Journal of Orthopaedic Surgery and Research

RESEARCH ARTICLE Open Access

The association of weight-adjusted waist index with the risk of osteoporosis in patients with type 2 diabetes: a cross-sectional study

Runzhou Pan[1,2] and Yukun Li[1*]

Abstract

Background The relationship between obesity and type 2 diabetes with bone health has always been a topic of debate. The weight-adjusted waist index has become a commonly used indicator for assessing central obesity, fat, and muscle mass. However, currently there is no research reporting the association between weight-adjusted waist index and risk of osteoporosis in populations of type 2 diabetes. Therefore, this study aims to provide new information on the association between weight-adjusted waist index and risk of osteoporosis in type 2 diabetes.

Methods This cross-sectional study involved 963 patients with type 2 diabetes who were admitted to the Department of Endocrinology of Cangzhou Central Hospital. Multivariate logistic regression models were used to assess the association between weight-adjusted waist index and osteoporosis. The potential nonlinear association was evaluated. The effects of interaction between subgroups were assessed using the likelihood ratio test.

Results Weight-adjusted waist index was positively associated with the risk of osteoporosis, regardless of traditional confounding factors. For each 1 unit increased in weight-adjusted waist index, the risk of osteoporosis increased by 67%. Furthermore, there was a nonlinear relationship between weight-adjusted waist index and osteoporosis. The subgroup analysis did not reveal any significant interactions.

Conclusions Our study indicated a positive association between weight-adjusted waist index and the risk of osteoporosis in adult Chinese type 2 diabetes patients, and this relationship was nonlinear.

Keywords Type 2 diabetes, Weight-adjusted waist index, Osteoporosis, Association, Cross-sectional study

Background

Due to its severity, chronic nature, and progression, osteoporosis (OP) has become a public health problem. In China, the prevalence of OP among adults over 20 years of age has reached 18.2% [1]. The clinical and economic burden of fractures related to OP is significant [2, 3]. Therefore, the treatment and prevention of osteoporosis and osteoporotic fractures are of significant clinical and public health importance. In recent years, the latest evidence on the modern management of OP has been presented, in order to provide patients with more treatment options [3–9]. Similarly, actively exploring

*Correspondence:
Yukun Li
36200702@hebmu.edu.cn
[1]Department of Endocrinology, The Third Hospital of Hebei Medical University, Shijiazhuang, Hebei Province, China
[2]Department of Endocrinology, Cangzhou Central Hospital, Cangzhou, Hebei Province, China

innovative approaches to prevent OP is also crucial to maintaining public health.

As two common metabolic disorders, the relationship between obesity and type 2 diabetes (T2D) with bone health has always been a topic of debate. T2D is associated with normal or higher bone mineral density (BMD), but paradoxically increases the risk of fractures [10]. Several factors related to diabetes are associated with increased fracture risk, including exogenous insulin therapy, vascular complications, and poor glycaemic control, although detailed comprehensive studies to identify the independent contributions of these factors are lacking [10]. Similarly, although the view that obesity is positively associated with BMD or bone mass was once widely accepted [11, 12], recent research suggests that the relationship between the two may be the opposite [13]. The presence of metabolic syndrome and/or high waist circumference seems to be playing a role in the loss of bone mass in obesity [14]. Obesity is a risk factor for T2D, so bone phenotypes in both conditions may overlap a lot.

In recent years, a type of obesity phenotype known as sarcopenic obesity (SO), characterised by increased fat accumulation, decreased muscle mass and strength, has been found to be prevalent in some clinical settings [15]. Individuals with SO are at increased risk of developing T2D compared to individuals who are obese but do not have SO [16]. Osteosarcopenic obesity (OSO) combines the characteristics of low bone mass with SO, and has been proposed as a new disease [17]. As traditional measures of obesity, body mass index (BMI) and waist have limitations in distinguishing between muscle and fat mass, which may lead to less accurate estimates of individual health risks, including bone health [18, 19]. In recent years, a new obesity measure called the weight-adjusted waist index (WWI) has been introduced and has become a commonly used indicator for assessing central obesity, fat, and muscle mass [20]. The relationship between WWI and bone health has been investigated in the general population [21–25]. However, currently there is no research reporting the association between WWI and risk of OP in T2D populations. Therefore, this population-based study aims to provide new information on the association between WWI and risk of OP in patients with T2D. Therefore, this population-based study aims to explore the relationship between WWI in T2D patients and the risk of OP, to provide new information for the prevention of OP in patients with T2D.

