Adiposity reduce prevalence of osteoporosis in Chinese rural population: the Henan Rural Cohort Study

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**SUBJECT AREAS**
- Health Policy
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**KEYWORDS**
- Adiposity
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- Rural population
Abstract

Background: Adiposity plays a crucial role in the risk of osteoporosis. However, the impact of body fat distribution on the skeleton is contentious. The study was designed to explore the association of various adiposity indices on bone mineral density (BMD) and osteoporosis based on body mass index (BMI), body fat percentage (BFP), waist circumference (WC), waist to hip ratio (WHR), waist to height ratio (WHtR), and visceral fat index (VFI).

Methods: A total of 8475 subjects derived from the Henan Rural Cohort Study were analyzed. The BMD of study participants were measured by calcaneal quantitative ultrasound (QUS). Linear and binary logistic regression was performed to estimate the association of adiposity and the outcomes.

Results: The crude and age-standardized prevalence of osteoporosis was 20.15% and 14.39%. Per unit increment in adiposity indices was associated with 0.008-0.014 g/cm² increase in BMD. The adjusted odds ratios (95% confidence interval) of osteoporosis for per 1 SD increase in WC, WHR, WHtR, BMI, BFP, and VFI were 0.756 (0.713-0.801), 0.774 (0.728-0.822), 0.763 (0.720-0.809), 0.746 (0.703-0.792), 0.794 (0.729-0.865), and 0.735 (0.688-0.786), respectively. Stratified analyses indicated greater effects on individuals aged 55 years or more.

Conclusions: The adiposity indices have an inverse association with the risk of osteoporosis among Chinese rural population, especially in the elderly. Keywords: Adiposity; Bone mineral density; Osteoporosis; Rural population

Background

Osteoporosis is a disorder condition characterized by low bone mineral density
(BMD) and deterioration of bone microstructure. It leads to increased bone fragility, eventually to fractures with high rates of mortality, morbidity, and disability [1]. A combined survey of the Americas and Europe reported osteoporotic fractures were the sixth burden of disability-adjusted life years (DALYs), higher than both hypertension and breast cancer [2]. Osteoporosis is becoming more common worldwide due to the aging of the global population. As the world’s most populous country, China is facing an unprecedented rate of growth in the elderly. A recent survey including 75321 adults reported the age-standardized prevalence of osteoporosis was 6.46% and 29.13% for men and women in the elderly [3]. The number of osteoporosis fractures annually will increase to 5.99 million, and the healthcare cost is predicted to be approximately 25.43 billion dollars by 2050 [4]. Thus, it is urgent to figure out the potential mechanism of lower BMD and osteoporosis in China.

To date, very many risk factors of osteoporosis have been proposed in previous studies [5–9], including age, sex, adiposity, smoking, alcohol intake, protein and calcium intake, use of glucocorticoids, physical exercise, reproductive history and others; among which adiposity is of importance in bone metabolism because of their complicated interaction [10]. Although numerous studies have explored the relationship between fat and bone, the impact of various adiposity indices on bone mass is conflicting. The previous epidemiological studies reported that body mass index (BMI) was positively associated with BMD [11, 12], while body fat percentage (BFP) showed a negative mediator of bone mass [12]. Increased waist circumference (WC), or waist to hip ratio (WHR) and waist to height ratio (WHtR) was associated with the occurrence of low BMD or fractures [13, 14]. Besides, literature reported visceral adiposity measured by visceral fat index (VFI) was deleterious to bone
microarchitecture [13, 15]. However, previous researches on the association between adiposity and bone were examined only by a single adiposity index in the previous studies including our researches; it remains unclear about the overall effect of adiposity on bone health using different adiposity indices [11, 16-18]. In addition, many people live in rural region, where is hotspot of the incidence of osteoporosis due to poor economic status and medical resource. Therefore, the current study was designed to explore the effect of adiposity on BMD and osteoporosis in China rural population, based on WC, WHR, WHtR, BMI, BFP, and VFI.

