Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy

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ORIGINAL RESEARCH

# Waist–Calf Circumference Ratio Is an Independent Risk Factor of HRQoL in Centenarians

This article was published in the following Dove Press journal:
*Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy*



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**Purpose:** To analyze the associations between waist circumference (WC), body mass index (BMI), waist–hip ratio (WHR), waist–height ratio (WHtR), calf circumference, waist-calf circumference ratio (WCR), and quality of life in Hainan centenarians.

**Patients and Methods:** A total of 1002 centenarians in Hainan were selected by a full sample survey. The EQ-5D visual analogue scale (EQ-5D-VAS) was used to investigate the quality of life. Restricted cubic splines were used to analyze and visualize the linear relationships.

**Results:** After adjustment, the standard β values for BMI, WC, WHR, WHtR, calf circumference, and WCR associated with EQ-5D score were 0.101, 0.126, −0.018, 0.100, 0.302, and −0.219, respectively; all associations except for WHR were significant ($P < 0.01$). With increasing BMI, WC, and calf circumference, the risk of EQ-5D score <1 decreased (odds ratios [ORs] 0.91 [95% confidence interval (CI): 0.86–0.97), 0.97 [95% CI: 0.95–0.99], and 0.87 [95% CI: 0.82–0.92] after adjustment, respectively). With increasing WCR, the risk also increased (OR 2.70 [95% CI: 1.54–4.75]).

**Conclusion:** After excluding nutritional and muscle retention factors, fat central distribution negatively impacted the health-related quality of life of the oldest old population.

**Keywords:** centenarians, waist–calf circumference ratio, quality of life, obesity

## Introduction

Health-related quality of life (HRQoL) is a comprehensive reflection of health-related factors such as physical health, psychological status, independence, social relations, and environmental factors in the elderly population that has received increasing attention.[1] Population aging is the inevitable result of social and economic development. Given the increasing proportions of elderly populations, successful aging (SA) is a cornerstone of healthy societal development. SA refers to the comprehensive bio-psycho-social aspects of elderly populations to not only be healthy in their daily lives and physiological functions but also their moods and social lives.[2,3] Centenarians may be the templates for SA,[4] and researchers in the United States, Japan, and Denmark have studied these populations.[5–7] Studies have also been performed on centenarians in Bama and Rugao in China, but the sample sizes were relatively small.[8,9]

Obesity is a common risk factor for cardiovascular and cerebrovascular disease, type 2 diabetes mellitus (T2DM), cancer, and other diseases.[10,11] Obesity is also a risk factor for poor HRQoL.[12,13] However, the results of studies on the effects of obesity on HRQoL among elderly populations are inconsistent.[14–16] The "obesity paradox" has been especially prevalent among the elderly older than 80 years and individuals with chronic diseases in recent decades; that is, unlike the general population, obese elderly and obese patients with chronic diseases have better HRQoL and prognosis as well as lower disability and mortality than those with normal weight/body mass index (BMI).[17,18]

Similar to the general population, body mass index (BMI) and waist circumference (WC) are also generally used as the criteria for obesity in the elderly. However, due to the natural aging progress, it is difficult to measure the height of the elderly and the accuracy of BMI or waist–height ratio (WHtR) in elderly populations is difficult to guarantee, especially those older than 80 years. Furthermore, unlike abdominal obesity (indicated by WC and WHtR) and general obesity (indicated by BMI), peripheral adiposity and larger hip circumference may offer protection from T2DM, cerebrovascular disease, and premature death.[19] Among the elderly, the mechanism of the obesity paradox is largely due to better nutritional status and higher muscle retention.[17,18] Calf circumference is often used to represent the degree of muscle retention and nutritional status in the elderly.[20,21] Considering the opposing effects of central obesity and peripheral adiposity, an indicator that assesses both masses simultaneously may better evaluate the risk of obesity on HRQoL than indicators that separately estimate either central obesity or peripheral adiposity; for example, waist–hip ratio (WHR). However, WHR may mask central obesity if both hip circumference and WC increase.[22] Recent studies have used the waist–calf ratio (WCR) an index to assess the disproportional relationships between abdominal fat and leg muscle mass and showed it to be an independent predictor of cardiovascular disease and hepatic steatosis and fibrosis.[23,24] Therefore, the obesity paradox in elderly populations may be related to the use of BMI and WC, which are prone to measurement accuracies and mixed nutritional factors and are, thus, not suitable for evaluating obesity in elderly populations, especially in the oldest old. Furthermore, research on the relationship between obesity and QOL in centenarians is very limited. If the obesity paradox on QOL in centenarians is also due to nutritional factors, the present centenarian study assumed that WC and calf circumference were positively correlated with HRQoL, while WCR and HRQoL were negatively correlated or unrelated.

This study used a series of common obesity evaluation indicators (BMI, WC, WHR, and WHtR) as well as calf circumference and WCR to evaluate the obesity status and analyzed the correlation between obesity status and HRQoL in a cluster sample of centenarians in China.

## Materials and Methods

### The China Hainan Centenarian Cohort Study (CHCCS)

The present analysis used CHCCS baseline data. The details of the methods have been reported elsewhere.[25] Briefly, according to the list of centenarians provided by the Hainan Provincial Civil Affairs Department, a full sample household survey was conducted among all centenarians of Hainan Province between June 2014 and June 2016, excluding those who had died, who failed to pass age verification, and centenarians or their family members who did not or could not cooperate with the examination. Among 1,811 living centenarians according to the household register provided by the civil affairs bureau in 2014, 1,473 were contacted after age verification and address survey and 1,002 centenarians were included in the present survey after excluding those who declined survey participation and those unable to take the physical exam.[25] The baseline data of these centenarians were collected by household survey, including questionnaire interviews, physical examinations, and laboratory blood sample testing. Questionnaire interviews including domains such as sociodemographics, functional capacity, cognitive function, behaviors, sleep quality, and quality of life[25] and human body indicators (height, weight, WC, hip circumference, calf circumference, blood pressure) were measured by trained local Hainan nurses who spoke the local language and could communicate with the centenarians without linguistic obstacles.