Methods

Study design and sample

This study is a cross-sectional study. Based on data from nearby cities, the prevalence of T2D in adults is 9.2% [26]. Assuming a two-sided $\alpha=0.05$ and a permissible error of 3%, using PASS 15 to calculate the sample size, we obtain $N=390$. This study involved 963 patients with T2D who were admitted to the Endocrinology Department of Cangzhou Central Hospital between October 2018 and December 2023. The inclusion criteria were adults aged 18 years or older, individuals diagnosed with T2D according to the 1999 World Health Organization (WHO) criteria [27]. The BMD levels of patients' total hip, femoral neck, and lumbar spine were measured using Hologic's DXA equipment. The diagnostic criteria for OP are based on the WHO diagnostic criteria: T-scores ≤ -2.5 were defined as OP, -2.5 < T-scores ≤ -1.0 were defined as osteopenia, T-scores > -1.0 were defined as normal BMD [28]. Patients with osteopenia and normal BMD are considered non-OP. Excluded from the study were patients with acute diabetes complications, a history of endocrine disorders affecting bone metabolism (such as thyroid disease, hypopituitarism, Addison's disease, Cushing syndrome, pituitary adenoma, parathyroid disease or hypogonadism), severe infections, inflammatory diseases, malignant tumours, severe liver or kidney dysfunction, or other secondary OP. Patients taking medications that affect bone metabolism were also excluded. This study was approved by the Ethics Committee of Cangzhou Central Hospital and was conducted according to the Helsinki Declaration guidelines, including all relevant details. As this study was retrospective, informed consent was not required.

WWI

Weight and waist were measured by well-trained hospital healthcare technicians. The subjects stood upright with their arms crossed in front (hands placed on opposite shoulders). A bilateral iliac palpation was performed and a horizontal line was drawn above the outermost part of the right iliac bone. Subsequently, the midline of the axilla was marked on the right side. The tape measure was placed at the intersection point of the two lines in a horizontal plane. The waist was then measured at the end of a normal exhalation by the individual. The participants' shoes and bulky clothing were removed to calculate their weight. WWI was determined by dividing the waist (cm) by the square root of weight (kg). The methodology to establish WWI was previously described in a separate study [29].

Covariates

Drawing from the existing literature [22, 24], multiple potential covariates were assessed, encompassing sex, age, hypertension, metabolic syndrome (MetS), smoking history, glycated hemoglobin (HbA1c), total cholesterol (TC), calcium, phosphorus, 25-hydroxy vitamin D (VID), serum creatinine (Cre), uric acid (UA), and insulin use. A definitive smoking history was established by current smoking and previous smoking (quit smoking after

a total of more than 100 cigarettes). Hypertension was confirmed with a systolic blood pressure of 130 mmHg or higher or a diastolic blood pressure of 80 mmHg or higher (or through antihypertensive medications). Laboratory data was obtained from the hospital information system.

Statistical analysis

The characteristics of the patients were calculated according to the WWI quartiles. Continuous variables were presented as mean±SD or median (interquartile range), while categorical variables were expressed as frequencies or percentages. One-way analysis of variance (normal distribution), Kruskal-Wallis test (skewed distribution), and Chi-square test (categorical variables) were used to determine statistical differences in group means and proportions. The multiple logistic regression model was used to investigate the linear association between WWI and the risk of OP. WWI was treated as both a categorical variable (quartiles) and a continuous variable input. The study comprised four models: Model 1 did not require variable adjustment. Model 2 adjusted for sex, age, hypertension, MetS, and smoking history. Model 3 adjusted for sex, age, hypertension, MetS, smoking history, HbA1c, TC, calcium, phosphorus, VID, Cre, and UA. Model 4 adjusted for Model 3 plus insulin use. A generalised additive model (GAM) with a natural spline function incorporating 4 knots was utilised to examine the nonlinear relationship between WWI and the risk of OP. In the cases where a nonlinear association was identified, a two-piece regression model was employed to determine the threshold effect. Subgroup analyses were performed to explore potential variations within different subgroups. For continuous variables, they were initially transformed into categorical variables based on clinical cut-off points, followed by an interaction test. The effects of interaction between subgroups were assessed using the likelihood ratio test. All statistical analyses were carried out using R Statistical Software (Version 4.2.2, The R Foundation, http://www.R-project.org) and the Free Statistics Analysis Platform (Version 1.9, Beijing, China, http://www.clinicalscientists.cn/freestatistics).

