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Body Mass Index, Waist-to-Hip Ratio and Cognitive Function among Chinese Elderly

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Body Mass Index, Waist-to-Hip Ratio and Cognitive Function among Chinese Elderly

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Abstract

Objectives: To investigate the associations between body mass index (BMI), waist-to-hip ratio (WHR) and cognitive function among Chinese elderly.

Design: Cross-sectional study.

Setting: Community.

Participants: Data was obtained from the baseline survey of a community based cohort in Zhejiang Province, and enrolled 9 326 persons aged 60 years and older.

Primary outcome measures: We investigated the effect of BMI on cognition, and then explored the effect of WHR on cognition across different quartiles of BMI.

Results: A sample of 9 087 persons was used in this study, including 4 375 men and 4 712 women. Higher WHR increased cognitive impairment risk in those with BMI > 25.3 kg/m^2 (OR (per 0.1 increase), 1.39, 95% CI, 1.13-1.70). No statistically significant association was found in other BMI categories.

Conclusions: WHR could increase risk for cognitive impairment among elderly with BMI > 25.3 kg/m^2. Our results suggest that it could be of benefit for the elderly with high BMI to control WHR.

Strengths and limitations of this study:

The strength of this study was the in-depth analysis of the effect of waist-to-hip ratio on cognitive impairment across different body mass index categories.

High fat diet, which is an important influence factor for cognitive function as mentioned above, was not included in this study.

Since this was a cross-sectional study, caution would be needed when generalizing the

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present findings.

Keywords: cognitive function, body mass index, abdominal obesity, elderly, Chinese

Introduction

Cognitive impairment is an important health issue in the elderly. An estimated 46.8 million people currently have dementia in the world, the most well-known form of cognitive impairment, and this number will rise to 131.5 million in 2050. It was estimated over 9.5 million people with dementia in China, which was 20% of the total number of people in the world with dementia. By 2030, the number of people living with dementia in China is expected to rise to over 16 million [1]. The incidence of dementia in people aged 60 years and older [2], is 9.87 cases per 1000 person-years in China, and the situation of cognitive impairment would be more serious [3].

Obesity was widely recognized as an influence factor of dementia [4 5]. Body mass index (BMI) and waist-to-hip ratio (WHR) are common index assessing obesity around the world. Both too high and low BMI are harmful to health, such as increasing risk for development of numerous chronic disease, and even associated with increased mortality [6 7]. Studies of BMI and cognitive impairment in the elderly have shown conflicting results: both positive and negative association have been reported [8-12]. One possible explanation for the heterogeneous findings is that BMI is affected by both fat and fat-free mass, which may have opposite effects on health [13]. This is a limitation of BMI when comparing individuals with same weight and height but different body fat content. The use of BMI as a surrogate for body fat may be particularly problematic in the elderly due to the effect of aging on fat distribution [14]. Therefore, WHR, as a proxy for body fat distribution, would be a complementary indicator in health related studies for the elderly. It has been reported that high WHR was associated with adverse health outcomes independent of BMI [15 16].

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However, to our knowledge, few studies have evaluated the effect of BMI and WHR on

cognitive impairment in a large Chinese elderly population. To help shed light on this area,

we investigated the associations between BMI, WHR and cognitive impairment among

Chinese aged 60 years and older.

Materials and Methods

Study Population

The present study used data collected from the baseline survey of a community-based

cohort study focusing on aging and health problems among the elderly in Zhejiang Province,

China since 2014. In brief, 6 out of 90 counties were randomly selected from Zhejiang

Province, with at least 1 500 permanent residents aged 60 years and above were randomly

recruited in each county for participation in 2014. Finally 9 326 subjects were enrolled.

During the baseline survey, we performed questionnaire based interview, physical

examinations and laboratory tests for each participant. Informed consent was obtained from

all participants, and the study was approved by the Ethics Committee of Zhejiang Provincial

Center for Disease Control and Prevention. A sample of 9 087 of 9 326 participants was

included in this study. The remained 239 were excluded because of missing values in age,

Chinese language version of the Mini-Mental State Examination (MMSE) score, or BMI.

Cognitive Function

Cognitive function was determined by MMSE, which included 30 items. The maximum

score of MMSE is 30, and higher scores indicate better cognitive function. According to

Wang et al., The questionnaire of MMSE has good reliability and validity as an instrument to

detect cognitive impairment among Chinese [17]. The widely accepted cut-off score of

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cognitive impairment in China is education-specific: 17/18 for illiteracy, 20/21 for people

with primary education level, 24/25 for people with higher than primary education level [18].

Body Mass Index (BMI)

BMI (kg/m^2) was calculated as the body weight (by kilograms) divided by the square of

the body height (by meters). All the participants were asked to remove shoes, heavy clothing,

and hats prior to height and weight measurements, and have the participants stand straight

with heels together, legs straight, and looking straight ahead.

Waist-to-hip Ratio (WHR)

Waist circumference was measured midway between the lower rib margin and iliac crest.

Hip circumference was measured at the level of the widest circumference over the greater

trochanters. In the baseline survey, waist circumference and hip circumference were

measured twice, and the difference of two measured values were restricted in ±2 centimeters.

Waist-hip ratio was calculated as waist circumference divided by hip circumference. In this

study, waist circumference and hip circumference were calculated as mean of two measured

values.

Covariates

Covariates were collected by face-to-face interview with questionnaire, including: age,

race, education level, marital status, economic status, smoking, alcohol drinking, physical

exercise, hypertension (diagnosed by doctors), diabetes (diagnosed by doctors), coronary

heart disease (diagnosed by doctors), and depressive symptom. Depressive symptom was

determined using the Patient Health Questionnaire- 9 scale (PHQ-9). Those scored 5 or above

were defined as depression [19].

Statistical Analysis

Descriptive statistics were applied to illustrate the socio-demographic and health

characteristics of the enrolled participants. Differences of the characteristics across different

cognitive status groups were assessed by *t*-test for continuous variables, and by Chi-square

test for categorical variables. Logistic regressions were used to examine the effects of BMI

and WHR on cognitive impairment. BMI was evaluated as categorical variable, divided by

quartiles. WHR was evaluated under different BMI levels. Both BMI and WHR were

assessed by 3 logistic models. In the basic model (model 1), no covariate was included when

assessing the effect of BMI on cognitive impairment, and BMI was adjusted when assessing

the effect of WHR. Model 2 was based on model 1, with adjusting for additional

socio-demographics variables (age, sex, nation, education, marital status, and family

economics). Model 3 was based on model 2, with additional adjustments of lifestyles

(smoking, drinking, and physic exercise) and health variables (hypertension, stroke, and

depression).

All statistical analyses were performed by SAS 9.4 (SAS Institute Inc., Cary, NC), and

two tailed *P*-value <0.05 was considered statistically significant.

Results

Socio-demographics and health Characteristics

Of the 9 087 subjects, 1 339 (14.7%) were defined as cognitive impairment by MMSE.

The mean age of all the subjects was 69.8 (±8.3). More than a half (51.9) was female. Among

the subjects with cognitive impairment, the mean MMSE score was 13.6 (±5.1), while the

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mean score was 25.8 (±3.1) in normal cognition group. The mean values of BMI and WHR

were 22.7±3.6, 0.9±0.1, respectively in the cognitive impairment group, and the mean values

were 23.3±3.3, 0.9±0.1, respectively in normal cognition group. Differences of BMI and

WHR between the two groups were both significant statistically. The subjects with cognitive

impairment tended to be older, female, minority ethnic group, without physical exercise, with

hypertension, with stroke, with depression. Also, cognitive impairment was associated with

education, marital status, family economics, smoking, and drinking. More details were shown

in Table 1.