Methods

Study participants

During July 2015 and September 2017, 39259 participants aged 18–79 years old were recruited from five counties of Henan province to the Henan Rural Cohort Study and finished the baseline survey. Detailed baseline characteristics had been described in a previous study [19]. Only 8475 participants who completed the BMD measurement were included in our present study. The survey was approved by the Zhengzhou University Life Science Ethics Committee, and written informed consent was obtained by all participants.

Data collection

Detailed information of demographic characteristics, lifestyle, the history of disease and medicine intake, family history of disease were collected using a structured questionnaire through a face-to-face interview by trained staff. The education level was divided into three categories: primary school or below, junior high school and high school or above. Average monthly household income was classified into “<500 RMB”, “500-1000 RMB” and “≥1000RMB”. Marital status was grouped into living
alone (unmarried/widowed/divorced) or not (married /cohabitation). Smoking and alcohol drinking status were grouped as non-, occasional and regular smoker/drinker. Physical activity was categorized as low, moderate and high, assessed by the International Physical Activity Questionnaire Short Form (IPAQ-SF) [20].

**Anthropometry and BMD measurements**

All measure devices were performed by trained investigators using calibrated equipment following the manufacturer’s instruction. Height of the participants was measured twice to the nearest 0.1 cm with bare feet and in an upright posture. WC and hip circumference (HC), respectively, were measured in duplicate around the waist (halfway between the lower rib and the iliac crest) and on the widest of hip at a level of 0.1 cm in a horizontal plane using a standard tape measure. If two readings were more than 0.5 cm apart, a third measurement was taken, and the average of the nearest two readings was taken. WHR was calculated by the ratio of WC to HC and WHtR was WC to height. BMI, BFI, and VFI were measured by the bioelectrical impedance device (V-body HBF-371; Omron, Kyoto, Japan). The subject was asked to stand erect on the sensing platform without shoes and holding the electrode parallel to the ground.

The calcaneus BMD was measured using a quantitative ultrasound bone densitometer (QUS, Sahara, Hologic, USA). Subjects were asked to furl the trouser legs and sit down, the left heel was tested three times and the average reading was taken. If the subjects had a history of fractures or any bone disease in the right foot, the other heel would be measured. T-score was calculated as the difference of the subject BMD and the mean BMD of healthy adults divided by the young adult standard deviation (SD). The healthy adult BMD and young adult SD were derived.
from a reference database provided by the manufacturer.

Definition of obesity

According to the criteria recommended by WGOC [21], BMI was categorized into normal (BMI < 24.0 kg/m²), overweight (24.0 kg/m² ≤ BMI < 28.0 kg/m²) and obesity (BMI ≥ 28.0 kg/m²) for Chinese adults. In reference to the guideline of WHO [22] and International Diabetes Federation Consensus Group's standard [23], central obesity was defined as WC equal to or greater than 90 cm for males and 80 cm for females, and further defined as WHR of over 0.90 for males and over 0.85 for females. WHtR above 0.5 was an effective indicator for health risks summarized in a review study [24]. Li L [25] proposed high-BFP with BFP ≥ 25.0% for males and BFP ≥ 35.0% for females in Chinese adults even if there is no agreement about cut-off points for the percentage of body fat that constitutes obesity in the world [26]. Owing to the inconsistent criteria in China, VFI was divided into two levels according to the cut-off value for the detection of osteoporosis (high-VFI: ≥9, low-VFI: <9).

Definition of osteoporosis

According to the given thresholds of the equipment, three general categories are proposed using measurements of QUS: normal (T-score ≥ -1), osteopenia (-2.5 < T-score < -1), and osteoporosis (T-score ≤ -2.5). In order to define osteoporosis as a dichotomous variable, two groups are analyzed in this survey: non-osteoporosis (T-score > -2.5), osteoporosis (T-score ≤ -2.5)

Statistical analysis

Continuous variables were expressed as means ± SD and categorical variables were presented as counts with their relative frequency percentages. The comparisons of the basic characteristics between the groups were conducted using Student’s t-test
for the continuous variables and Pearson’s chi-square test for categorical variables. The age-standard prevalence of osteoporosis was calculated based on the sixth census data of China in 2010.