Results

Characteristics of the study population

This study enrolled 963 eligible T2D patients, aged 58.7±12.1 years. The mean levels of total hip BMD, femoral neck BMD, and lumbar spine BMD were 0.982±0.159 g/cm^2, 0.820±0.151 g/cm^2, and 1.047±0.166 g/cm^2, respectively. The incidence of OP was approximately 9.4%. The baseline characteristics of the participants, stratified by WWI, are presented in Table 1. As the WWI quartiles increase, total hip BMD, femoral neck BMD, and lumbar spine BMD show a gradual decreasing trend, and the incidence rate of OP is showing an increasing trend. Compared to patients in the first or second quartiles of WWI, patients in the third or fourth quartiles of WWI were older, had higher BMI levels, a higher proportion of female patients, more cases of hypertension, MetS, history of smoking, and insulin use. Laboratory indicators such as TG, UA, and phosphorus levels were higher, while HDL-C levels were lower in patients in the third or fourth quartiles of WWI ($P<0.05$). No significant differences were found between the groups in other laboratory indicators including TC, LDL-C, Cre, FBG, HbA1c, calcium and VID ($P>0.05$) (Table 1).

Association between WWI and the risk of OP

In univariate logistic regression analyses, WWI expressed as a continuous variable (Per 1 cm/√kg) was increased associated with the risk of OP [odds radio (OR)=2.36, 95% confidence interval (CI)=1.71 ~ 3.26, $P<0.001$] (Table 2, model 1). This association was attenuated but remained statistically significant (OR=1.69, 95% CI=1.15 ~ 2.48, $P=0.007$), independent of potential confounders (Table 2, model 4). When WWI was expressed in quartiles in logistic regression analysis, patients in the highest quartile of WWI had a 3.26-fold increased risk of OP compared to those in the lowest quartile of WWI (OR=4.26, 95% CI=2.19 ~ 8.3, $P<0.001$) (Table 2, model 1). Even after adjusting for potential confounders, this association remained significant and independent (OR=2.20, 95% CI=1.02 ~ 4.77, $P=0.045$) (Table 2, model 4). In addition, multivariable-adjusted restricted cubic spline analyses indicated nonlinear relationship between WWI and the risk of OP ($P=0.029$) (Fig. 1). when the WWI<11.14 cm/√kg, there appears to be a decreasing trend in the risk of OP for patients with T2D with increasing WWI, but this difference is not significant. However, when WWI≥11.14 cm/√kg, there is a significant positive association between WWI and the risk of OP, with an OR of 4.29 (95% CI, 1.66–11.07; $P=0.003$) (Table 3).

Stratified analyses were carried out in several subgroups (Male or Female, Age<50 years or Age≥50 years, BMI<24 kg/m^2, 24 kg/m^2≤BMI<28 kg/m^2 or BMI>28 kg/m^2, MetS or not, insulin use or not, VID<50 nmol/L or VID>50 nmol/L) to assess the potential impact of the relationship between WWI and OP in the population with T2D. The results of the subgroup analysis did not reveal any significant interactions ($P>0.05$) (Fig. 2).

Discussion

This cross-sectional study indicates that there is a nonlinear association between WWI and OP among adult T2D patients in China. This relationship remains stable