Table 1. Socio-demographics and health characteristics of 9087 participants by cognitive
status

Characteristics	Normal cognition (*n*=7748)	Cognitive impairment (*n*=1339)	Overall	*P*
Age, years(mean, SD)	68.8±7.8	75.4±8.5	69.8±8.3	<0.001
Sex				<0.001
Male	3877(50.0)	498(37.2)	4375(48.1)	
Female	3871(50.0)	841(62.8)	4712(51.9)	
Nation				<0.001
Han	7489(96.7)	1213(90.6)	8702(95.8)	
Minority	259(3.3)	126(9.4)	385(4.2)	
Education				<0.001
Illiteracy	3703(47.8)	893(66.7)	4596(50.6)	
Primary school	3461(44.7)	379(28.3)	3840(42.3)	
Middle school or higher	584(7.5)	67(5.0)	651(7.2)	
Marital status				<0.001
Single	104(1.4)	38(2.8)	142(1.6)	
Married	6060(78.4)	776(58.0)	6836(75.4)	
Windowed/Divorced	1566(20.3)	525(39.2)	2091(23.1)	
Family economics				<0.001
Rich	796(10.3)	77(5.8)	873(9.6)	
Median	6135(79.2)	984(73.5)	7119(78.4)	
Poor	817(10.5)	277(20.7)	1094(12.0)	
Smoking				<0.001
Current smokers	1749(22.6)	173(12.9)	1922(21.2)	
Ex-smokers	768(9.9)	121(9.0)	889(9.8)	
Never smokers	5231(67.5)	1045(78.0)	6276(69.1)	

Drinking				<0.001
Current drinkers	2079(26.8)	204(15.2)	2283(25.1)	
Ex-drinkers	662(8.5)	158(11.8)	820(9.0)	
Never drinkers	5007(64.6)	977(73.0)	5984(65.9)	
Physic exercise	1499(19.4)	190(14.2)	1689(18.6)	<0.001
Hypertension	3462(44.7)	648(48.4)	4110(45.2)	0.011
Diabetes	667(8.6)	113(8.4)	780(8.6)	0.838
Coronary heart disease	230(3.0)	48(3.6)	278(3.1)	0.227
Stroke	204(2.6)	91(6.8)	295(3.2)	<0.001
Depression	664(8.6)	275(20.5)	939(10.3)	<0.001
Body mass index	23.3±3.3	22.7±3.6	23.2±3.4	<0.001
Waist-to-Hip ratio	0.9±0.1	0.9±0.1	0.9±0.1	0.026
MMSE score	25.8±3.1	13.6±5.1	24.0±5.6	<0.001

Association between BMI and cognitive impairment

The mean MMSE scores were calculated by quartiles of BMI. The highest quartile of

BMI had the highest mean MMSE score (24.36±5.28), and the lowest quartile had the lowest

mean value (23.33±5.94). Compared with the 2rd quartile of BMI, the odds ratio (OR) of the

lowest quartile was 1.42 (95% confidence interval (CI), 1.21-1.67), the OR of the highest

quartile was 0.86 (95% CI, 0.72-1.02), and the 3rd quartile had an OR value of 0.92 (95% CI,

0.77-1.08). In model 3, the OR of Q1 BMI was close to being statistically significant, and

these results were essentially unchanged after adjustment for more covariates (Table 2).

Table 2. Association between body mass index and cognitive impairment

Quartiles of body mass index	Odds ratio (95% confidence interval)		
	Model 1[a] (*n*=9087)	Model 2[b] (*n*=9068)	Model 3[c] (*n*=9068)
Q1 (12.1-20.8)	1.42 (1.21-1.67)	1.20 (1.01-1.42)	1.18 (0.99-1.40)
Q2 (>20.8-22.9)	1	1	1
Q3 (>22.9-25.3)	0.92 (0.77-1.08)	1.02 (0.85-1.22)	1.02 (0.85-1.22)
Q4 (>25.3-42.8)	0.86 (0.72-1.02)	0.95 (0.79-1.14)	0.93 (0.77-1.12)

[a] No covariate was included.

[b] Adjusted for age, sex, nation, education, marital status, and family economics.

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c Based on model 2, model 3 was further adjusted for smoking, drinking, physic exercise, hypertension, stroke, and depression.

Association between waist-to-hip ratio and cognitive impairment

We detected two-way interaction between BMI and WHR, and the result was significant (*P*=0.002). Further, the association between WHR and cognitive impairment was assessed under each BMI group. Under the lowest BMI group, the association between WHR and cognitive impairment was not statistically significant. The situation was similar in the 2nd and 3rd quartile of BMI. In the highest BMI group, each 0.1 higher WHR corresponded to a 1.39 folds higher risk of cognitive impairment in the basic model. The OR value remained significant after adjusting for more covariates in model 2 and model 3, which were 1.36 (95% CI, 1.10-1.69) and 1.37 (95% CI, 1.10-1.71), respectively (Table 3).

Table 3. Association of waist-to-hip ratio (per 0.1 increase) with cognitive impairment under different body mass index group

	Quartiles of body mass index			
	Q1	Q2	Q3	Q4
Subjects (*n*)	2244	2266	2311	2266
Waist-to-hip ratio				
Range	0.61-1.26	0.46-1.29	0.49-1.49	0.58-1.38
Mean	0.87±0.07	0.89±0.06	0.91±0.06	0.93±0.06
Model 1[a]	1.13 (0.98-1.31)	1.12 (0.93-1.35)	1.38 (1.14-1.65)	1.39 (1.13-1.70)
Model 2[b]	1.01 (0.86-1.18)	0.93 (0.75-1.13)	1.13 (0.94-1.41)	1.36 (1.10-1.69)
Model 3[c]	0.99 (0.83-1.17)	0.92 (0.75-1.13)	1.14 (0.93-1.40)	1.37 (1.10-1.71)

[a] Adjusted for body mass index.

[b] Based on model 1, model 2 was further adjusted for age, sex, nation, education, marital status, and family economics.

[c] Based on model 2, model 3 was further adjusted for smoking, drinking, physic exercise, hypertension, stroke, and depression.

Discussion

In this cross-sectional study of 9087 Chinese elderly aged 60 years and older, we

investigated the associations between BMI, WHR and cognitive impairment risk. We found

that each 0.1 unit increase in WHR corresponded to 1.37 (1.10-1.71) evaluated cognitive

impairment risk in high BMI (>25.3 kg/m^2) group in the fully adjusted model (model 3).

In our study, compared with Q2 BMI (>20.8-22.9 kg/m^2), Q1 BMI (≤ 20.8 kg/m^2) was a

risk factor for cognitive impairment, while Q4 BMI tended to be a protective factor, though

not statistically significant. In previous studies, some have shown that high BMI tended to be

a risk factor for cognitive decline [10-12], while others observed protective effect of high

BMI on cognitive function [4 5 8 9]. The inconsistence suggests the relationship between

BMI and cognitive function is complex.