Multiple linear regression analysis and binary logistic regression were used to evaluate the association of the six adiposity indices with BMD and the risk of osteoporosis. Moderate or high correlations were found among the adiposity indices, thus only single-adiposity index models were applied (table S1). In multivariate models, we adjusted for age, gender, education level, marital status, income level, smoking status, alcohol intake, physical activity, and dietary habits (meat and poultry intake, fresh fish, beans, vegetables and fruits).

Furthermore, we performed stratified analyses by gender (male, female), age (< 55, ≥ 55 years) and sensitivity analysis by excluding osteopenia patients. Akaike information criteria (AIC) were used to assess the relative goodness fit of the adiposity index models, where the lower the AIC, the better the fit. All statistical analyses were conducted using SAS 9.1. Statistical significance was less than 0.05 with 2-tailed tests.

Results

Characteristics of study participants

Among the 8475 subjects, 1708 individuals were identified with osteoporosis, and the crude and age-standardized prevalence of osteoporosis was 20.15% and 14.39%. The mean BMD and T-score of non-osteoporosis subjects were higher than individuals with osteoporosis (P < 0.001). Table 1 shows the general demographic and clinical characteristics of the study population. As anticipated, subjects with osteoporosis were female, older, of lower education level, living alone, more likely
to smoke and drink alcohol, insufficient dietary intake of meat and poultry, fresh fish, beans, vegetables and fruits, compared to those without osteoporosis (P < 0.05). WC, WHR, WHtR, and VFI were lower but BFP were higher in osteoporosis patients.

### Table 1
Baseline characteristics of the study population

| Variables                               | Non-osteoporosis (n = 6767) | Osteoporosis (n = 1708) | P     |
|-----------------------------------------|-----------------------------|-------------------------|-------|
| Age (years), means (SD)                 | 54.70 (10.64)               | 60.61 (10.22)           | < 0.001 |
| Male, n (%)                             | 2713 (40.09)                | 462 (27.05)             | < 0.001 |
| Education level, n (%)                  |                             |                         | < 0.001 |
| Elementary school or below              | 2791 (41.25)                | 1003 (58.79)            |       |
| Junior high school                      | 2936 (43.39)                | 528 (30.95)             |       |
| High school or above                    | 1039 (15.36)                | 175 (10.26)             |       |
| Average monthly individual income, n (%)|                             |                         | < 0.001 |
| < 500 RMB                               | 2130 (31.48)                | 639 (37.41)             |       |
| 500–1000 RMB                            | 2020 (29.85)                | 515 (30.15)             |       |
| ≥ 1000 RMB                              | 2617 (38.67)                | 554 (32.44)             |       |
| Marital status, n (%)                   |                             |                         | < 0.001 |
| Married/cohabitating                    | 6246 (92.30)                | 1452 (85.01)            |       |
| Unmarried/divorced/widowed              | 521 (7.70)                  | 256 (14.99)             |       |
| Smoker, n (%)                           |                             |                         | < 0.001 |
| Non-smoker                              | 4900 (73.43)                | 1367 (80.70)            |       |
| Occasional smoker                       | 349 (5.23)                  | 44 (2.60)               |       |
| Regular smoke                           | 1424 (21.34)                | 283 (16.70)             |       |
| Drinker, n (%)                          |                             |                         | < 0.001 |
| Non-drinker                             | 5107 (76.48)                | 1419 (83.76)            |       |
| Occasional drinker                      | 1004 (15.04)                | 168 (9.92)              |       |
| Regular drinker                         | 566 (8.48)                  | 107 (6.32)              |       |
| Physical activity, n (%)                |                             |                         | 0.168 |
| Low                                     | 1922 (28.40)                | 524 (30.68)             |       |
| Moderate                                | 2634 (38.93)                | 637 (37.29)             |       |
| High                                    | 2211 (32.67)                | 547 (32.03)             |       |
| Dietary habits (g/day), mean (SD)       | 48.86 (69.04)               | 36.18 (41.42)           | < 0.001 |
| Fish                                    | 4.76 (13.92)                | 3.73 (10.07)            | 0.001 |
| Vegetables and fruits                   | 535.75 (266.03)             | 469.57 (243.34)         | < 0.001 |
| Bean                                    | 32.81 (48.00)               | 29.53 (82.96)           | 0.034 |
| WC (cm), mean (SD)                      | 84.58 (10.19)               | 81.84 (10.42)           | < 0.001 |
| WHR, mean (SD)                          | 0.90 (0.08)                 | 0.89 (0.08)             | < 0.001 |
| WHtR, mean (SD)                         | 0.53 (0.06)                 | 0.52 (0.07)             | < 0.001 |
| BMI (kg/m²), mean (SD)                  | 24.86 (3.38)                | 23.85 (3.50)            | < 0.001 |
| BFP, mean (SD)                          | 29.76 (6.23)                | 31.11 (6.60)            | < 0.001 |
| VFI, mean (SD)                          | 9.37 (4.40)                 | 8.21 (4.02)             | < 0.001 |
| BMD (g/cm²), mean (SD)                  | 0.47 (0.10)                 | 0.29 (0.04)             | < 0.001 |
| T-score, mean (SD)                      | -1.15 (0.99)                | -2.95 (0.37)            | < 0.001 |

