.06	0.679	1.32	0.75	2.31	0.331	0.86	0.726
Action level 2	1.78	0.99	3.22	0.055	1.52	0.88	2.62	0.134	1.17	0.700
WC-China										
Level 0	1.00				1.00				1.00	
Level 1	2.03	1.10	3.74	0.023	1.44	0.85	2.43	0.174	1.41	0.404
Level 2	2.20	1.14	4.24	0.020	1.38	0.77	2.47	0.280	1.59	0.298
WC-China combined with BMI-Asian/HK										
Group 1	1				1.00				1.00	
Group 2	1.77	0.87	3.62	0.116	1.25	0.68	2.30	0.473	1.42	0.467
Group 3	2.10	0.92	4.79	0.079	1.56	0.78	3.13	0.212	1.35	0.589
Group 4	2.65	1.23	5.70	0.013	1.56	0.80	3.02	0.189	1.70	0.306

HR, hazard ratio; BMI, body mass index; WC, waist circumference; CI, confidence interval; RHR, ratio of hazard ratio; WHO, World Health Organization; HK, Hong Kong.
[a]Adjusted for age (continuous), sex, urban-rural, education level, income, smoking, drinking alcohol, walking or group touring, marital status, help available when needed, have trusted friends, relationship with neighbours, feeling lonely, worrying, hypertension status group, hypercholesterolemia, and depression & dementia, [b]BMI quartile variable uses male and female data combined.

of incident DM in relation to adiposity in men compared to their female counterparts. There were no significant gender differences in the association of adiposity with the risk of DM (Table 4).

DISCUSSION

Our community-based cohort study from China examined the risk of incident diabetes in relation to adiposity measured by BMI and WC in older people. The predictive value of BMI in this study seemed to be better than WC in their continuous and quartile data analysis. Using different criteria for BMI cut-off points to define overweight and obesity in older Chinese, we found that the BMI Asian/Hong Kong cut-off point criteria was better at predicting risk of DM than BMI-WHO and BMI-China. Data of waist action level showed a similar predictive value for incident DM risk to Asian/Hong Kong BMI. The WC-China criteria may be slightly better than WC-WHO. When combining the cut-off point data of the BMI-Asian/Hong Kong with WC-China for adiposity measurements, we found its predictive value for diabetes risk was the highest. There were no significant gender differences in the impact of older age adiposity on incident DM.

BMI and WC measured for adiposity associated with incidence of diabetes

Previous studies suggested similar predictive values of BMI and WC on the incidence of diabetes [9,14], but these would be subject to which cut-off points were used. A recent meta-analysis study [17] showed that compared to BMI ≥30 kg/m^2, WC ≥102 cm in men or 88 in women cm was a better predictor for the development of diabetes at ages over 60 years. Lee et al. [28] performed a meta-analysis, including 21 studies with 154,998 participants and 9,342 cases of incidence of diabetes to compare the ability of commonly used anthropometric measures associated with incident diabetes. They found that a one SD increment in WC was more strongly associated with the 5-year risk of incidence of DM than BMI in the general population, but there was no appreciable difference between these measures in the predictive accuracy for diabetes. Further analysis for the subgroups by age showed that the point estimates for the impacts of BMI and WC on incident DM seemed greater in populations aged <50 years than those aged ≥50, but the 95% CIs overlapped. In previous literature [17,28], most studies were conducted in the west and HICs and in young and middle-aged populations, and their findings may not be generalisable to people in China, particularly in the older Chinese population. Compared to white Caucasians, Chinese and Asians appear to have higher morbidity at lower cut-off points for BMI and WC [29]. We have analysed different cut-off points of BMI and found that the BMI-Asian/Hong Kong criteria was the best predictor of incident DM in older Chinese people.

Few studies measured both BMI and WC simultaneously to predict diabetes in older people. Recently, there have been several studies published to examine which of the two obesity measures is the better predictor of incident diabetes in the Chinese population [23,30-33]. Jia et al. [31] followed 48,015 men and 13,688 women adults aged 18 to 85 years old, which were derived from the health examinations of employees of the Kailuan Company in Tangshan city, China, for a median duration of two years and found that WC measurements could be a better predictor of DM than BMI. In a cohort study of 15,752 Chinese people aged ≥50 years with 4-year follow-up, Xu et al. [33] found that the predictive value of WC for incident diabetes risk (adjusted odds ratio, 1.93; 95% CI, 1.71 to 2.17) was higher than BMI (adjusted odds ratio, 1.76; 95% CI, 1.50 to 2.06). The authors suggested that measuring abdominal obesity was a better predictor of diabetes risk in participants than measuring general obesity. However, these findings were mainly in middle-aged populations, and only a few studies included and focused on the older population. Our study of Chinese aged ≥60 years with 10-year follow-up, demonstrated adiposity significantly increased the risk of DM, with a stronger predictive value of BMI than WC in terms of their continuous variable and quartile variable data analysis.