Zhou et al. [20] suggested that subjects who were both with obesity and dementia had a

high mortality rate, which might very likely remove those with high BMI and dementia, and

leave moderate or severe dementia subjects with low BMI, thus enforce the association

between BMI and dementia. Assuming the survivor bias existed, the observed association

between high BMI and cognition impairment would be biased towards the null, and such bias

would be even more serious in cross-sectional study if it exists. Nevertheless, the hypothesis

is not enough to explain the relationship between low BMI and cognitive impairment.

Furthermore, several cohort studies reported that both persons with low BMI and persons

with high BMI have lower cognitive functions in later life [21-25].

Among the participants of this study, the mean value of WHR tended to increase within

higher BMI group. We observed a strong positive association between WHR and cognitive

impairment risk under Q4 BMI (>25.3 kg/m^2) group, but no significant association was found

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among other BMI group (Q1-Q3). The association remained after adjusting for covariates.

Our results reveled that elderly with higher WHR in the highest BMI group have an elevated

risk of cognitive impairment, which suggested targeted prevention and screening for this

high-risk group. It is reported that adipokines might be a link between obesity and dementia.

Adipokines include hundreds of polypeptides secreted by the cells of white adipose tissue.

The action of adipokines could be altered during neurodegenerative events and might

feedback to contribute to neurodegeneration [26]. It is noteworthy to mention that previous

studies have reported high fat diet exacerbates cognitive decline [27 28]. Amyloid deposition,

and cerebral microvasculature dysfunction are the most discussed reasons in relevant studies

[27-30]. These findings suggest further studies are needed to explore the mechanisms that

underlie the association between obesity and cognitive impairment.

Some limitations of the present study should be noted. One limitation is that, high fat diet,

which is an important influence factor for cognitive function as mentioned above, was not

included in this study. It is probable that high fat diet leads to central obesity with high BMI

and WHR among Chinese elderly. Further studies are needed to explore the relationship

within diet, WHR and cognitive impairment. Besides, caution would be needed when

generalizing the present findings, as our results were based on cross-sectional study.

Conclusions

Higher WHR significantly increase risk for cognitive impairment among the elderly with

BMI > 25.3 kg/m^2. The results of this study suggest that it is of benefit for the elderly with

high BMI to control WHR.

interviewers of the Zhejiang Ageing and Health Cohort Study.

Competing interests: None declared.

Patient consent: Obtained.

Data sharing statement: Data are not publicly available due to local ethical restrictions.

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STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract **(Page 1-3)**	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale **(Page 4-5)**	2	Explain the scientific background and rationale for the investigation being reported
Objectives **(Page 5)**	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design **(Page 5)**	4	Present key elements of study design early in the paper
Setting **(Page 5)**	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants **(Page 5)**	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables **(Page 5-6)**	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement **(Page 5-6)**	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9	Describe any efforts to address potential sources of bias
Study size	10	Explain how the study size was arrived at
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods **(Page 7)**	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses

Continued on next page

Results

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data **(Page 7-9)**	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)
Outcome data **(Page 7-9)**	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures
Main results **(Page 9-10)**	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses

Discussion

Key results **(Page 10-11)**	18	Summarise key results with reference to study objectives
Limitations **(Page 12)**	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation **(Page 11-12)**	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability **(Page 12)**	21	Discuss the generalisability (external validity) of the study results

Other information

Funding **(Page 13)**	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Body Mass Index, Waist-to-Hip Ratio and Cognitive Function among Chinese Elderly: A Cross-Sectional Study

Body Mass Index, Waist-to-Hip Ratio and Cognitive Function among Chinese Elderly: A Cross-Sectional Study

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Abstract

Objectives: To investigate the associations between body mass index (BMI), waist-to-hip ratio (WHR) and cognitive function among Chinese elderly.

Design: Cross-sectional study.

Setting: Community.

Participants: Data was obtained from the baseline survey of a community-based cohort in Zhejiang Province, and enrolled 9 326 persons aged 60 years and older.

Primary outcome measures: We investigated the association between BMI and cognition, and then explored the association between WHR and cognition across different quartiles of BMI.

Results: A sample of 9 087 persons was used in this study, including 4 375 men and 4 712 women. Higher WHR increased cognitive impairment risk in those with BMI > 25.3 kg/m^2 (OR (per 0.1 increase), 1.39, 95% CI, 1.13-1.70). No statistically significant association was found in other BMI categories.

Conclusions: Higher WHR could increase risk for cognitive impairment among elderly with BMI > 25.3 kg/m^2. Our results suggest that it could be of benefit for the elderly with high BMI to control WHR.

Strengths and limitations of this study:

1. The strength of this study was the in-depth analysis of the association between waist-to-hip ratio and cognitive impairment across different body mass index categories.

2. High fat diet, which is an important influence factor for cognitive function as mentioned above, was not included in this study.

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3. Since this was a cross-sectional study, caution would be needed when generalizing the present findings.

Keywords: cognitive function, body mass index, abdominal obesity, elderly, Chinese

Introduction

Cognitive impairment is an important health issue in the elderly. According to

Alzheimer's Disease International (ADI) [1], an estimated 46.8 million people currently have

dementia in the world, the most well-known form of cognitive impairment, and this number

will rise to 131.5 million in 2050. ADI estimated over 9.5 million people with dementia in

China, which was 20% of the total number of people in the world with dementia. By 2030,

the number of people living with dementia in China is expected to rise to over 16 million.

The incidence of dementia in people aged 60 years and older, is 9.87 cases per 1000

person-years in China [2], and the situation of cognitive impairment would be more serious

[3].

Obesity was normally recognized as an influence factor of dementia [4 5]. The possible

reasons included inflammation and β-amyloid metabolism, which had been observed

connection with obesity [6]. However, studies on association between BMI and cognitive

impairment in the elderly have shown conflicting results: both positive and negative

association have been reported [7-11]. There is a limitation of BMI when comparing

individuals with same weight and height but different body fat mass. BMI is affected by both

fat and fat-free mass, which may have opposite effects on health [12]. The use of BMI as a

surrogate for obesity may be particularly problematic in the elderly due to the effect of aging

on fat distribution [13]. WHR, as a proxy for body fat distribution, would be a

complementary indicator in health-related studies for the elderly. It has been reported that

high WHR was associated with adverse health outcomes independent of BMI [14 15].

Actually, high WHR could increase death even with normal BMI [16 17]. Therefore, it would

be necessary to evaluate the effect of WHR when BMI was within a certain range.

However, to our knowledge, studies evaluating the association between BMI-specific

WHR and cognitive impairment in a large Chinese elderly population were lacking. To help

shed light on this area, we investigated the associations between BMI, WHR and cognitive

impairment among Chinese aged 60 years and older.

Materials and Methods

Study Population

The present study used data collected from the baseline survey of a community-based

cohort study focusing on aging and health problems among the elderly in Zhejiang Province,

China since 2014. In brief, 6 out of 90 counties were randomly selected from Zhejiang

Province, with at least 1 500 participants were randomly recruited in each county for

participation in 2014. Inclusion criteria were as following: 1) permanent residents who lived

for over 6 months in the past year; 2) aged 60 years and above. Exclusion criterion was

inability to complete interview due to physical disability. Finally, 9 326 subjects were

enrolled, with a response rate of 76%. During the baseline survey, we performed

questionnaire-based interview, physical examinations and laboratory tests for each participant.

Informed consent was obtained from all participants, and the study was approved by the

Ethics Committee of Zhejiang Provincial Center for Disease Control and Prevention. A

sample of 9 087 of 9 326 participants was included in this study. The remained 239 were

excluded because of missing values in age, Chinese language version of the Mini-Mental

State Examination (MMSE) score, or BMI.