### Ethics

The CHCCS was conducted in accordance with the Declaration of Helsinki and was approved by the Medical Ethics Committee of the Chinese PLA General Hospital (301hn11-206-01). All participants provided written informed consent before joining the study.

### Exposures

The obesity indicators included BMI, WC, WHR, waist–height ratio (WHtR), calf circumference, and WCR. The body measurements, including height (measured by a unified scale), weight (measured by a unified scale with the participants wearing light clothing), WC, hip, and calf circumference (measured by a tape measure with the participants standing and wearing light clothing), were performed by trained nurses. For the measurements, the centenarians were required to remove their shoes, hats, and coats and to remove personal belongings such as keys, mobile phones, etc. The height measurements were accurate to 0.5 cm, while the weight measurement required two consecutive results with an error of less than 0.5 kg. The waist and calf circumference measurements were accurate to 0.1 cm.[26] BMI = height/weight$^2$, WHR= WC/hip circumference, WHtR= WC/height, WCR = WC/calf circumference. According to the Guidelines for Prevention and Control of Overweight and Obesity in Chinese Adults,[27] obesity was defined as (1) BMI ≥28 kg/m$^2$; (2) WC ≥90 cm in men or ≥85 cm in women; (3) WHR ≥0.9 in men or ≥0.8 in women; and (4) WHtR ≥0.6.

## Study Outcomes

The EuroQol five dimensions questionnaire-visual analogue scale (EQ-5D-VAS)[28] was used to measure HRQoL. The EQ-5D is a validated and extensively used general health questionnaire that covers five health domains (mobility, self-care, usual activities, pain/discomfort, and anxiety/depression) that was also validated in the Chinese elderly population before data collection. The EQ-5D index was calculated using the Japanese population-based time trade-off (TTO) model which was the most suitable tool for Chinese individuals at the time of the present study.[29] The EQ-5D scores after TTO conversion ranged from −0.11 to 1. Interviewees without any problems in the five domains of EQ-5D scored 1, and were defined as having a high QOL, while interviewees with EQ-5D scores <1 were defined as having a low QOL. The VAS is a self-rating tool used to assess health status on a 20-cm vertical scale in which values of 100 (at the top) 0 (at the bottom) indicate the best and worst health statuses, respectively. Information from the EQ-5D and VAS were collected by trained nurses.

## Measurements

Information on demographic characteristics and lifestyle including age, sex, ethnicity (Han, Li, or others), education, marital status (married, widowed, divorced, or never married), residential type (living with family or living alone), smoking (never, former, or current), alcohol use (never, former, or current) and physical activity (low, medium, or high)[25] was collected via questionnaires administered by trained nurses. Education was assessed and classified into three groups: illiterate (0 years), primary school (1–6 years), or middle school or higher (>6 years).

## Statistical Analysis

IBM SPSS Statistics for Windows, version 24.0 and R 3.5.2 were used for the data analyses. The significance level for all tests was set at a two-tailed α value of 0.05. The differences in the means and proportions were evaluated using Student's t- and chi-square tests, respectively. Linear and logistic regression models were used to identify the associations between obesity indicators and EQ-5D/VAS scores. Restricted cubic splines were used to display and test the relationships between the risk of low QOL (EQ-5D score <1) and obesity-related indicators (WC, BMI, WHR, WHtR, calf circumference, and WCR). The linear and logistic regression models were repeated in men and women to determine if the associations differed by sex. The graphs were created in R 3.5.2 and were arranged into the final format in Adobe Illustrator.

## Patient Involvement

No patients were involved in setting the research question or the outcome measures, nor were they involved in the study design and implementation. There are no plans to involve patients in the dissemination of these findings.

# Results

## Socio-Demographic Characteristics

Of 1,002 centenarians of CHCCS recruited from June 2014 to June 2016, 822 (82.2%) were females. The mean age was 102.77 (standard deviation [SD] 2.75) years. Compared to that in men, more women more commonly had central obesity as defined by WC (12.8 vs 6.8%, P=0.021) and the group with central obesity had similar demographic and lifestyle characteristics including age, ethnicity, education, marital status, residential type, smoking, alcohol use, and physical activity (P>0.05, Table 1).

The average EQ-5D index was 0.62±0.25 (range: −0.-11–1.00) and the average VAS score was 61.60±15.56 (range: 0–100). The average EQ-5D indices for centenarians with and without central obesity were 0.61±0.25 and 0.65±0.22, respectively. The overall coefficient of EQ-5D and VAS was 0.414 (P<0.01). Scores >1 were observed in 873 centenarians (143 men and 730 women).

The average WC, BMI, WHR, WHtR, calf circumference, and WCR were 75.27±8.79 cm, 18.11±3.22 kg/m$^2$, 0.90±0.14, 0.52±0.07, 24.73±3.67 cm, and 3.08±0.41, respectively (Table 1).