Abbreviation: RMB, renminbi; SD, standard deviation; WC, waist circumference; WHR, waist to hip ratio; WHtR, waist to height ratio; BMI, body mass index; BFP, body fat percentage; VFI, visceral fat index; BMD, bone mineral density.

The mean and SD of BMD according to the adiposity indices in different strata are
presented in Table 2. People with osteoporosis had lower BMD in all groups (P < 0.001). Subjects with obesity based on BFP had lower BMD than the normal groups (P < 0.001), while obesity based on WHtR, BMI, and VFI had higher BMD only in subjects without osteoporosis. However, the distribution of BMD between the different levels had no significant difference (P > 0.05), except for the group defined by BFP and VFI in osteoporosis patients.

Table 2
The distribution of bone mineral density grouped by the adiposity indices

| Variables | Non-osteoporosis (n = 6767) | Osteoporosis (n = 1708) | P      |
|-----------|-----------------------------|-------------------------|--------|
| WC        |                             |                         |        |
| Normal    | 0.474 ± 0.105               | 0.286 ± 0.039           | <0.001 |
| Obesity   | 0.470 ± 0.099               | 0.285 ± 0.044           | <0.001 |
| WHR       |                             |                         |        |
| Normal    | 0.473 ± 0.104               | 0.286 ± 0.038           | <0.001 |
| Obesity   | 0.471 ± 0.100               | 0.286 ± 0.043           | <0.001 |
| WHtR      |                             |                         |        |
| Normal    | 0.470 ± 0.103               | 0.286 ± 0.038           | <0.001 |
| Obesity   | 0.473 ± 0.101               | 0.285 ± 0.043           | <0.001 |
| BMI       |                             |                         |        |
| Normal/Overweight | 0.472 ± 0.103 | 0.286 ± 0.042 | <0.001 |
| Obesity   | 0.472 ± 0.094               | 0.284 ± 0.040           | <0.001 |
| BFP       |                             |                         |        |
| Normal    | 0.474 ± 0.104               | 0.289 ± 0.042*          | <0.001 |
| Obesity   | 0.469 ± 0.098               | 0.282 ± 0.039*          | <0.001 |
| VFI       |                             |                         |        |
| Low       | 0.469 ± 0.104               | 0.283 ± 0.038*          | <0.001 |
| High      | 0.475 ± 0.099               | 0.290 ± 0.046*          | <0.001 |

*The difference between the adiposity levels is significant at the 0.05 level (2-tailed).