Cognitive Function

Cognitive function was determined by MMSE, which included 30 items. The maximum

score of MMSE is 30, and higher scores indicate better cognitive function. According to

Wang et al., The questionnaire of MMSE has good reliability and validity as an instrument to

detect cognitive impairment among Chinese [18]. The cut-off score of cognitive impairment

is education-specific: 17/18 for illiteracy, 20/21 for people with primary education level,

24/25 for people with higher than primary education level [19].

Body Mass Index (BMI)

BMI (kg/m^2) was calculated as the body weight (by kilograms) divided by the square of

the body height (by meters). Body weight and height was measured by digital weight and

height scale. All the participants were asked to remove shoes, heavy clothing, and hats prior

to height and weight measurements, and have the participants stand straight with heels

together, legs straight, and looking straight ahead.

Waist-to-hip Ratio (WHR)

Waist circumference was measured midway between the lower rib margin and iliac crest,

with a soft cloth tape measure. Hip circumference was measured at the level of the widest

circumference over the greater trochanters, with a soft cloth tape measure. In the baseline

survey, waist circumference and hip circumference were measured twice, and the difference

of two measured values were restricted in ±2 centimeters. Waist-hip ratio was calculated as

waist circumference divided by hip circumference. In this study, waist circumference and hip

circumference were calculated as mean of two measured values.

Covariates

Covariates were collected by face-to-face interview with questionnaire, including: age,

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race, education level (self-reported), marital status (self-reported), economic status (self-reported), smoking (self-reported), alcohol drinking (self-reported), physical exercise (activities which were carried out to sustain or improve health and fitness in one's spare time), hypertension (diagnosed by doctors), diabetes (diagnosed by doctors), coronary heart disease (diagnosed by doctors), and depressive symptom. Depressive symptom was determined using the Patient Health Questionnaire- 9 scale (PHQ-9). Those scored 5 or above were defined as depression [20].

Statistical Analysis

Descriptive statistics were applied to illustrate the socio-demographic and health characteristics of the enrolled participants. Differences of the characteristics across different cognitive status groups were assessed by t-test for continuous variables, and by Chi-square test for categorical variables. Logistic regressions were used to examine the association between BMI, WHR and cognitive impairment. BMI was evaluated as categorical variable, divided by quartiles. WHR was evaluated under different BMI levels. Both BMI and WHR were assessed by 3 logistic models. In the basic model (model 1), no covariate was included when assessing the association between BMI and cognitive impairment, and BMI was adjusted when assessing the association between WHR and cognitive impairment. Model 2 was based on model 1, with adjusting for additional socio-demographics variables (age, sex, nation, education, marital status, and family economics). Model 3 was based on model 2, with additional adjustments of lifestyles (smoking, drinking, and physic exercise) and health variables (hypertension, stroke, and depression).

All statistical analyses were performed by SAS 9.4 (SAS Institute Inc., Cary, NC), and

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two tailed *P*-value <0.05 was considered statistically significant.

Patient and Public Involvement

No patients were involved in setting the research question or the outcome measures, nor

were they involved in developing plans for design or implementation of the study. No

patients were asked to advise on interpretation or writing up of results. There are no plans to

disseminate the results of the research to study participants or the relevant patient community.

Results

Socio-demographics and health Characteristics

Of the 9 087 subjects, 1 339 (14.7%) were defined as cognitive impairment by MMSE.

The mean age of all the subjects was 69.8 (±8.3). More than a half (51.9%) was female.

Among the subjects with cognitive impairment, the mean MMSE score was 13.6 (±5.1),

while the mean score was 25.8 (±3.1) in normal cognition group. The mean values of BMI

and WHR were 22.7±3.6, 0.9±0.1, respectively in the cognitive impairment group, and the

mean values were 23.3±3.3, 0.9±0.1, respectively in normal cognition group. Differences of

BMI and WHR between the two groups were both significant statistically. The subjects with

cognitive impairment tended to be older, female, minority ethnic group, without physical

exercise, with hypertension, with stroke, with depression. Also, cognitive impairment was

associated with education, marital status, family economics, smoking, and drinking. More

details were shown in Table 1.

Table 1. Socio-demographics and health characteristics of 9087 participants by cognitive

status

Characteristics	Normal cognition (*n*=7748)	Cognitive impairment (*n*=1339)	Overall	*P*
Age, years(mean, SD)	68.8±7.8	75.4±8.5	69.8±8.3	<0.001

Sex				<0.001
Male	3877(50.0)	498(37.2)	4375(48.1)	
Female	3871(50.0)	841(62.8)	4712(51.9)	
Nation				<0.001
Han	7489(96.7)	1213(90.6)	8702(95.8)	
Minority	259(3.3)	126(9.4)	385(4.2)	
Education				<0.001
Illiteracy	3703(47.8)	893(66.7)	4596(50.6)	
Primary school	3461(44.7)	379(28.3)	3840(42.3)	
Middle school or higher	584(7.5)	67(5.0)	651(7.2)	
Marital status				<0.001
Single	104(1.4)	38(2.8)	142(1.6)	
Married	6060(78.4)	776(58.0)	6836(75.4)	
Windowed/Divorced	1566(20.3)	525(39.2)	2091(23.1)	
Family economics				<0.001
Rich	796(10.3)	77(5.8)	873(9.6)	
Median	6135(79.2)	984(73.5)	7119(78.4)	
Poor	817(10.5)	277(20.7)	1094(12.0)	
Smoking				<0.001
Current smokers	1749(22.6)	173(12.9)	1922(21.2)	
Ex-smokers	768(9.9)	121(9.0)	889(9.8)	
Never smokers	5231(67.5)	1045(78.0)	6276(69.1)	
Drinking				<0.001
Current drinkers	2079(26.8)	204(15.2)	2283(25.1)	
Ex-drinkers	662(8.5)	158(11.8)	820(9.0)	
Never drinkers	5007(64.6)	977(73.0)	5984(65.9)	
Physical exercise	1499(19.4)	190(14.2)	1689(18.6)	<0.001
Hypertension	3462(44.7)	648(48.4)	4110(45.2)	0.011
Diabetes	667(8.6)	113(8.4)	780(8.6)	0.838
Coronary heart disease	230(3.0)	48(3.6)	278(3.1)	0.227
Stroke	204(2.6)	91(6.8)	295(3.2)	<0.001
Depression	664(8.6)	275(20.5)	939(10.3)	<0.001
Body mass index	23.3±3.3	22.7±3.6	23.2±3.4	<0.001
Waist-to-Hip ratio	0.9±0.1	0.9±0.1	0.9±0.1	0.026
MMSE score	25.8±3.1	13.6±5.1	24.0±5.6	<0.001

Association between BMI and cognitive impairment

The mean MMSE scores were calculated by quartiles of BMI. The highest quartile of

BMI had the highest mean MMSE score (24.36±5.28), and the lowest quartile had the lowest

mean value (23.33±5.94). Compared with the 2rd quartile of BMI, the odds ratio (OR) of the

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lowest quartile was 1.42 (95% confidence interval (CI), 1.21-1.67), the OR of the highest

quartile was 0.86 (95% CI, 0.72-1.02), and the 3rd quartile had an OR value of 0.92 (95% CI,

0.77-1.08). In model 3, the OR of Q1 BMI was close to being statistically significant, and

these results were essentially unchanged after adjustment for more covariates (Table 2).