**Table 1** Sociodemographic Variables of the CHCCS Participants

| | All (n=1002) | Normal (n=885) | Central Obesity (n=117) | P |
|---|---|---|---|---|
| Mean±SD | | | | |
| Age (years) | 102.77±2.75 | 102.82±2.79 | 102.38±2.41 | 0.110 |
| Height (cm) | 144.52±8.95 | 144.40±9.05 | 145.45±8.12 | 0.230 |
| Weight (kg) | 37.85±7.69 | 37.09±7.16 | 43.61±8.99 | <0.001 |
| Waist circumference (cm) | 75.27±8.79 | 73.23±6.84 | 90.68±6.2 | <0.001 |
| BMI | 18.11±3.22 | 17.78±2.92 | 20.66±4.13 | <0.001 |
| WHR | 0.90±0.14 | 0.89±0.14 | 0.98±0.09 | <0.001 |
| WHtR | 0.52±0.07 | 0.51±0.05 | 0.63±0.05 | <0.001 |
| Calf circumference | 24.73±3.67 | 24.39±3.21 | 27.09±3.15 | <0.001 |
| WCR | 3.08±0.41 | 3.04±0.39 | 3.39±0.43 | <0.001 |
| EQ5D | 0.62±0.25 | 0.61±0.25 | 0.65±0.22 | 0.113 |
| VAS | 61.60±15.56 | 61.41±15.76 | 63.05±13.93 | 0.283 |
| N (%) | | | | |
| Gender | | | | 0.021 |
| Male | 180 (18.0) | 168 (93.3) | 12 (6.7) | |
| Female | 822 (82.0) | 717 (87.2) | 105 (12.8) | |
| Ethnic | | | | 0.175 |
| Han | 883 (88.1) | 777 (88.0) | 106 (12.0) | |
| Li | 106 (10.6) | 98 (92.5) | 8 (7.5) | |
| Others | 13 (1.3) | 10 (76.9) | 3 (23.1) | |
| Marital Status | | | | 0.269 |
| Married | 100 (10.0) | 90 (90.0) | 10 (10.0) | |
| Widowed | 836 (83.4) | 733 (87.7) | 103 (12.3) | |
| Divorced or never married | 66 (6.6) | 62 (93.9) | 4 (6.1) | |
| Education Level | | | | 0.603 |
| Illiterate | 915 (91.3) | 806 (88.1) | 109 (11.9) | |
| Primary school | 67 (6.7) | 60 (89.6) | 7 (10.4) | |
| Middle school or higher | 20 (2.0) | 19 (95.0) | 1 (5.0) | |
| Residential Type | | | | 0.358 |
| Living together with families | 863 (86.1) | 759 (87.9) | 104 (12.1) | |
| Living alone at home | 139 (13.9) | 126 (90.6) | 13 (9.4) | |
| Body Mass Index (kg/m$^2$) | | | | <0.001 |
| Underweight (<18.5) | 575 (57.4) | 538 (93.6) | 37 (6.4) | |
| Normal (18.5–24.0) | 391 (39.0) | 327 (83.6) | 64 (16.4) | |
| Overweight (24.0–27.9) | 28 (2.8) | 20 (71.4) | 8 (28.6) | |
| Obese (≥28.0) | 8 (0.8) | 0 (0.0) | 8 (100.0) | |
| WHR | | | | <0.001 |
| Normal | 177 (17.7) | 176 (99.4) | 1 (0.6) | |
| Obese | 825 (82.3) | 709 (85.9) | 116 (14.1) | |
| WHtR | | | | <0.001 |
| Normal | 128 (12.8) | 841 (96.2) | 33 (3.8) | |
| Obese | 874 (87.2) | 44 (34.4) | 84 (65.6) | |
| Smoking Status | | | | 0.574 |
| Non-smoker | 919 (91.7) | 809 (88.0) | 110 (12.0) | |
| Former | 52 (5.2) | 47 (90.4) | 5 (9.6) | |

*(Continued)*

**Table 1** (Continued).

| | All (n=1002) | Normal (n=885) | Central Obesity (n=117) | P |
|---|---|---|---|---|
| Current | 31 (3.1) | 29 (93.5) | 2 (6.5) | |
| Drinking Status | | | | 0.129 |
| Non-drinker | 872 (87.0) | 764 (87.6) | 108 (12.4) | |
| Former | 81 (8.1) | 77 (95.1) | 4 (4.9) | |
| Current | 49 (4.9) | 44 (89.8) | 5 (10.2) | |
| Physical Activity | | | | 0.449 |
| Low | 874 (87.2) | 768 (87.9) | 106 (12.1) | |
| Medium | 37 (3.7) | 33 (89.2) | 4 (10.8) | |
| High | 91 (9.1) | 84 (92.3) | 7 (7.7) | |

## Results of Linear Regression Models

Obesity-related indicators including WC, BMI, WHR, WHtR, calf circumference, and WCR were included in the linear regression models as continuous variables. Demographic and lifestyle characteristics including age, sex, ethnicity, education, marital status, residential type, smoking, alcohol use, and physical activity were included as adjust variables by the stepwise method.

As shown in Table 2, with the EQ-5D index as the dependent variable, WC, BMI, WHtR, and calf circumference had positive impacts on the EQ-5D index. After adjustment, the standard β values were 0.101, 0.126, 0.100, and 0.302, respectively (P <0.001), while WCR negatively impacted the EQ-5D index (standard β=−0.219 after adjustment, P<0.001). Similar results were observed in women. In men, only calf circumference and WCR significantly impacted EQ-5D after adjustment.

A shown in Table 3, with VAS as the dependent variable, WC, BMI, WHtR, and calf circumference positively impacted the VAS score. The standard β values were 0.082, 0.076, and 0.156 after adjustment, respectively (P =0.009, 0.014, and <0.001, respectively), while WCR negatively impacted the VAS score (standard β=−0.117 after adjustment, P<0.001). Similar results were found in women. The associations were not significant in men.