Data are mean ± Standard Deviation. BMD was scaled to the adiposity levels (WC: <90 cm for males and < 80 cm for females was normal; ≥90 cm for males and < 80 cm for females was obesity; WHR: <0.9 for males and < 0.85 for females was normal; ≥0.9 for males and ≥ 0.85 for females was obesity; WHtR: <0.5 was normal; ≥0.5 was obesity; BMI: <28.0 kg/m² was normal/overweight; ≥28.0 kg/m² was obesity; BFP%: <25% for males and < 35% for females was normal; ≥25% for males and ≥ 35% for females was obesity; VFI: <9 was low; ≥9 was high).

Abbreviation: WC, waist circumference; WHR, waist to hip ratio; WHtR, waist to height ratio; BMI, body mass index; BFP, body fat percentage; VFI, visceral fat index.

Associations between adiposity indices and BMD

We estimated the association between the six adiposity indices and BMD. All six adiposity indices were positively associated with BMD (P < 0.05). For 1 SD increment of the adiposity indices, there was 0.008-0.014 g/cm² BMD increase (Table 3). The associations were likely to be stronger for VFI. More robust associations were found in the sensitivity analysis that excluded the subjects who were osteopenia (Table S3). When stratified by age and gender, the relationship between the adiposity
indices and BMD remained (Table 3). Stratified analyses showed that the effect estimates were greater in the elderly subjects, however, there was no statistical significance grouped by gender.

| Table 3 |
|-----------------------------------------------|
| Adjusted estimates for measurements per SD increase of the adiposity indices* |
|-----------------------------------------------|

|          | Total       | Male          | Female        | < 55 years old | ≥ 55 years old |
|----------|-------------|---------------|---------------|----------------|----------------|
| WC       | 0.008 (0.005, 0.010) | 0.010 (0.006, 0.014) | 0.011 (0.008, 0.014) | 0.003 (-0.001, 0.007) | 0.014 (0.010, 0.017) |
| WHR      | 0.007 (0.004, 0.009) | 0.009 (0.005, 0.015) | 0.010 (0.007, 0.014) | 0.002 (-0.002, 0.007) | 0.013 (0.009, 0.016) |
| WHR      | 0.010 (0.007, 0.012) | 0.014 (0.009, 0.018) | 0.012 (0.009, 0.015) | 0.008 (0.004, 0.012) | 0.014 (0.010, 0.017) |
| BMI      | 0.013 (0.010, 0.015) | 0.016 (0.011, 0.020) | 0.014 (0.011, 0.017) | 0.009 (0.005, 0.017) | 0.017 (0.013, 0.020) |
| BFP      | 0.012 (0.008, 0.016) | 0.013 (0.007, 0.019) | 0.017 (0.011, 0.022) | 0.008 (0.002, 0.014) | 0.018 (0.013, 0.023) |
| VFI      | 0.014 (0.011, 0.017) | 0.014 (0.010, 0.018) | 0.017 (0.013, 0.021) | 0.011 (0.006, 0.016) | 0.017 (0.013, 0.020) |

*Data are β (95% Confidence Interval). β indicates partial regression coefficient. Estimates were scaled to per SD for the adiposity indexes (10.30 cm for WC, 0.080 for WHR, 0.065 for WHR, 3.43 kg/m² for BMI, 6.33% for BFP, and 4.35 for VFI).

Data are adjusted for age, gender, education level, marital status, income level, smoking, alcohol intake, physical activity and diet (meat and poultry, fresh fish, beans, vegetables and fruits).