Table 2. Association between body mass index and cognitive impairment

Quartiles of body mass index, kg/m^2	Odds ratio (95% confidence interval)		
	Model 1^a (*n*=9087)	Model 2^b (*n*=9068)	Model 3^c (*n*=9068)
12.1-20.8	1.42 (1.21-1.67)	1.20 (1.01-1.42)	1.18 (0.99-1.40)
>20.8-22.9	1	1	1
>22.9-25.3	0.92 (0.77-1.08)	1.02 (0.85-1.22)	1.02 (0.85-1.22)
>25.3-42.8	0.86 (0.72-1.02)	0.95 (0.79-1.14)	0.93 (0.77-1.12)

^{a} No covariate was included.

^{b} Adjusted for age, sex, nation, education, marital status, and family economics.

^{c} Based on model 2, model 3 was further adjusted for smoking, drinking, physical exercise, hypertension,

stroke, and depression.

Association between waist-to-hip ratio and cognitive impairment

We detected two-way interaction between BMI and WHR, and the result was significant

(*P*=0.002). Further, the association between WHR and cognitive impairment was assessed

under each BMI group. Under the lowest BMI group, the association between WHR and

cognitive impairment was not statistically significant. The situation was similar in the 2nd

and 3rd quartile of BMI. In the highest BMI group, each 0.1 higher WHR corresponded to a

1.39 folds higher risk of cognitive impairment in the basic model. The OR value remained

significant after adjusting for more covariates in model 2 and model 3, which were 1.36 (95%

CI, 1.10-1.69) and 1.37 (95% CI, 1.10-1.71), respectively (Table 3).

Table 3. Association of waist-to-hip ratio (per 0.1 increase) with cognitive impairment

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under different body mass index group

	Quartiles of body mass index, kg/m²			
	12.1-20.8	>20.8-22.9	>22.9-25.3	>25.3-42.8
Subjects (*n*)	2244	2266	2311	2266
Waist-to-hip ratio				
Range	0.61-1.26	0.46-1.29	0.49-1.49	0.58-1.38
Mean	0.87±0.07	0.89±0.06	0.91±0.06	0.93±0.06
Model 1[a]	1.13 (0.98-1.31)	1.12 (0.93-1.35)	1.38 (1.14-1.65)	1.39 (1.13-1.70)
Model 2[b]	1.01 (0.86-1.18)	0.93 (0.75-1.13)	1.13 (0.94-1.41)	1.36 (1.10-1.69)
Model 3[c]	0.99 (0.83-1.17)	0.92 (0.75-1.13)	1.14 (0.93-1.40)	1.37 (1.10-1.71)

[a] Adjusted for body mass index.

[b] Based on model 1, model 2 was further adjusted for age, sex, nation, education, marital status, and family economics.

[c] Based on model 2, model 3 was further adjusted for smoking, drinking, physical exercise, hypertension, stroke, and depression.

Association between waist circumference and cognitive impairment

Similarly, we assessed the association of waist circumference with cognitive impairment within various BMI levels. When BMI, age, sex, nation, education, marital status, family economics, smoking, drinking, physic exercise, hypertension, stroke, and depression were controlled, each 1 unit higher waist circumference corresponded to a 1.02 folds higher risk of cognitive impairment among the elderly with BMI >22.9 kg/m² (Table 4).

Table 4. Association of waist circumference with cognitive impairment under different body mass index group

	Quartiles of body mass index, kg/m²			
	12.1-20.8	>20.8-22.9	>22.9-25.3	>25.3-42.8
Subjects (*n*)	2244	2266	2311	2266
Model 1[a]	1.03(1.01-1.05)	1.03(1.01-1.05)	1.04(1.02-1.06)	1.03(1.01-1.04)
Model 2[b]	1.02(1.001-1.04)	1.02(0.995-1.03)	1.03(1.01-1.05)	1.02(1.01-1.04)
Model 3[c]	1.01(0.996-1.03)	1.01(0.993-1.03)	1.02(1.004-1.05)	1.02(1.01-1.04)

[a] Adjusted for body mass index.

[b] Based on model 1, model 2 was further adjusted for age, sex, nation, education, marital status, and family economics.

[c] Based on model 2, model 3 was further adjusted for smoking, drinking, physical exercise, hypertension, stroke, and depression.

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Discussion

In this cross-sectional study of 9087 Chinese elderly aged 60 years and older, we

investigated the associations between BMI, WHR and cognitive impairment risk. We found

that each 0.1 unit increase in WHR corresponded to 1.37 (1.10-1.71) evaluated cognitive

impairment risk in high BMI (>25.3 kg/m^2) group in the fully adjusted model (model 3).

In our study, compared with Q2 BMI (>20.8-22.9 kg/m^2), Q1 BMI (≤20.8 kg/m^2) was a

risk factor for cognitive impairment, while Q4 BMI tended to be a protective factor, though

not statistically significant. In previous studies, some have shown that high BMI tended to be

a risk factor for cognitive decline [9-11], while others observed negative association between

high BMI and cognitive function [4 5 7 8]. The inconsistence suggests the relationship

between BMI and cognitive function is complex.

Zhou et al. [21] suggested that subjects who were both with obesity and dementia had a

high mortality rate, which might very likely remove those with high BMI and dementia, and

leave moderate or severe dementia subjects with low BMI, thus enforce the association

between BMI and dementia. Assuming the survivor bias existed, the observed association

between high BMI and cognition impairment would be biased towards the null, and such bias

would be even more serious in cross-sectional study if it exists. Nevertheless, the hypothesis

is not enough to explain the relationship between low BMI and cognitive impairment.

Furthermore, several cohort studies reported that both persons with low BMI and persons

with high BMI have lower cognitive functions in later life [22-26].

Among the participants of this study, the mean value of WHR tended to increase within

higher BMI group. We observed a strong positive association between WHR and cognitive

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impairment risk under Q4 BMI (>25.3 kg/m^2) group. The association remained after

adjusting for covariates. Similar results were observed when evaluating association between

waist circumference and cognitive impairment. These findings led us to speculate that body

fat and muscle had reverse effect on cognition. Adipokines might be a link between body fat

and dementia. Adipokines include hundreds of polypeptides secreted by the cells of white

adipose tissue. The action of adipokines could be altered during neurodegenerative events and

might feedback to contribute to neurodegeneration [27]. Age-related reduction of muscle

mass and strength were a major public health concern in older persons. The association

between muscle and cognition could mainly derived from muscle strength. Boyle et al. [28]

found muscle strength decreased risk of AD, and Chen et al. [29] had similar findings.

It is noteworthy to mention that previous studies have reported high fat diet exacerbates

cognitive decline [30 31]. Amyloid deposition, and cerebral microvasculature dysfunction are

the most discussed mechanisms in relevant studies [30-33]. These findings suggest further

studies are needed to explore the mechanisms that underlie the association between obesity

and cognitive impairment.

Some limitations of the present study should be noted. One limitation is that, high fat diet,

which is an important influence factor for cognitive function as mentioned above, was not

included in this study. It is probable that high fat diet leads to central obesity with high BMI

and WHR among Chinese elderly. Further studies are needed to explore the relationship

within diet, WHR and cognitive impairment. Besides, caution would be needed when

generalizing the present findings, as our results were based on cross-sectional study.

Conclusions

Higher WHR significantly increase risk for cognitive impairment among the elderly with

BMI > 25.3 kg/m^2. The results of this study suggest that it is of benefit for the elderly with

high BMI to control WHR.