## Results of Logistic Regression Models

Table 4 model C shows that, after adjustment, compared to lower BMI, WC, and calf circumference, the odds ratios (AORs) of EQ-5D score <1 for centenarians with 1 kg/m$^2$ or 1 cm increases were 0.91 (95% CI: 0.86–0.97), 0.97 (95% CI: 0.95–0.99) and 0.87 (0.82–0.92), respectively (Table 4). WCR was a risk factor for low QOL ((EQ-5D score <1) (OR=2.70,

**Table 2** Association Between BMI, WC, WHR, WHtR, Calf Circumference, WCR, and EQ-5D

| | Model A | | | | | Model B | | | | | Model C | | | | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | β | 95% CI | | Standard β | P | β | 95% CI | | Standard β | P | β | 95% CI | | Standard β | |
| | | Lower | Upper | | | | Lower | Upper | | | | Lower | Upper | | |
| Male | | | | | | | | | | | | | | | |
| BMI | −0.003 | −0.016 | 0.010 | −0.034 | 0.652 | −0.003 | −0.016 | 0.010 | −0.036 | 0.629 | −0.002 | −0.014 | 0.010 | −0.028 | 0.696 |
| WC | −0.002 | −0.006 | 0.002 | −0.064 | 0.392 | −0.003 | −0.007 | 0.002 | −0.097 | 0.203 | −0.003 | −0.007 | 0.002 | −0.087 | 0.230 |
| WHR | −0.333 | −0.806 | 0.139 | −0.104 | 0.166 | −0.313 | −0.782 | 0.155 | −0.098 | 0.188 | −0.230 | −0.680 | 0.219 | −0.072 | 0.313 |
| WHtR | −0.468 | −1.079 | 0.143 | −0.113 | 0.133 | −0.527 | −1.135 | 0.082 | −0.127 | 0.089 | −0.417 | −1.005 | 0.172 | −0.100 | 0.164 |
| Calf circumference | 0.015 | 0.005 | 0.025 | 0.212 | 0.004 | 0.013 | 0.003 | 0.023 | 0.190 | 0.011 | 0.015 | 0.005 | 0.024 | 0.213 | 0.003 |
| WCR | −0.166 | −0.256 | −0.076 | −0.264 | <0.001 | −0.168 | −0.257 | −0.078 | −0.266 | <0.001 | −0.168 | −0.252 | −0.083 | −0.266 | <0.001 |
| Female | | | | | | | | | | | | | | | |
| BMI | 0.010 | 0.005 | 0.015 | 0.132 | 0.000 | 0.010 | 0.005 | 0.015 | 0.132 | 0.000 | 0.009 | 0.004 | 0.014 | 0.123 | 0.000 |
| WC | 0.004 | 0.003 | 0.006 | 0.159 | 0.000 | 0.004 | 0.003 | 0.006 | 0.158 | 0.000 | 0.005 | 0.003 | 0.007 | 0.168 | 0.000 |
| WHR | −0.030 | −0.142 | 0.082 | −0.018 | 0.597 | −0.031 | −0.144 | 0.081 | −0.019 | 0.583 | −0.006 | −0.114 | 0.102 | −0.004 | 0.916 |
| WHtR | 0.483 | 0.229 | 0.737 | 0.129 | 0.000 | 0.483 | 0.229 | 0.738 | 0.129 | 0.000 | 0.507 | 0.264 | 0.750 | 0.136 | 0.000 |
| Calf circumference | 0.024 | 0.019 | 0.029 | 0.342 | 0.000 | 0.024 | 0.020 | 0.029 | 0.343 | 0.000 | 0.022 | 0.017 | 0.026 | 0.310 | 0.000 |
| WCR | −0.151 | −0.191 | −0.110 | −0.246 | <0.001 | −0.151 | −0.192 | −0.110 | −0.246 | <0.001 | −0.123 | −0.163 | −0.083 | −0.200 | <0.001 |
| Total | | | | | | | | | | | | | | | |
| BMI | 0.009 | 0.005 | 0.014 | 0.122 | <0.001 | 0.008 | 0.003 | 0.013 | 0.107 | 0.001 | 0.008 | 0.003 | 0.012 | 0.101 | 0.001 |
| WC | 0.004 | 0.002 | 0.005 | 0.130 | <0.001 | 0.003 | 0.002 | 0.005 | 0.117 | 0.000 | 0.004 | 0.002 | 0.005 | 0.126 | <0.001 |
| WHR | −0.054 | −0.163 | 0.055 | −0.031 | 0.330 | −0.046 | −0.154 | 0.063 | −0.026 | 0.411 | −0.032 | −0.136 | 0.072 | −0.018 | 0.551 |
| WHtR | 0.267 | 0.033 | 0.501 | 0.071 | 0.025 | 0.342 | 0.107 | 0.576 | 0.090 | 0.004 | 0.377 | 0.152 | 0.602 | 0.100 | 0.001 |
| Calf circumference | 0.023 | 0.019 | 0.027 | 0.338 | <0.001 | 0.022 | 0.018 | 0.026 | 0.327 | <0.001 | 0.020 | 0.017 | 0.024 | 0.302 | <0.001 |
| WCR | −0.161 | −0.198 | −0.125 | −0.268 | <0.001 | −0.154 | −0.191 | −0.117 | −0.255 | <0.001 | −0.132 | −0.168 | −0.096 | −0.219 | <0.001 |

**Notes:** Model A: Crude model; Model B: Adjusted for gender, age, ethnic, education level, residential type; Model C: Adjusted for gender, age, ethnic, education level, residential type, smoking, drinking, physical activity.