Table 1 Participants characteristics and outcome parameters

Characteristics	WWI quartiles[a](cm/√kg)					*p*-Value
	Total	Q1(8.48–10.29)	Q2(10.29–10.78)	Q3(10.78–11.23)	Q4(11.23–12.97)	
n	**963**	**241**	**240**	**241**	**241**	
Sex, n(%)						< 0.001
Male	554 (57.5)	182 (75.5)	151 (62.9)	135 (56)	86 (35.7)	
Female	409 (42.5)	59 (24.5)	89 (37.1)	106 (44)	155 (64.3)	
Age(years), Mean ± SD	58.7 ± 12.1	54.6 ± 12.7	58.8 ± 11.7	59.9 ± 11.7	61.5 ± 11.4	< 0.001
BMI(kg/m^2), Mean ± SD	27.2 ± 5.7	24.2 ± 4.7	26.6 ± 4.7	28.0 ± 5.4	30.2 ± 6.3	< 0.001
TC(mmol/L), Mean ± SD	4.8 ± 1.1	4.7 ± 1.1	4.6 ± 1.1	4.9 ± 1.1	4.8 ± 1.2	0.059
TG(mmol/L), Median (IQR)	1.6 (0.9, 2.9)	1.4 (0.8, 2.4)	1.6 (0.8, 2.6)	1.8 (1.0, 3.4)	1.8 (1.0, 2.9)	0.007
HDL-C(mmol/L), Mean ± SD	1.25 ± 0.36	1.34 ± 0.40	1.24 ± 0.38	1.22 ± 0.34	1.21 ± 0.32	< 0.001
LDL-C(mmol/L), Mean ± SD	2.5 ± 0.9	2.5 ± 0.9	2.4 ± 0.8	2.6 ± 0.9	2.5 ± 0.9	0.148
Cre(umol/L), Mean ± SD	81.6 ± 34.5	84.6 ± 42.5	84.5 ± 37.9	79.1 ± 23.8	78.4 ± 30.5	0.08
UA(mmol/L), Mean ± SD	326.6 ± 88.0	314.3 ± 79.0	329.1 ± 88.7	325.2 ± 84.5	337.8 ± 97.8	0.031
FBG(mmol/L), Mean ± SD	9.2 ± 3.9	9.1 ± 3.9	9.2 ± 3.7	9.2 ± 4.1	9.3 ± 3.8	0.967
HbA1c(%), Mean ± SD	7.5 ± 1.9	7.5 ± 2.0	7.4 ± 1.9	7.4 ± 1.7	7.6 ± 1.8	0.5
Phosphorus(mmol/L), Mean ± SD	1.20 ± 0.18	1.18 ± 0.18	1.19 ± 0.17	1.19 ± 0.17	1.23 ± 0.17	0.019
Calcium(mmol/L), Mean ± SD	2.36 ± 0.10	2.37 ± 0.10	2.37 ± 0.10	2.36 ± 0.10	2.35 ± 0.10	0.462
VID (nmol/L), Mean ± SD	60.5 ± 25.5	59.8 ± 25.3	59.9 ± 27.9	61.4 ± 23.3	61.1 ± 25.3	0.857
Total hip BMD(g/cm^2), Mean ± SD	0.982 ± 0.159	1.010 ± 0.165	0.995 ± 0.158	0.984 ± 0.154	0.938 ± 0.151	< 0.001
Femoral neck BMD(g/cm^2), Mean ± SD	0.820 ± 0.151	0.847 ± 0.156	0.840 ± 0.158	0.810 ± 0.135	0.781 ± 0.147	< 0.001
Lumbar spine BMD(g/cm^2), Mean ± SD	1.047 ± 0.166	1.085 ± 0.168	1.059 ± 0.163	1.040 ± 0.163	1.003 ± 0.159	< 0.001
OP, n(%)	91 (9.4)	12 (5)	18 (7.5)	17 (7.1)	44 (18.3)	< 0.001
Hypertension, n(%)	574 (59.6)	125 (51.9)	130 (54.2)	148 (61.4)	171 (71)	< 0.001
MetS, n(%)	682 (70.8)	114 (47.3)	166 (69.2)	190 (78.8)	212 (88)	< 0.001
Smoking history, n(%)	455 (47.2)	116 (48.1)	101 (42.1)	106 (44)	132 (54.8)	0.027
Insulin use, n(%)	158 (16.4)	29 (12)	33 (13.8)	43 (17.8)	53 (22)	0.015

p-Value < 0.05 was considered significant. *Abbreviations* WWI, weight-adjusted waist index; BMI, body mass index; FBG, fasting blood glucose; HbA1c, glycogen hemoglobin; TC, total cholesterol; TG, triglyceride; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; VID, 25-hydroxy vitamin D; Cre, serum creatinine; UA, Uric Acid; BMD, bone mineral density; OP, osteoporosis; MetS, metabolic syndrome; SD, standard deviation; IQR, interquartile range.
[a]WWI quartiles based on separate quartile intervals for participants