Patient consent: Obtained.

Data sharing statement: Data are not publicly available due to local ethical restrictions.

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STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract **(Page 1-3)**	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale **(Page 4-5)**	2	Explain the scientific background and rationale for the investigation being reported
Objectives **(Page 5)**	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design **(Page 5)**	4	Present key elements of study design early in the paper
Setting **(Page 5)**	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants **(Page 5)**	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables **(Page 5-6)**	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement **(Page 5-6)**	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9	Describe any efforts to address potential sources of bias
Study size	10	Explain how the study size was arrived at
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods **(Page 7)**	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses

Continued on next page

Results

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data **(Page 5-9)**	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)
Outcome data **(Page 8-9)**	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures
Main results **(Page 8-11)**	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses

Discussion

Key results **(Page 11-12)**	18	Summarise key results with reference to study objectives
Limitations **(Page 13)**	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation **(Page 11-13)**	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability **(Page 13)**	21	Discuss the generalisability (external validity) of the study results

Other information

Funding **(Page 14)**	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Body Mass Index, Waist-to-Hip Ratio and Cognitive Function among Chinese Elderly: A Cross-Sectional Study

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**Body Mass Index, Waist-to-Hip Ratio and Cognitive Function among Chinese Elderly:
A Cross-Sectional Study**

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Abstract

Objectives: To investigate the associations between body mass index (BMI), waist-to-hip ratio (WHR) and cognitive function among Chinese elderly.

Design: Cross-sectional study.

Setting: Community.

Participants: Data were obtained from the baseline survey of a community-based cohort in Zhejiang Province, and 9 326 persons aged 60 years and older were enrolled.

Primary outcome measures: We investigated the association between BMI and cognition, and then explored the association between WHR and cognition across different quartiles of BMI.

Results: A sample of 9 087 persons was used in this study, including 4 375 men and 4 712 women. Higher WHR increased cognitive impairment risk in those with BMI > 25.3 kg/m^2 (OR (per 0.1 increase), 1.39; 95% CI, 1.13-1.70). No statistically significant association was found in other BMI categories.

Conclusions: Higher WHR could increase the risk for cognitive impairment among elderly with BMI > 25.3 kg/m^2. Our results suggest that it could be of benefit to the elderly with high BMI to control WHR.

Strengths and limitations of this study:

1. The strength of this study was the in-depth analysis of the association between waist-to-hip ratio and cognitive impairment across different body mass index categories.

2. High-fat diet, which is an important influence factor for cognitive function, was not included in this study.

3. Since this was a cross-sectional study, caution would be needed when generalizing the

present findings.

Keywords: cognitive function, body mass index, abdominal obesity, elderly, Chinese

Introduction

Cognitive impairment is an important health issue in the elderly. According to

Alzheimer's Disease International (ADI) [1], an estimated 46.8 million people currently have

dementia in the world, the most well-known form of cognitive impairment, and this number

will rise to 131.5 million in 2050. ADI estimated over 9.5 million people with dementia in

China, which was 20% of the total number of dementia cases in the world. By 2030, the

number of people living with dementia in China is expected to rise to over 16 million. The

incidence of dementia in people aged 60 years and older is 9.87 cases per 1000 person-years

in China [2], and the situation of cognitive impairment would be more serious [3].

Obesity was normally recognized as an influence factor of dementia [4 5]. The possible

reasons included inflammation and β-amyloid metabolism, which had been observed

connection with obesity [6]. However, studies on association between BMI and cognitive

impairment in the elderly have shown conflicting results: both positive and negative

association have been reported [7-11]. There is a limitation of BMI when comparing

individuals with the same weight and height but different body fat mass. BMI is affected by

both fat and fat-free mass, which may have opposite effects on health [12]. Using BMI as a

surrogate for obesity may be particularly problematic in the elderly due to the effect of aging

on fat distribution [13]. Waist-to-hip ratio (WHR), as a proxy for body fat distribution, would

be a complementary indicator in health-related studies for the elderly. It has been reported

that high WHR was associated with adverse health outcomes independent of BMI [14 15].

Actually, high WHR could increase death even with normal BMI [16 17]. Therefore, it would

be necessary to evaluate the effect of WHR when BMI was within a certain range.

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However, to our knowledge, studies evaluating the association between BMI-specific

WHR and cognitive impairment in a large Chinese elderly population were lacking. To help

shed light on this area, we investigated the associations between BMI, WHR and cognitive

impairment among Chinese aged 60 years and older.

Materials and Methods

Study Population

The present study used data collected from the baseline survey of a community-based

cohort study focusing on aging and health problems among the elderly in Zhejiang Province,

China since 2014. In brief, 6 out of 90 counties were randomly selected from Zhejiang

Province, with at least 1 500 participants were randomly recruited in each county for

participation in 2014. Inclusion criteria were as following: 1) permanent residents who lived

for over 6 months in the past year; 2) aged 60 years and above. Exclusion criterion was an

inability to complete the interview due to physical disability. Finally, 9 326 subjects were

enrolled, with a response rate of 76%. During the baseline survey, we performed

questionnaire-based interview, physical examinations and laboratory tests for each participant.

Informed consent was obtained from each participant, and the study was approved by the

Ethics Committee of Zhejiang Provincial Center for Disease Control and Prevention. A total

of 239 participants were excluded because of missing values in age, Chinese language

version of the Mini-Mental State Examination (MMSE) score, or BMI, leaving 9 087

available for analyses.

Cognitive Function

Cognitive function was determined by MMSE, which included 30 items. The maximum

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score of MMSE is 30, and higher scores indicate better cognitive function. According to

Wang et al., the questionnaire of MMSE has good reliability and validity as an instrument to

detect cognitive impairment among Chinese [18]. The cut-off score of cognitive impairment

is education-specific: 17/18 for illiteracy, 20/21 for people with primary education level,

24/25 for people with higher than primary education level [19].

Body Mass Index (BMI)

BMI (kg/m^2) was calculated as a person's body weight (in kilograms) divided by the

square of the body height (in meters). Body weight and height were measured by digital

weight and height scale, respectively. All the participants were asked to remove shoes, heavy

clothing, and hats prior to height and weight measurements, and had the participants stand

straight with heels together, legs straight, and looking straight ahead.

WHR

Waist circumference was measured midway between the lower rib margin and the iliac

crest, with a soft cloth tape measure. Hip circumference was measured at the level of the

widest circumference over the greater trochanters, with a soft cloth tape measure. In the

baseline survey, waist circumference and hip circumference were measured twice, and the

difference of two measured values was restricted in ±2 centimeters. WHR was calculated as a

person's waist circumference divided by the hip circumference. In this study, waist

circumference and hip circumference were calculated as the mean of two measured values.

Covariates

Covariates were collected by face-to-face interview with questionnaire, including: age,

race, education level (self-reported), marital status (self-reported), economic status

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(self-reported), smoking (self-reported), alcohol drinking (self-reported), physical exercise

(activities which were carried out to sustain or improve health and fitness in one's spare time),

hypertension (diagnosed by doctors), diabetes (diagnosed by doctors), coronary heart disease

(diagnosed by doctors), and depressive symptom. Depressive symptom was determined using

the Patient Health Questionnaire- 9 scale (PHQ-9). Those scored 5 or above were defined as

depression [20].