**Table 3** Association Between BMI, WC, WHR, WHtR, Calf Circumference, WCR, and VAS

| | Model A | | | | | Model B | | | | | Model C | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | β | 95% CI | | Standard β | P | β | 95% CI | | Standard β | P | β | 95% CI | | Standard β | P |
| | | Lower | Upper | | | | Lower | Upper | | | | Lower | Upper | | |
| Male | | | | | | | | | | | | | | | |
| BMI | 0.182 | −0.573 | 0.937 | 0.036 | 0.634 | 0.219 | −0.532 | 0.971 | 0.043 | 0.565 | 0.230 | −0.511 | 0.971 | 0.045 | 0.541 |
| WC | 0.044 | −0.211 | 0.299 | 0.025 | 0.735 | 0.021 | −0.237 | 0.279 | 0.012 | 0.874 | 0.028 | −0.226 | 0.282 | 0.016 | 0.828 |
| WHR | −11.311 | −39.527 | 16.906 | −0.059 | 0.430 | −9.447 | −37.436 | 18.541 | −0.049 | 0.506 | −6.248 | −33.936 | 21.440 | −0.033 | 0.657 |
| WHtR | −2.051 | −38.636 | 34.535 | −0.008 | 0.912 | −2.717 | −39.227 | 33.793 | −0.011 | 0.883 | 0.113 | −36.260 | 36.486 | 0.000 | 0.995 |
| Calf circumference | 0.569 | −0.035 | 1.172 | 0.138 | 0.065 | 0.490 | −0.118 | 1.099 | 0.119 | 0.113 | 0.542 | −0.056 | 1.139 | 0.131 | 0.075 |
| WCR | −4.381 | −9.888 | 1.125 | −0.117 | 0.118 | −4.100 | −9.592 | 1.391 | −0.109 | 0.142 | −4.177 | −9.561 | 1.208 | −0.111 | 0.128 |
| Female | | | | | | | | | | | | | | | |
| BMI | 0.450 | 0.121 | 0.779 | 0.093 | 0.007 | 0.454 | 0.126 | 0.782 | 0.094 | 0.007 | 0.434 | 0.110 | 0.758 | 0.090 | 0.009 |
| WC | 0.155 | 0.034 | 0.276 | 0.087 | 0.012 | 0.150 | 0.029 | 0.271 | 0.084 | 0.015 | 0.161 | 0.041 | 0.280 | 0.091 | 0.008 |
| WHR | −1.302 | −8.391 | 5.787 | −0.013 | 0.719 | −1.426 | −8.504 | 5.652 | −0.014 | 0.693 | −1.118 | −8.147 | 5.911 | −0.011 | 0.755 |
| WHtR | 15.457 | −0.720 | 31.635 | 0.065 | 0.061 | 15.391 | −0.746 | 31.528 | 0.065 | 0.062 | 16.433 | 0.499 | 32.367 | 0.069 | 0.043 |
| Calf circumference | 0.761 | 0.461 | 1.061 | 0.171 | <0.001 | 0.772 | 0.472 | 1.071 | 0.174 | <0.001 | 0.700 | 0.401 | 0.998 | 0.158 | <0.001 |
| WCR | −5.312 | −7.946 | −2.678 | −0.137 | <0.001 | −5.396 | −8.023 | −2.768 | −0.139 | <0.001 | −4.406 | −7.052 | −1.760 | −0.114 | 0.001 |
| Total | | | | | | | | | | | | | | | |
| BMI | 0.485 | 0.187 | 0.783 | 0.100 | 0.001 | 0.409 | 0.109 | 0.708 | 0.085 | 0.008 | 0.396 | 0.100 | 0.692 | 0.082 | 0.009 |
| WC | 0.152 | 0.043 | 0.262 | 0.086 | 0.006 | 0.124 | 0.015 | 0.234 | 0.070 | 0.026 | 0.135 | 0.027 | 0.243 | 0.076 | 0.014 |
| WHR | −2.321 | −9.156 | 4.514 | −0.021 | 0.505 | −1.845 | −8.632 | 4.942 | −0.017 | 0.594 | −1.525 | −8.220 | 5.170 | −0.014 | 0.655 |
| WHtR | 8.443 | −6.223 | 23.110 | 0.036 | 0.259 | 12.319 | −2.404 | 27.042 | 0.052 | 0.101 | 13.720 | −0.817 | 28.256 | 0.058 | 0.064 |
| Calf circumference | 0.802 | 0.543 | 1.060 | 0.189 | <0.001 | 0.713 | 0.444 | 0.981 | 0.168 | <0.001 | 0.661 | 0.395 | 0.927 | 0.156 | <0.001 |
| WCR | −5.855 | −8.169 | −3.541 | −0.155 | <0.001 | −5.231 | −7.599 | −2.862 | −0.139 | <0.001 | −4.401 | −6.763 | −2.039 | −0.117 | <0.001 |

**Notes:** Model A: Crude model; Model B: Adjusted for gender, age, ethnic, education level, residential type; Model C: Adjusted for gender, age, ethnic, education level, residential type, smoking, drinking, physical activity.