Table 2 The association of WWI(cm/√kg) with the risk of OP

	WWI		WWI quartiles						
	(*n* = 963)		Q1(*n* = 241)	Q2(*n* = 240)		Q3(*n* = 241)		Q4(*n* = 241)	
	OR(95%CI)	*p*-Value	Reference	OR (95%CI)	*p*-Value	OR (95%CI)	*p*-Value	OR (95%CI)	*p*-Value
Model 1	2.36 (1.71 ~ 3.26)	< 0.001	1	1.55 (0.73 ~ 3.29)	0.256	1.45 (0.68 ~ 3.10)	0.34	4.26 (2.19 ~ 8.30)	< 0.001
Model 2	1.73 (1.20 ~ 2.49)	0.003	1	1.17 (0.53 ~ 2.58)	0.703	0.97 (0.43 ~ 2.18)	0.938	2.25 (1.07 ~ 4.74)	0.033
Model 3	1.65 (1.13 ~ 2.41)	0.01	1	1.19 (0.53 ~ 2.66)	0.670	0.90 (0.39 ~ 2.04)	0.794	2.12 (0.98 ~ 4.58)	0.055
Model 4	1.69 (1.15 ~ 2.48)	0.007	1	1.21 (0.54 ~ 2.71)	0.642	0.93 (0.40 ~ 2.12)	0.855	2.20 (1.02 ~ 4.77)	0.045

p-Value < 0.05 was considered significant

Abbreviations WWI, weight-adjusted waist index; OP, osteoporosis; OR, odds radio; CI, confidence interval

Model 1: unadjusted

Model 2: adjusted for age, sex, hypertension, metabolic syndrome (MetS), and smoking history

Model 3: adjusted for Model 2 plus glycogen hemoglobin (HbA1c), total cholesterol (TC), calcium, phosphorus, 25-hydroxy vitamin D (VID), serum creatinine (Cre) and uric acid (UA).

Model 4: adjusted for Model 3 plus insulin use

in subgroup analysis based on different sex, BMI, MetS, ages, insulin use and vitamin D levels.

Obesity and overweight have previously been identified as preventive factors for fractures and OP. Excess body fat can not only promote the secretion of various hormones, including oestrogen, insulin, and leptin, which can prevent bone loss, but also exert more static mechanical stress on the bones, promoting the formation of cortical bone in obese individuals [30]. BMI and waist are two internationally recognized parameters for identifying obesity, and many early studies have found a positive association between BMI, waist, and BMD [11, 12]. As traditional body measurement indices, BMI and waist have a stronger association with high fat mass and

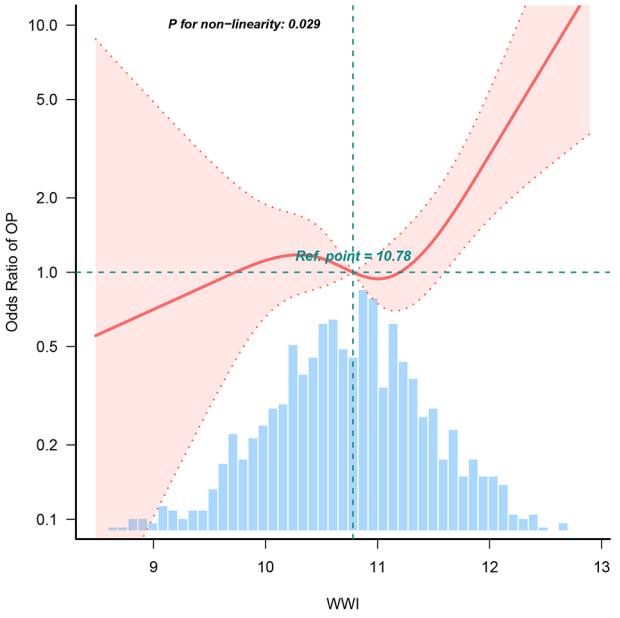

Fig. 1 The association of WWI(cm/√kg) and the risk of OP. (Solid and dashed lines represent the predicted value and 99.9% confidence intervals) Abbreviations: WWI, waist circumference index; OP, osteoporosis. Adjust for age, sex, hypertension, metabolic syndrome (MetS), smoking history, glycogen hemoglobin (HbA1c), total cholesterol (TC), calcium, phosphorus, 25-hydroxy vitamin D (VID), serum creatinine (Cre), uric acid (UA) and insulin use