Statistical Analysis

Descriptive statistics were applied to illustrate the socio-demographic and health

characteristics of the enrolled participants. Differences of the characteristics across different

cognitive status groups were assessed by t-test for continuous variables, and by Chi-square

test for categorical variables. Logistic regressions were used to examine the associations

between BMI, WHR and cognitive impairment. BMI was evaluated as a categorical variable,

divided by quartiles. WHR was evaluated under different BMI levels. Both BMI and WHR

were assessed by 3 logistic models. In the basic model (model 1), no covariate was included

when assessing the association between BMI and cognitive impairment, and BMI was

adjusted when assessing the association between WHR and cognitive impairment. Model 2

was based on model 1, with additional adjusting for socio-demographic variables (age, sex,

nation, education, marital status, and family economics). Model 3 was based on model 2,

with additional adjustments of lifestyles (smoking, drinking, and physic exercise) and health

variables (hypertension, stroke, and depression).

All statistical analyses were performed by SAS 9.4 (SAS Institute Inc., Cary, NC), and

two-tailed P-value <0.05 was considered statistically significant.

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Patient and Public Involvement

No patients were involved in setting the research question or the outcome measures, nor

were they involved in developing plans for design or implementation of the study. No

patients were asked to advise on interpretation or writing up of results. There are no plans to

disseminate the results of the research to study participants or the relevant patient community.

Results

Socio-demographics and health Characteristics

Of the 9 087 subjects, 1 339 (14.7%) were defined as cognitive impairment by MMSE.

The mean age of all subjects was 69.8 (±8.3). More than a half (51.9%) were female. Among

the subjects with cognitive impairment, the mean MMSE score was 13.6 (±5.1), while the

mean score was 25.8 (±3.1) in normal cognition group. The mean values of BMI and WHR

were 22.7±3.6, 0.9±0.1, respectively in the cognitive impairment group, and the mean values

were 23.3±3.3, 0.9±0.1, respectively in normal cognition group. Differences of BMI and

WHR between the two groups were both statistically significant. The subjects with cognitive

impairment tended to be older, female, minority ethnic group, without physical exercise, with

hypertension, with stroke, with depression. Also, cognitive impairment was associated with

education, marital status, family economics, smoking, and drinking. More details are shown

in Table 1.

Table 1. Socio-demographics and health characteristics of 9087 participants by cognitive
status

Characteristics	Normal cognition (*n*=7748)	Cognitive impairment (*n*=1339)	Overall	*P*
Age, years(mean, SD)	68.8±7.8	75.4±8.5	69.8±8.3	<0.001
Sex				<0.001
Male	3877(50.0)	498(37.2)	4375(48.1)	

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Female	3871(50.0)	841(62.8)	4712(51.9)	
Nation				<0.001
Han	7489(96.7)	1213(90.6)	8702(95.8)	
Minority	259(3.3)	126(9.4)	385(4.2)	
Education				<0.001
Illiteracy	3703(47.8)	893(66.7)	4596(50.6)	
Primary school	3461(44.7)	379(28.3)	3840(42.3)	
Middle school or higher	584(7.5)	67(5.0)	651(7.2)	
Marital status				<0.001
Single	104(1.4)	38(2.8)	142(1.6)	
Married	6060(78.4)	776(58.0)	6836(75.4)	
Windowed/Divorced	1566(20.3)	525(39.2)	2091(23.1)	
Family economics				<0.001
Rich	796(10.3)	77(5.8)	873(9.6)	
Median	6135(79.2)	984(73.5)	7119(78.4)	
Poor	817(10.5)	277(20.7)	1094(12.0)	
Smoking				<0.001
Current smokers	1749(22.6)	173(12.9)	1922(21.2)	
Ex-smokers	768(9.9)	121(9.0)	889(9.8)	
Never smokers	5231(67.5)	1045(78.0)	6276(69.1)	
Drinking				<0.001
Current drinkers	2079(26.8)	204(15.2)	2283(25.1)	
Ex-drinkers	662(8.5)	158(11.8)	820(9.0)	
Never drinkers	5007(64.6)	977(73.0)	5984(65.9)	
Physical exercise	1499(19.4)	190(14.2)	1689(18.6)	<0.001
Hypertension	3462(44.7)	648(48.4)	4110(45.2)	0.011
Diabetes	667(8.6)	113(8.4)	780(8.6)	0.838
Coronary heart disease	230(3.0)	48(3.6)	278(3.1)	0.227
Stroke	204(2.6)	91(6.8)	295(3.2)	<0.001
Depression	664(8.6)	275(20.5)	939(10.3)	<0.001
Body mass index	23.3±3.3	22.7±3.6	23.2±3.4	<0.001
Waist-to-Hip ratio	0.9±0.1	0.9±0.1	0.9±0.1	0.026
MMSE score	25.8±3.1	13.6±5.1	24.0±5.6	<0.001

Association between BMI and cognitive impairment

The mean MMSE scores were calculated by quartiles of BMI. Subjects in the highest

BMI quartile category had the highest mean MMSE score (24.36±5.28), and those in the

lowest quartile category had the lowest mean MMSE value (23.33±5.94). Compared with the

2nd quartile of BMI, the odds ratio (OR) of the lowest quartile was 1.42 (95% confidence

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interval (CI), 1.21-1.67), the OR of the highest quartile was 0.86 (95% CI, 0.72-1.02), and the

3rd quartile had an OR value of 0.92 (95% CI, 0.77-1.08). In model 3, the OR of Q1 BMI

was close to being statistically significant, and these results were essentially unchanged after

adjustment for more covariates (Table 2).

Table 2. Association between body mass index and cognitive impairment

Quartiles of body mass index, kg/m^2	Odds ratio (95% confidence interval)		
	Model 1[a] (*n*=9087)	Model 2[b] (*n*=9068)	Model 3[c] (*n*=9068)
12.1-20.8	1.42 (1.21-1.67)	1.20 (1.01-1.42)	1.18 (0.99-1.40)
>20.8-22.9	1	1	1
>22.9-25.3	0.92 (0.77-1.08)	1.02 (0.85-1.22)	1.02 (0.85-1.22)
>25.3-42.8	0.86 (0.72-1.02)	0.95 (0.79-1.14)	0.93 (0.77-1.12)

[a] No covariate was included.

[b] Adjusted for age, sex, nation, education, marital status, and family economics.

[c] Based on model 2, model 3 was further adjusted for smoking, drinking, physical exercise, hypertension, stroke, and depression.

Association between waist-to-hip ratio and cognitive impairment

We detected two-way interaction between BMI and WHR, and the result was statistically

significant (*P*=0.002). Further, the association between WHR and cognitive impairment was

assessed under each BMI group. Under the lowest BMI group, the association between WHR

and cognitive impairment was not statistically significant. Similar results were found in the

2nd and 3rd quartile of BMI. In the highest BMI group, each 0.1 higher WHR corresponded

to a 1.39 folds higher risk of cognitive impairment in the basic model. The OR value

remained significant after adjusting for more covariates in model 2 and model 3, which were

1.36 (95% CI, 1.10-1.69) and 1.37 (95% CI, 1.10-1.71), respectively (Table 3).