Abbreviation: WC, waist circumference; WHR, waist to hip ratio; WHR, waist to height ratio; BMI, body mass index; BFP, body fat percentage; VFI, visceral fat index.

| Table 4 |
|-----------------------------------------------|
| Adjusted OR for osteoporosis with a SD increase of the adiposity indices. |
|-----------------------------------------------|

|          | Total       | Male          | Female        | < 55 years old | ≥ 55 years old |
|----------|-------------|---------------|---------------|----------------|----------------|
| WC       | 0.756 (0.713, 0.801) | 0.686 (0.616, 0.764) | 0.749 (0.697, 0.805) | 0.729 (0.653, 0.815) | 0.746 (0.695, 0.801) |
| WHR      | 0.774 (0.728, 0.822) | 0.727 (0.648, 0.816) | 0.752 (0.698, 0.810) | 0.784 (0.696, 0.883) | 0.741 (0.688, 0.797) |
| WHR      | 0.763 (0.720, 0.809) | 0.668 (0.596, 0.748) | 0.764 (0.712, 0.819) | 0.719 (0.642, 0.806) | 0.758 (0.707, 0.813) |
| BMI      | 0.746 (0.703, 0.792) | 0.602 (0.535, 0.678) | 0.779 (0.726, 0.836) | 0.722 (0.648, 0.804) | 0.753 (0.700, 0.810) |
| BFP      | 0.794 (0.729, 0.865) | 0.716 (0.625, 0.820) | 0.798 (0.714, 0.891) | 0.754 (0.651, 0.874) | 0.797 (0.717, 0.886) |
| VFI      | 0.735 (0.688, 0.786) | 0.647 (0.581, 0.720) | 0.763 (0.700, 0.832) | 0.691 (0.607, 0.788) | 0.743 (0.687, 0.804) |

Data are OR (95% Confidence Interval), OR was scaled to the SD for each adiposity index (10.30 cm for WC, 0.080 for WHR, 0.065 for WHR, 3.43 kg/m² for BMI, 6.33% for BFP, and 4.35 for VFI).

Data are adjusted for age, gender, education level, marital status, income level, smoking, alcohol intake, physical activity and diet (meat and poultry, fresh fish, beans, vegetables and fruits).

Abbreviation: OR, odd ratio; WC, waist circumference; WHR, waist to hip ratio; WHR, waist to height ratio; BMI, body mass index; BFP, body fat percentage; VFI, visceral fat index.

**Associations between adiposity indices and osteoporosis**

For the osteoporosis patients per 1 SD increase in the adiposity indexes, we observed inverse association with all the six adiposity indexes (Table 4). Per unit increment of WC, WHR, WHR, BMI, BFP, and VFI was associated a 24.4%, 22.6%, 23.7%, 25.4%, 20.6%, and 26.5% decreased the risk of osteoporosis, respectively.
Moreover, the model including VFI had a good fit (AIC = 7598), after adjusting for all potential confounders (Table S3). To the robustness, we also found people who were obese with the different definition of the adiposity indices, had a lower risk of osteoporosis (Table 5). After we removed the osteopenia subjects, the inverse association did not change significantly for the adiposity indices (Table S4).

Stratified analysis by sex and age, presented the decrease in osteoporosis risk seemed to be greater for individuals who were younger (aged < 55 years) (Table 4, Table 5).

Table 5
Associations of obesity by different definitions and osteoporosis

|        | Total         | Male          | Female        | < 55 years old | ≥ 55 years old |
|--------|---------------|---------------|---------------|----------------|----------------|
| WC     | 0.586 (0.520, 0.661) | 0.519 (0.406, 0.664) | 0.574 (0.499, 0.660) | 0.601 (0.488, 0.740) | 0.558 (0.480, 0.650) |
| WHR    | 0.605 (0.536, 0.682) | 0.603 (0.490, 0.742) | 0.557 (0.478, 0.648) | 0.622 (0.507, 0.762) | 0.564 (0.482, 0.658) |
| WHR    | 0.568 (0.503, 0.641) | 0.516 (0.419, 0.635) | 0.547 (0.469, 0.638) | 0.601 (0.489, 0.738) | 0.531 (0.454, 0.620) |
| BMI    | 0.664 (0.560, 0.787) | 0.568 (0.396, 0.814) | 0.661 (0.543, 0.804) | 0.534 (0.391, 0.730) | 0.725 (0.588, 0.895) |
| BFP    | 0.847 (0.753, 0.952) | 0.690 (0.558, 0.853) | 0.873 (0.757, 1.007) | 0.822 (0.657, 1.029) | 0.820 (0.713, 0.944) |
| VFI    | 0.651 (0.579, 0.733) | 0.470 (0.380, 0.581) | 0.702 (0.609, 0.809) | 0.590 (0.470, 0.740) | 0.650 (0.564, 0.749) |