**Table 4** Odds Ratios (ORs) for Having a Low QOL

| | Model A | Model B | Model C |
|---|---|---|---|
| Male | | | |
| BMI | 0.95 (0.83–1.08) | 0.95 (0.83–1.09) | 0.93 (0.81–1.08) |
| WC | 0.99 (0.95–1.03) | 1.00 (0.95–1.04) | 0.99 (0.95–1.04) |
| WHR | 0.24 (0.00–23.95) | 0.23 (0.00–24.81) | 0.08 (0.00–11.62) |
| WHtR | 0.60 (0.00–304.59) | 1.43 (0.00–942.95) | 0.38 (0.00–392.32) |
| Calf circumference | **0.87 (0.78–0.98)** | **0.88 (0.79–0.99)** | **0.87 (0.77–0.98)** |
| WCR | **2.76 (0.93–8.20)** | **3.16 (1.03–9.69)** | **3.39 (1.06–10.89)** |
| BMI obese | | | |
| WC obese | 3.00 (0.37–24.01) | 3.31 (0.41–27.05) | 2.20 (0.26–18.49) |
| WHR obese | 0.80 (0.38–1.66) | 0.83 (0.39–1.76) | 0.73 (0.33–1.61) |
| WHtR obese | 1.58 (0.18–13.52) | 1.41 (0.16–12.52) | 1.34 (0.15–12.34) |
| Female | | | |
| BMI | **0.91 (0.86–0.97)** | **0.91 (0.86–0.97)** | **0.90 (0.84–0.97)** |
| WC | **0.97 (0.95–1.00)** | **0.97 (0.95–1.00)** | **0.97 (0.94–0.99)** |
| WHR | 3.59 (0.30–43.03) | 3.93 (0.31–49.41) | 2.94 (0.20–42.26) |
| WHtR | 0.13 (0.01–3.22) | 0.13 (0.01–3.31) | 0.06 (0.00–2.05) |
| Calf circumference | **0.85 (0.80–0.92)** | **0.86 (0.80–0.92)** | **0.87 (0.81–0.94)** |
| WCR | **3.43 (1.84–6.39)** | **3.46 (1.85–6.46)** | **2.45 (1.28–4.70)** |
| BMI obese | 0.88 (0.11–7.24) | 0.92 (0.11–7.61) | 0.67 (0.08–5.83) |
| WC obese | **0.56 (0.32–0.98)** | **0.56 (0.32–0.98)** | **0.48 (0.26–0.87)** |
| WHR obese | 1.44 (0.71–2.93) | 1.46 (0.71–2.97) | 1.49 (0.70–3.15) |
| WHtR obese | 0.80 (0.45–1.42) | 0.82 (0.46–1.47) | 0.76 (0.41–1.40) |
| Total | | | |
| BMI | **0.91 (0.86–0.96)** | **0.92 (0.87–0.97)** | **0.91 (0.86–0.97)** |
| WC | **0.97 (0.95–0.99)** | **0.98 (0.96–0.99)** | **0.97 (0.95–0.99)** |
| WHR | 2.41 (0.33–17.48) | 2.26 (0.31–16.69) | 1.82 (0.24–13.88) |
| WHtR | 0.42 (0.03–6.90) | 0.20 (0.01–3.60) | 0.09 (0.00–1.88) |
| Calf circumference | **0.85 (0.80–0.90)** | **0.86 (0.81–0.91)** | **0.87 (0.82–0.92)** |
| WCR | **3.74 (2.21–6.33)** | **3.39 (1.96–5.85)** | **2.70 (1.54–4.75)** |
| BMI obese | 1.04 (0.13–8.48) | 0.90 (0.11–7.45) | 0.77 (0.09–6.49) |
| WC obese | 0.73 (0.43–1.24) | 0.68 (0.40–1.17) | 0.59 (0.34–1.03) |
| WHR obese | 1.58 (1.01–2.45) | 1.12 (0.65–1.92) | 1.08 (0.61–1.92) |
| WHtR obese | 0.96 (0.56–1.66) | 0.86 (0.49–1.50) | 0.81 (0.45–1.45) |

**Notes:** Model A: Crude model; Model B: Adjusted for gender, age, ethnic, education level, residential type; Model C: Adjusted for gender, age, ethnic, education level, residential type, smoking, drinking, physical activity. Bold Values: P<0.05.

95% CI: 1.54–4.75) Table 4). When BMI, WC, WHR, and WHtR included involved as binary variables (obesity or not), the association was no longer significant (Table 4). Similar results were observed in women. In men, only calf circumference and WCR significantly impacted low QOL.

Further division of BMI, WC, WHR, WHtR, calf circumference, and WCR by quintile and inclusion as categorical variables in the logistic regression models showed that, compared to Q1, an increase in calf circumference decreased the risk of low QOL, while an increase in WCR increased the risk (P for trend <0.01, OR of Q5 calf circumference: 0.11 [95% CI: 0.05–0.27], OR of Q5 WCR: 3.73 (95% CI: 1.76–7.93) after adjustment) (Table 5).

## Restricted Cubic Splines

Restricted cubic splines were used to display and test the relationships between the risk of QOL and obesity-related indicators (WC, BMI, WHR, WHtR, calf circumference, and WCR) (Figure 1) (non-linear P >0.05).

# Discussion

The results of this study showed that calf circumference and WCR is a risk factor for HRQoL and that calf circumference was a protective factor among centenarians in China. To our knowledge, this study was the first to show the association between obesity-related indicators

**Table 5** Odds Ratios (ORs) for Having a Low QOL (Quintile)

| | Model A | Model B | Model C |
|---|---|---|---|
| BMI | | | |
| Q1 | 1 | 1 | 1 |
| Q2 | **0.45(0.23–0.90)** | **0.45(0.22–0.91)** | **0.41 (0.20–0.86)** |
| Q3 | 0.52(0.26–1.06) | 0.53(0.26–1.08) | 0.52 (0.25–1.09) |
| Q4 | **0.34(0.17–0.67)** | **0.35(0.18–0.70)** | **0.34 (0.17–0.70)** |
| Q5 | **0.36(0.19–0.72)** | **0.36(0.18–0.71)** | **0.33 (0.16–0.67)** |
| WC | | | |
| Q1 | 1 | 1 | 1 |
| Q2 | 1.21(0.63–2.32) | 1.28(0.66–2.49) | 0.99 (0.50–1.98) |
| Q3 | 0.87(0.48–1.59) | 0.85(0.47–1.57) | 0.83 (0.44–1.57) |
| Q4 | 0.61(0.36–1.05) | 0.63(0.36–1.10) | **0.54 (0.30–0.97)** |
| Q5 | **0.56(0.32–0.99)** | 0.60(0.34–1.06) | **0.48 (0.26–0.88)** |
| WHR | | | |
| Q1 | 1 | 1 | 1 |
| Q2 | 1.33(0.76–2.32) | 1.39(0.79–2.44) | 1.50 (0.83–2.71) |
| Q3 | 1.32(0.73–2.40) | 1.31(0.72–2.40) | 1.46 (0.78–2.76) |
| Q4 | 1.78(0.97–3.23) | 1.80(0.98–3.31) | 1.70 (0.90–3.21) |
| Q5 | 1.09(0.62–1.92) | 1.15(0.65–2.03) | 1.16 (0.64–2.12) |
| WHtR | | | |
| Q1 | 1 | 1 | 1 |
| Q2 | 0.77(0.41–1.44) | 0.82(0.44–1.56) | 0.82 (0.42–1.61) |
| Q3 | 0.90(0.48–1.71) | 0.97(0.51–1.86) | 0.92 (0.46–1.81) |
| Q4 | 0.57(0.31–1.06) | 0.60(0.32–1.11) | 0.55 (0.29–1.05) |
| Q5 | 0.68(0.37–1.26) | 0.71(0.38–1.33) | 0.60 (0.31–1.16) |
| Calf Circumference | | | |
| Q1 | 1 | 1 | 1 |
| Q2 | **0.25 (0.11–0.60)** | **0.25 (0.11–0.60)** | **0.28 (0.12–0.68)** |
| Q3 | **0.18 (0.07–0.46)** | **0.19 (0.08–0.48)** | **0.23 (0.09–0.59)** |
| Q4 | **0.14 (0.06–0.31)** | **0.14 (0.06–0.33)** | **0.19 (0.08–0.44)** |
| Q5 | **0.09 (0.04–0.21)** | **0.10 (0.04–0.24)** | **0.11 (0.05–0.27)** |
| WCR | | | |
| Q1 | 1 | 1 | 1 |
| Q2 | 1.56 (0.94–2.60) | 1.45 (0.86–2.43) | 1.26 (0.73–2.17) |
| Q3 | **1.91 (1.11–3.26)** | **1.75 (1.01–3.04)** | 1.58 (0.88–2.82) |
| Q4 | **2.67 (1.50–4.77)** | **2.43 (1.34–4.38)** | **2.03 (1.09–3.76)** |
| Q5 | **5.53 (2.7–11.34)** | **5.02 (2.4–10.46)** | **3.73 (1.76–7.93)** |