Table 3. Association of waist-to-hip ratio (per 0.1 increase) with cognitive impairment
under different body mass index group

	Quartiles of body mass index, kg/m^2			
	12.1-20.8	>20.8-22.9	>22.9-25.3	>25.3-42.8
Subjects (*n*)	2244	2266	2311	2266
Waist-to-hip ratio				
Range	0.61-1.26	0.46-1.29	0.49-1.49	0.58-1.38
Mean	0.87±0.07	0.89±0.06	0.91±0.06	0.93±0.06
Model 1[a]	1.13 (0.98-1.31)	1.12 (0.93-1.35)	1.38 (1.14-1.65)	1.39 (1.13-1.70)
Model 2[b]	1.01 (0.86-1.18)	0.93 (0.75-1.13)	1.13 (0.94-1.41)	1.36 (1.10-1.69)
Model 3[c]	0.99 (0.83-1.17)	0.92 (0.75-1.13)	1.14 (0.93-1.40)	1.37 (1.10-1.71)

[a] Adjusted for body mass index.

[b] Based on model 1, model 2 was further adjusted for age, sex, nation, education, marital status, and family

economics.

[c] Based on model 2, model 3 was further adjusted for smoking, drinking, physical exercise, hypertension, stroke,

and depression.

Association between waist circumference and cognitive impairment

Similarly, we assessed the associations between waist circumference and cognitive

impairment within various BMI levels. When BMI, age, sex, nation, education, marital status,

family economics, smoking, drinking, physic exercise, hypertension, stroke, and depression

were controlled, each 1 unit higher waist circumference corresponded to a 1.02 folds higher

risk of cognitive impairment among the elderly with BMI >22.9 kg/m^2 (Table 4).

Table 4. Association of waist circumference with cognitive impairment under different

body mass index group

	Quartiles of body mass index, kg/m^2			
	12.1-20.8	>20.8-22.9	>22.9-25.3	>25.3-42.8
Subjects (*n*)	2244	2266	2311	2266
Model 1[a]	1.03(1.01-1.05)	1.03(1.01-1.05)	1.04(1.02-1.06)	1.03(1.01-1.04)
Model 2[b]	1.02(1.001-1.04)	1.02(0.995-1.03)	1.03(1.01-1.05)	1.02(1.01-1.04)
Model 3[c]	1.01(0.996-1.03)	1.01(0.993-1.03)	1.02(1.004-1.05)	1.02(1.01-1.04)

[a] Adjusted for body mass index.

[b] Based on model 1, model 2 was further adjusted for age, sex, nation, education, marital status, and family

economics.

[c] Based on model 2, model 3 was further adjusted for smoking, drinking, physical exercise, hypertension, stroke,

and depression.

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Discussion

In this cross-sectional study of 9087 Chinese elderly aged 60 years and older, we investigated the associations between BMI, WHR and cognitive impairment risk. We found that each 0.1 unit increase in WHR corresponded to 1.37 (1.10-1.71) evaluated cognitive impairment risk in high BMI (>25.3 kg/m^2) group in the fully adjusted model (model 3).

In our study, compared with Q2 BMI (>20.8-22.9 kg/m^2), Q1 BMI (≤20.8 kg/m^2) was a risk factor for cognitive impairment, while Q4 BMI tended to be a protective factor, though not statistically significant. In previous studies, some reported that high BMI tended to be a risk factor for cognitive decline [9-11], while others observed a negative association between high BMI and cognitive function [4 5 7 8]. The inconsistency suggests the complex relationship between BMI and cognitive function.

Zhou et al. [21] suggested that subjects who were both with obesity and dementia had a high mortality rate, which might very likely remove those with high BMI and dementia, and leave moderate or severe dementia subjects with low BMI, thus enforce the association between BMI and dementia. Assuming the survivor bias existed, the observed association between high BMI and cognition impairment would be biased towards the null, and such bias would be even more serious in cross-sectional study if it exists. Nevertheless, the hypothesis is not enough to explain the relationship between low BMI and cognitive impairment. Furthermore, several cohort studies reported that both persons with low BMI and persons with high BMI had lower cognitive functions in later life [22-26].

Among the participants of this study, the mean value of WHR tended to increase within higher BMI group. We observed a strong positive association between WHR and cognitive

impairment risk under Q4 BMI (>25.3 kg/m^2) group. The association remained after

adjusting for covariates. Similar results were observed when evaluating the association

between waist circumference and cognitive impairment. These findings led us to speculate

that body fat and muscle had a reverse effect on cognition. Adipokines might be a link

between body fat and dementia. Adipokines include hundreds of polypeptides secreted by the

cells of white adipose tissue. The action of adipokines could be altered during

neurodegenerative events and might feedback to contribute to neurodegeneration [27].

Age-related reduction of muscle mass and strength is a major public health concern in older

persons. The association between muscle and cognition could mainly be derived from muscle

strength. Boyle et al. [28] found that high muscle strength decreased the risk of AD, and Chen

et al. [29] had similar findings.

It is noteworthy to mention that previous studies have reported high-fat diet exacerbates

cognitive decline [30 31]. Amyloid deposition and cerebral microvasculature dysfunction are

the most discussed mechanisms in relevant studies [30-33]. These findings suggest further

studies are needed to explore the mechanisms that underlie the association between obesity

and cognitive impairment.

Some limitations of the present study should be noted. One limitation is that, high-fat diet,

which is an important influence factor for cognitive function as mentioned above, was not

included in this study. It is probable that high-fat diet leads to central obesity with high BMI

and WHR among Chinese elderly. Further studies are needed to explore the relationship

within diet, WHR, and cognitive impairment. Besides, caution would be needed when

generalizing the present findings, as our results were based on a cross-sectional study.

Conclusions

Higher WHR significantly increases the risk for cognitive impairment among the elderly

with BMI > 25.3 kg/m^2. The results of this study suggest that it is of benefit to the elderly

with high BMI to control WHR.

Competing interests: None declared.

Patient consent: Obtained.

Data sharing statement: Data are not publicly available due to local ethical restrictions.

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STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation
Title and abstract **(Page 1-3)**	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction		
Background/rationale **(Page 4-5)**	2	Explain the scientific background and rationale for the investigation being reported
Objectives **(Page 5)**	3	State specific objectives, including any prespecified hypotheses
Methods		
Study design **(Page 5)**	4	Present key elements of study design early in the paper
Setting **(Page 5)**	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants **(Page 5)**	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case
Variables **(Page 5-6)**	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement **(Page 5-6)**	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9	Describe any efforts to address potential sources of bias
Study size	10	Explain how the study size was arrived at
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods **(Page 7)**	12	(*a*) Describe all statistical methods, including those used to control for confounding
		(*b*) Describe any methods used to examine subgroups and interactions
		(*c*) Explain how missing data were addressed
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy
		(*e*) Describe any sensitivity analyses

Continued on next page

Results

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
		(b) Give reasons for non-participation at each stage
		(c) Consider use of a flow diagram
Descriptive data **(Page 5-9)**	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
		(b) Indicate number of participants with missing data for each variable of interest
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)
Outcome data **(Page 8-9)**	15*	*Cohort study*—Report numbers of outcome events or summary measures over time
		Case-control study—Report numbers in each exposure category, or summary measures of exposure
		Cross-sectional study—Report numbers of outcome events or summary measures
Main results **(Page 8-11)**	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
		(*b*) Report category boundaries when continuous variables were categorized
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses

Discussion

Key results **(Page 11-12)**	18	Summarise key results with reference to study objectives
Limitations **(Page 13)**	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation **(Page 11-13)**	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability **(Page 13)**	21	Discuss the generalisability (external validity) of the study results

Other information

Funding **(Page 14)**	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.