Gender differences in the association of adiposity with incident diabetes

Gender differences in the impact of older age adiposity on diabetes risk is not well investigated [17]. Most studies on gender differences have focused on middle-aged populations [34,35]. In Scotland, Logue et al. [34] examined 51,920 men and 43,137 women aged ≥20 years, and found that men were diagnosed with T2DM at a lower BMI than women across age groups. A meta-analysis by Seo et al. [17] found that central obesity may be a more serious risk factor for diabetes in people aged ≥60 years and in women than their counterparts. Lee et al. [28] reported a stronger impact of WC in women than men as well, but the impact of BMI on DM was stronger in men than women. In a cohort study of 990 men and 1,033 women aged 70 years and over in China who were examined at baseline and after 36 months, Woo et al. [30] found that both BMI and WC were positively associated with diabetes, in men but not women. In the United States, Biggs et al. [13] examined 4,193 men and women aged ≥65 years with a median follow-up of 12.4 years, and found that compared to women, men had a higher risk of T2DM at a lower BMI and WC. Our study showed no significant gender differences in the impact of adiposity measured by BMI and WC on the risk of diabetes, suggesting that the contributions of general and central obesity on incident DM were equally important for men and women.

Strengths and limitations of the study

To the best of our knowledge, this study is the first to examine the predictive values of adiposity measured by different cut-off points of BMI and WC in older age for incidence of DM in China. It included 2,809 older people living in the rural and urban communities with a long-term follow-up, and adjusted for many important confounders. The predictive values for incidence of DM using different cut-off points of BMI and WC and the combination of BMI and WC were explored. This has allowed for more predictive values of adiposity measurement on diabetes risk to be investigated rather than the traditional snapshot of obesity measurements such as BMI, or WC alone. The study has limitations. First, the information about diabetes was largely obtained from a self-reported doctor diagnosis at the interview, rather than actual glycaemia, which may miss those who did not have detected or diagnosed DM, leading to an underestimation of the association of adiposity with incident DM in this study. However, previous studies have shown that self-reported diabetes in older people are acceptably reliable [36], and self-reported doctor diagnosis of diabetes has been validated in the older Chinese population [37]. Thus, the underestimated effect should be minimised. Nevertheless, a large-scale cohort study based on measurement of actual glycaemia is required to examine the impact of older age obesity on incidence of diabetes. Second, there were 336 participants who were lost to follow-up in the original cohort; we do not know whether they had a higher or lower level of risk in developing diabetes than the 2,809 cohort members. This may have led to either an over- or under-estimation of the predictive values. However, the rate of loss to follow-up in our study is similar to those in some studies undertaken in Western countries [38], and due to its small proportion of the loss to follow-up (10.7%) the effect would be minimised. Third, our study examined the associations of BMI and WC at baseline with followed-up incidence of diabetes, but did not consider any body weight changes including weight loss, weight gain, and stable weight during the follow-up period for analysis. Thus, our findings of the associations of adiposity measured in older age with incidence of DM may be more conservative. More research is needed to examine the adiposity changes in the follow-up of the cohort associated with incidence of DM in older people.

Implications

Our study has shown that increased BMI and WC in older age were significantly associated with a greater risk of developing diabetes in both men and women. This highlights the importance of management of overall and central obesity in older people. Our study does not support the paradox of 'beneficial impacts of overweight and obesity in older age' due to reduced risk of dementia and all-cause mortality [39]. Together with our findings of this and other studies of overweight and obesity in older age associated with morbidities and mortality (e.g., COVID-19) [40], we strongly recommend that older men and women in China should maintain an ideal bodyweight (using the BMI-Asian/Hong-Kong criteria for management) and girth growth (using WC-China criteria for management) to reduce the risk of DM and other co-morbidities.

Our findings demonstrate that the combined BMI and WC measurement for adiposity was a strong predictor of incident diabetes in older Chinese. This suggests that such a combination measure for adiposity in older people should be used for bodyweight management in older people, since it would require little extra cost or equipment and could increase clinicians' ability to identify individuals at high risk for diabetes. To reduce the risk of diabetes in late life, older people should undergo lifestyle interventions such as increased physical activity, bodyweight management, a reduced fat, sugar, and calorie diet [41,42].

In conclusion, adiposity in older age significantly increased the risk of incident diabetes in both men and women. It would be considered more appropriate to use the Asian/Hong Kong criteria of BMI cut-off point and WC-China to analyse adiposity in older age instead of the other BMI and WC criterion mentioned. Our study suggested that the combined use of BMI and WC was a stronger predictor of diabetes risk in older people. There were no significant gender differences in the predictive values of BMI and WC measurements on diabetes risk, and thus it would be of equal importance for controlling adiposity in older men and women to reduce the risk of DM.

SUPPLEMENTARY MATERIALS

Supplementary materials related to this article can be found online at https://doi.org/10.4093/dmj.2021.0215.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

AUTHOR CONTRIBUTIONS

Conception or design: A.C., Y.D., Z.H., R.C.
Acquisition, analysis, or interpretation of data: A.C., W.Z., J.H., A.N., Y.W., R.J., X.Q., R.C.
Drafting the work or revising: A.C., W.Z., J.H., A.N., Y.D., R.J, X.Q., Z.H., R.C.
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