**Notes:** Model A: Crude model; Model B: Adjusted for gender, age, ethnic, education level, residential type; Model C: Adjusted for gender, age, ethnic, education level, residential type, smoking, drinking, physical activity. Bold Values: P<0.05.

(WC, BMI, WHR, WHtR, calf circumference, and WCR) and HRQoL in centenarians. The major strength of our study was its comprehensive control and adjustment for a wide range of potential confounders using different statistical models. The similarity in results demonstrated their robustness. Moreover, as the accuracy of height measurement in the oldest old population is difficult to guarantee, in addition to commonly used indicators such as BMI, WC, WHR, and WHtR, this study also included calf circumference and WCR as indicators of nutrition/muscle retention and central obesity. Calf circumference and WCR were more powerful protective and risk factors, respectively, for HRQoL.

The correlation coefficient of EQ-5D and VAS in this centenarian sample was 0.414, slightly lower than that reported in the fifth National Health Service Survey of China in 2013[30] and higher than that in the British population.[31] This discordance may be due to differences in social structures and culture as well as different ages of the study samples. A study of elderly people over 72 years of age in German communities reported an EQ-5D index of 78.3+15.8; they used the original value from 0 to 100 and did not report the EQ-5D index calculated by TTO.[32] The average VAS in our population was 61.60 +15.56, which was higher than that in a previous survey based on cognitive impairment in the elderly. In this study, 12.9% of participants had no problems based on EQ-5D score (score=1), a rate higher than that among elderly with cognitive impairment (6.1%). This observation indicates that the centenarians in the present study were relatively healthy.[33]

Studies on the impact of obesity on HRQoL in centenarians are limited. A study on this impact in Spanish adults (aged above 18 years) showed that HRQoL decreased along with BMI.[34] Worldwide, most studies in adults have confirmed the significant negative correlation between BMI and HRQoL using the SF-36 or EQ-5D to evaluate HRQoL.[35–37] The obesity paradox in elderly populations shows that, compared to normal-weight elderly and patients with chronic disease, obese elderly people and obese patients had higher HRQoL, better prognosis, lower disability, and lower mortality.[17,18] However, the criteria for evaluating obesity in these studies were usually BMI or WC; due to the natural aging progress, it is difficult to accurately measure the height of the elderly. Secondly, it is difficult to exclude the impact of nutrition and muscle retention in WC measurements; thus, the conclusion that obesity was beneficial to maintain a better HRQoL was biased. Furthermore, WHR is generally used to balance the relationship between fat distribution and nutrition or muscle retention; however, this measurement may mask central obesity if both hip circumference and WC increase.[22] In this study, increased BMI and WC resulted in increased HRQoL (reflected by EQ-5D-VAS) and decreased risk of low QOL in centenarians. The WHR was not significantly correlated with HRQoL in this population. However, the analysis of calf circumference and WCR showed that the protective effect of calf