Table 3 Threshold effect analysis of relationship of WWI(cm/√kg) with OP

	Adjusted OR(95% CI)	*P*
WWI < 11.14	0.77 (0.37,1.62)	0.49
WWI ≥ 11.14	4.29 (1.66, 11.07)	0.003
Log-likelihood ratio test		0.011

p-Value < 0.05 was considered significant. *Abbreviations* WWI, weight-adjusted waist index; OP, osteoporosis; OR, odds radio; CI, confidence interval. Adjust for age, sex, hypertension, metabolic syndrome (MetS), smoking history, glycogen hemoglobin (HbA1c), total cholesterol (TC), calcium, phosphorus, 25-hydroxy vitamin D (VID), serum creatinine (Cre), uric acid (UA) and insulin use

are valuable in predicting health risks related to obesity [14, 31]. However, these indices cannot be used as accurate indicators of obesity due to their inability to differentiate between fat and muscle mass, as well as their limitations influenced by age, gender, and race [32]. In recent years, the viewpoint that obesity is a protective factor for OP has gradually shifted [13]. A simple linear association cannot fully reflect the relationship between BMI and BMD [33]. Previous studies have shown that SO, rather than simple obesity, significantly increases the risk of morbidity and mortality. This elevated risk of mortality is not only related to obesity [34, 35]. Recently, as a new entity, OSO combines excessive fat accumulation (obesity), decreased muscle mass and strength (sarcopenia), and low bone mass (osteopenia/OP), and is increasingly gaining attention [17]. This highlights the need to consider the complex effects of fat and muscle mass on the body when calculating bone health risks. WWI shows minimal differences between races and is widely applicable in multiethnic environments. It is positively associated with body fat and negatively associated with muscle mass [20]. It represents the complex condition of SO, reflecting changes in abdominal components with age and excluding interference from muscle mass in high body weight [36]. Therefore, when assessing various health outcomes, especially bone health, WWI can perform better than traditional indicators such as BMI and waist.

Some studies based on the NHANES and KNHANES database have found a negative association between WWI and total hip BMD, femoral neck BMD, and lumbar spine BMD in adult populations in the United States (US) and South Korea [21, 22, 25], and a negative association between WWI and total femoral BMD in adolescent populations [24]. Recently, a study in the US population aged 65 and older found a U-shaped relationship between WWI and OP [23]. Compared to previous studies, this study adjusted for potential confounders and used multivariate regression analysis of data from Chinese patients with T2D, making the results generalisable to the Chinese population with T2D. We found a positive association between WWI and OP. To evaluate the effects of age, sex, blood pressure, smoking history, lipid metabolism, calcium, phosphorus, VID, Cre, UA, and insulin on the association between WWI and OP, we constructed four models and compared the results before and after adjusting for the above covariates. In Model 2, which considers age, sex, hypertension, MetS, and smoking, and Model 3, which further considers TC, calcium, phosphorus, VID, Cre, and UA on the basis of Model 2, this association remains stable. Additionally, it should be noted that insulin is closely associated with both obesity and bone [37, 38]. Therefore, in Model 4, we adjusted for whether the patients used insulin and the results confirmed that the relationship between WWI and OP remains robust. The exact underlying cause of the association between WWI and OP remains uncertain. Potential mechanisms may include the following: The presence of fat in bone and muscle is a key pathophysiological factor in low bone mass [39]. A key mechanism of bone loss involves bone marrow mesenchymal stem cells (BMSCs) that expend bone marrow adipose tissue at the expense of osteoblasts. The 'fattening' of bones, coupled with reduced bone formation, lowers trabecular bone density, leading to a higher risk of fractures [40]. Fat inflammation leads to redistribution of fat from subcutaneous spaces to intra-abdominal fat (visceral fat) and skeletal muscle (fat infiltration), resulting in decreased muscle strength and function [41]. The central pathway shared by muscles and bones is the growth hormone/insulin-like growth factor-1 axis, which plays a crucial role in regulating bone