Data are OR (95% Confidence Interval), OR was scaled to the SD for each adiposity index (10.30 cm for WC, 0.080 for WHR, 0.065 for WHR, 3.43 kg/m² for BMI, 6.33% for BFP, and 4.35 for VFI).

Data are adjusted for age, gender, education level, marital status, income level, smoking, alcohol intake, physical activity and dietary (meat and poultry, fresh fish, beans, vegetables and fruits).

Abbreviation: OR, odd ratio; WC, waist circumference; WHR, waist to hip ratio; WHR, waist to height ratio; BMI, body mass index; BFP, body fat percentage; VFI, visceral fat index.

Discussion

To our knowledge, this is the first time to explore the association of the six anthropometric adiposity indices with BMD and osteoporosis in a large epidemiological study. We found that increment in all adiposity indices was significantly associated with higher BMD and lower risk of osteoporosis. The association was independent of established risk factors, including age, gender, education level, marital status, income level, smoking, alcohol intake, physical activity, and dietary factors. In addition, we observed that the elderly subjects
appeared to be more susceptible to the fat-protect-bone effects.

Comparison with other studies

Several previous studies investigated the associations between adiposity indices and BMD or osteoporosis, but the findings were inconsistent [11-13, 17, 18]. In agreement with our findings, a cohort of 16500 women aged 50 years and older found high BMD in the highest BMI values (≥ 30 kg/m²) [11]. Meanwhile, a cross-sectional case-control study designed by Evans AL and colleagues revealed the obese adults had higher BMD at all sites and more favorable bone microarchitecture than the normal weight adults [27]. A meta-analysis included 60000 subjects with over 250000 person-years reported that the risk of hip fracture with a BMI of 20 kg/m² was increased two-fold comparing with a BMI of 25 kg/m² [16]. Another meta-analysis included 5958 children reported that overweight and obese children have higher bone mineral content than the normal weight children [17]. However, existing studies found subcutaneous fat was beneficial to bone structure, but visceral fat had the opposite effect [15]. Similar result has also been reported in a meta-analysis that absolute adiposity correlated positively with bone mineral and relative adiposity correlated negatively with BMD [28]. The reasons for the contradictory results among the studies of adiposity indices and BMD are unclear. It may be the differences in population characteristics (age, region, lifestyles, and social status) and the site-specific differences in BMD and bone mineral content.

Biological mechanism of obesity and osteoporosis

Although the underlying biological mechanisms whereby obesity may protect against osteoporosis are not entirely clear, several potential biological pathways have been proposed. One straightforward explanation is that obese individuals have
higher BMD in order to withstand the greater force of fat mass mechanical loading on the bones than their normal-weight counterparts [29]. However, because fat mass is less than 40% of total body weight in human, it means that large weight-induced gravitational forces coupled with increased fat mass may be incomplete to explain the positive effect of obesity on bone [30]. Besides, the protective effect has been found even at non-weight-bearing bone sites [31]. Thus, another explanation has been proposed that some adipokines such as leptin [32], adiponectin [33], resistin [34], secreted by adipose tissue stimulate bone formation by inducing the differentiation of mesenchymal stem cells (MSCs) to osteoblast and increasing osteoblast proliferation. For example, leptin, regarded as a link of bone and fat, exerts direct or indirect effects on bone metabolism. First, it stimulates bone growth and bone size directly like a growth factor in early life [35]. Second, it can affect bone remodeling by endocrine actions or through their influence on hypothalamic Centre [36]. The positive associations between obesity with BMD in our study support these mechanisms and provide support for the obesity effects on osteoporosis.