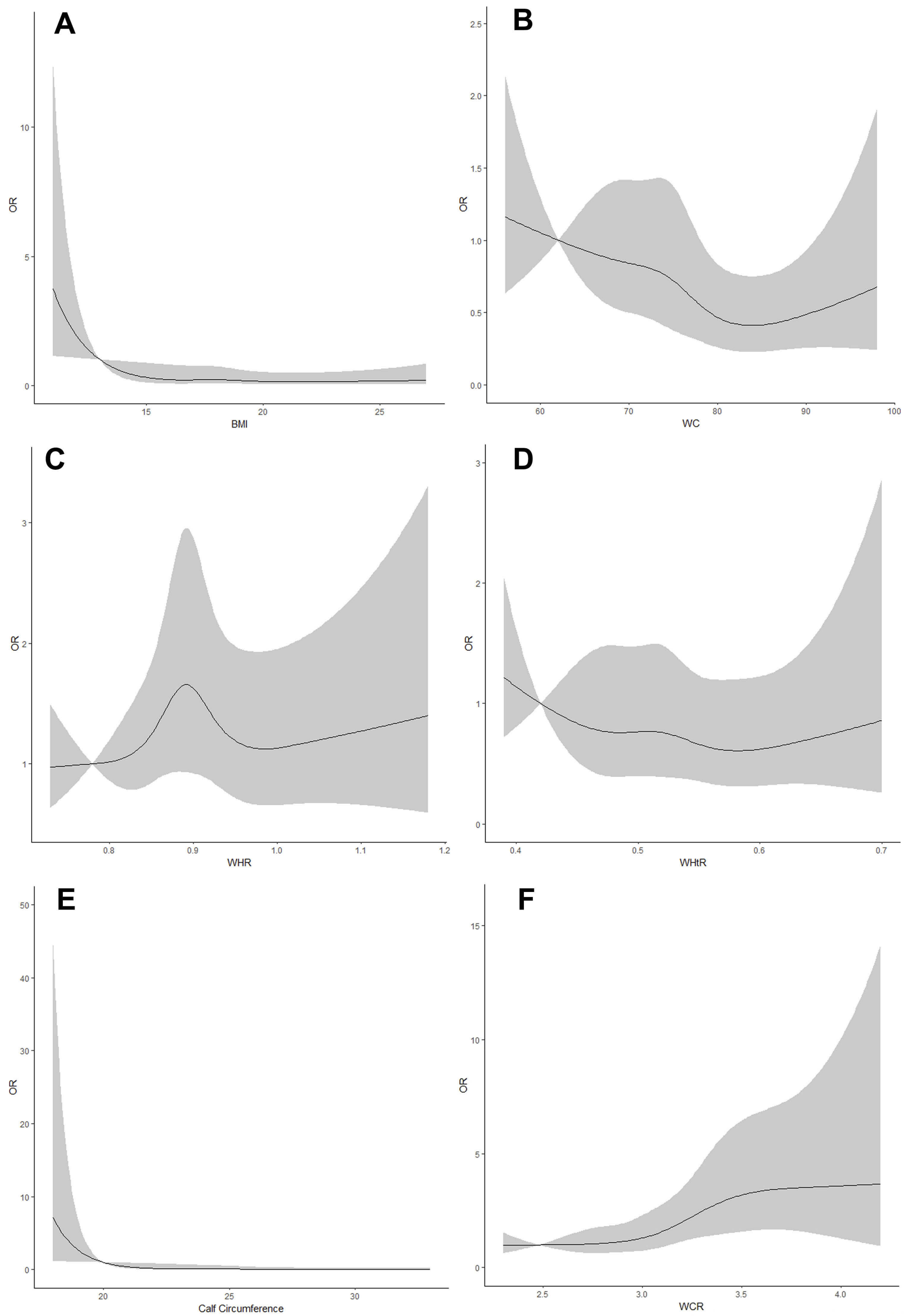


**Figure 1** Restricted cubic splines of the relationship between (**A**) BMI, (**B**) WC, (**C**) WHR, (**D**) WHtR, (**E**) calf circumference, (**F**) WCR and the risk of EQ-5D scored less than 1 after adjusting for gender, age, ethnic, education level, residential type, smoking, drinking, physical activity.

circumference (the indicator of nutrition and muscle retention[20,21]) on HRQoL compared to those for BMI and WC. We also observed that WCR (the indicator simultaneously assessing both central obesity and nutrition and muscle retention and excluding the effects of nutrition and muscle retention to reflect the central distribution of fat), was a risk factor for HRQoL in centenarians. The results of the restrictive cubic spline analysis also showed the linear correlation between WCR and the risk of low QOL.

The major strength of our study was the comprehensive control and adjustment for a wide range of potential confounders using different statistical models. Moreover, to our knowledge, this study is the first to analyze the correlations between obesity-related indicators (especially calf circumference and WCR) and HRQoL in a large sample of Chinese centenarians.

This study has several limitations. Firstly, this study used baseline data from the CHCCS; thus, these cross-sectional data do not permit causal deduction. Secondly, the large sample of centenarians of this study had lived in the island environment for nearly their entire lives; therefore, caution is required in extrapolating the conclusions of the present study. Further, as the results and implications were based on centenarians, caution is required regarding the external validity. Thirdly, due to the natural aging of the elderly population, there may be errors in height measurement; thus, BMI and WHtR may have had corresponding errors that may have consequently affected the correlation analysis of BMI/WHtR and EQ-5D-VAS.

## Conclusions

Despite the limitations, this study analyzed the correlations between obesity-related indicators (especially calf circumference and WCR) and the HRQoL in a large sample of Chinese centenarians. In this study, calf circumference (the indicator of nutrition and muscle retention) was a protective factor for the HRQoL of centenarians, while WCR was a risk factor. These results showed the negative impact of central fat distribution on HRQoL in the oldest old population after excluding nutritional and muscle retention factors. As the height of elderly individuals is difficult to measure, calf circumference and WCR can be used as measurement indicators of nutrition and obesity, respectively, in these populations.

## Abbreviations

HRQoL, Health-related quality of life; WC, Waist circumference; BMI, Body mass index; WCR, Waist-calf circumference ratio; WHR, Waist–hip ratio; WHtR, Waist–height ratio; CHCCS, The China Hainan Centenarian Cohort Study; EQ-5D-VAS, EuroQol five dimensions questionnaire-visual analogue scale; TTO, time trade-off.

## Data Sharing Statement

All data relevant to the study are included in the article.

## Acknowledgments

The abstract for this paper was presented at the Eighth Chinese Congress on Gerontology and Health Industry and was published in the Journal of the American Geriatrics Society, Vol 67, Issue S4. Shanshan Yang and Miao Liu are co-first authors for this study.

## Author Contributions

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; gave final approval of the version to be published; and agree to be accountable for all aspects of the work.

## Funding

This study was supported by the National Natural Science Foundation of China (81773502, 81703308, and 81703285).

## Disclosure

The authors report no conflicts of interest in this work.

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