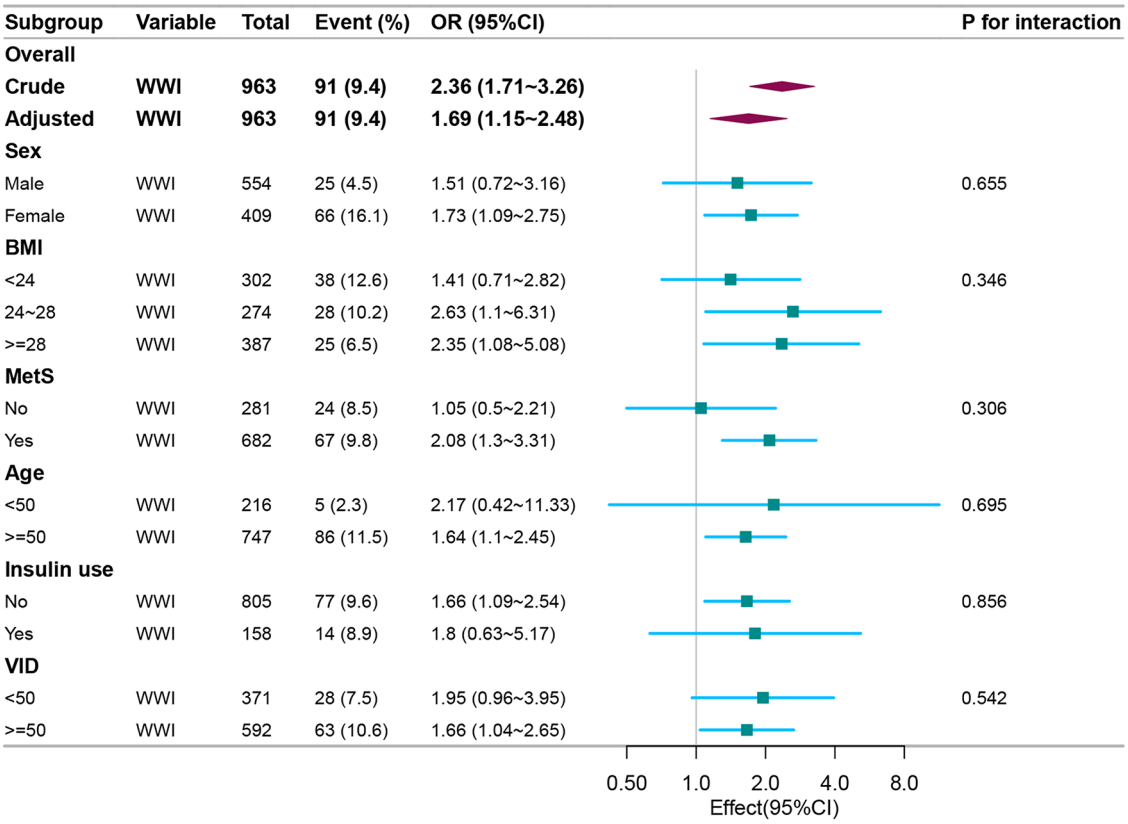

Fig. 2 Association between WWI and the risk of OP according to the general characteristics. p-Value < 0.05 was considered significant. Abbreviations: WWI, waist circumference index; OP, osteoporosis; BMI, body mass index; MetS, metabolic syndrome; VID, 25-hydroxy vitamin D; OR, odds radio; CI, confidence interval. Except for the stratification factor itself, the stratifications were adjusted for all variables, including age, sex, hypertension, MetS, smoking history, glycogen hemoglobin (HbA1c), total cholesterol (TC), calcium, phosphorus, VID, serum creatinine (Cre), uric acid (UA) and insulin use

and muscle growth [42]. Complex bidirectional crosstalk between muscles and bones, including mechanical interactions and paracrine and endocrine communication, functions in the homeostasis of bones and muscles. Decreased muscle function and performance lead to reduced skeletal loading and subsequent deterioration of BMD. Muscle paralysis, atrophy, or immobilisation can promote bone loss and OP [39, 43]. The coexistence of obesity and sarcopenia under the so-called 'SO' phenotype may have a synergistic effect, chronic inflammation being a common factor in both conditions, potentially playing a significant role in bone remodelling, especially driving and accelerating the transition to a resorptive state, leading to decreased bone mass [44]. Furthermore, although the underlying mechanisms are not yet clear, both T2D and obesity can induce oxidative stress and inflammation. T2D further exacerbates the damage to the bones due to obesity [45]. Studies have shown that T2D is associated with the transition from osteogenesis to fat generation, with an increase in bone marrow adiposity leading to the replacement of cell marrow by fat. BMSCs may be involved in the shared pathological processes of obesity, diabetes, and skeletal fragility [45, 46].