Age-stratification descriptive and potential biological mechanism

In an age-stratified analysis, we observed that the association of obesity and BMD was stronger among the elder subgroup (≥ 55 years). These findings were partially consistent with the previous epidemiological studies which explore the effects of obesity on BMD [27, 37–39]. For example, a large cohort study [37] reported that BMD at the lumbar spine among the premenopausal women was 1.5-fold higher than the postmenopausal women. Another large study [39] reported that in the older group lower BMI levels were associated with decreased BMD levels at femoral site, and the effect of BMI on BMD was significantly enhanced with aging at the hip.
recent research [27] included the younger and the older simultaneously, showed that the older individuals had stronger effects on a BMD than the younger individuals, without any gender interaction. Although the potential biological mechanism that obesity may protect age-related bone loss is not fully understood, a plausible explanation for our results is that obese subjects had to withstand stronger mechanical loading to the bone with aging, and the effect surpasses the accelerated bone loss compared to the young subjects.

Strengths and limitations

One noticed strength of our research is that it can compare the magnitude of the impact of those adiposity indices on BMD and osteoporosis. The partial regression coefficients of the six adiposity indices, in their respective SD, provide a reliable comparison for the comparable increments [40]. Although this was a large cross-sectional study to assess the relationship between obesity and osteoporosis, some limitations should be considered as well. First, QUS was used for measuring BMD in our present study not the gold standard dual-energy X-ray, which may reduce the accuracy of BMD measurement. But it is convenient, suitable, and available for us to measuring BMD than DXA in the large-scale study. Second, some adiposity indices were measured by bioelectrical impedance methods in our research, which was less accurate, compare to the gold standard, but this method was widely used in previous studies [41, 42]. Third, this is an observation study. As same to all observational studies, some unmeasured confounding possibly exists. However, our results were robust even if we adjusted for numerous potential confounding including the lifestyle factors, exercise, and the dietary factors. Moreover, the unraveling reverse causality cannot be ruled out because of the survey based on a
cross-sectional study. But lots of prospective studies and meta-analysis were conducted prior to this research, which were parallel to our finding.

Conclusions

In conclusion, the study indicated that increased adiposity indices were associated with higher BMD and lower risk of osteoporosis in Chinese rural adults. In addition, the elderly were more vulnerable to be protective for poor bone health. These data suggest a potential role of moderate adiposity in the prevention of osteoporosis risks. Considering the limitations of our study, more longitudinal researches are needed to evaluate the effects of adiposity on bone health.

Declarations

Ethics approval and consent to participate

All procedures performed in studies involving human participants were in accordance with the ethical standards of “Zhengzhou University Life Science Ethics Committee” and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Ethic approval code: [2015] MEC (S128). Informed consent was obtained from all individual participants included in the study.

Consent for publication

This manuscript does not contain data from any individual person. Consent for publication is “not applicable.”

Availability of data and materials

The data used in this study are available and will be provided by the corresponding author on a reasonable request.

Conflicts of interests
Huiling Tian, Jun Pan, Dou Qiao, Xiaokang Dong, Ruiying Li, Yikang Wang, Runqi Tu, Tanko Abdulai, Xiaotian Liu, Jian Hou, Gongyuan Zhang and Chongjian Wang declare that they have no conflict of interest.

Author Contributions

CJW and GYZ conceived and designed the experiments. HLT, JP, DQ, XKD, RYL, RQT and JH collected data. HLT, DQ, YKW, and JH analyzed data. JP, XKD, YKW, and RQT searched literature and generated figures. HLT and JP wrote the manuscript. TA, XTL provided the writing assistance. All authors have read and approved the final version of manuscript.

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