It should be noted that our results showed a nonlinear relationship between WWI and OP in the T2D population, with a critical value of 11.14 cm/√kg. When WWI < 11.14 cm/√kg, we did not find an association between WWI and OP. However, when WWI ≥ 11.14 cm/√kg, there was a significant positive association between WWI and an increased risk of OP. Therefore, we speculate that in a low WWI state, the increase in weight and the positive effects of hormone secretion on the skeleton may counteract the decrease in the negative impact of decreased muscle mass, increased body fat and T2D on bones. However, as WWI increases beyond the threshold, this negative impact can become more prominent, leading to an increased risk of OP in patients. Interestingly, this nonlinear relationship is different from the U-shaped relationship found in a previous study of the general elderly population in the US [23]: When WWI is below the threshold, WWI does not show a negative association with OP, as observed in the previous study. However, when WWI exceeds the threshold, the OR of OP reaches 4.13, exceeding the previously reported OR value of 2.23. The difference may be attributed to the different study populations. Firstly, unlike

previous studies that included the general population, our study includes T2D patients, so we need to consider the adverse effects of T2D on bone metabolism. The impact of diabetes on bones is multifaceted. In cases where BMD is normal or increased, various factors in T2D patients such as central obesity, insulin resistance, hyperinsulinemia, hyperglycemia, accumulation of advanced glycation end-products, occurrence of microvascular and macrovascular complications, and the use of exogenous insulin lead to impaired bone parameters (reduced bone turnover, cortical defects such as increased cortical porosity, decreased cortical volumetric BMD, reduced cortical cross-sectional area), and decreased bone quality [10]. Secondly, unlike previous studies that included US populations, our study includes Chinese populations. Research indicates that compared to western populations, Asians have a higher percentage of body fat, prominent abdominal obesity, and a significantly higher visceral fat [47]. Compared to general obesity, central obesity can have more inflammatory markers, visceral fat can be more active than other fats, secreting a greater variety of cytokines, such as inflammatory cytokines that disrupt the bone remodelling process [48]. Increased in insulin resistance caused by central obesity can inhibit insulin-like growth factor-1, thereby reducing the proliferation and differentiation of osteoblasts [49]. Whether the negative impact of T2D itself, as well as abdominal obesity and increased visceral fat on bone, is the cause of this difference deserves further exploration.

No significant interactions were observed in the subgroup analysis, demonstrating that the positive association between WWI and OP risk in T2D patients is robust across different subgroups. It is important to note that the prevalence of OP varies among different subgroups. Epidemiological studies suggest that age and female gender are independent risk factors for osteoporosis [50, 51]. A recent study on T2D patients in Japan without a history of fractures or OP treatment has confirmed that elderly women have the highest risk of bone loss and OP [52]. Our result shows that the prevalence of OP is higher in patients over 50 years of age, as well as in female patients, consistent with previous research findings. In addition, compared to patients with a low BMI, the prevalence of OP is lower in patients with a high BMI, possibly due to the positive effects that obesity and overweight can have on the bones [30].

The strength of this article is that previous studies have focused primarily on the skeletal health of the general population, with limited information on the relationship between WWI and the risk of OP in patients with T2D. Our study selected adult T2D patients to elucidate some of these issues. However, there are several limitations that need attention. Firstly, since this study used a cross-sectional design, it cannot establish a causal relationship between WWI and the risk of OP. Secondly, despite adjusting for several potential confounding factors, there may be other unknown or unmeasured factors that could affect our research results. Future studies should consider these limitations to improve understanding and applicability of using WWI as a measure to evaluate bone health.

Conclusions

This study indicated a positive association between WWI and OP risk in Chinese adult patients with T2D, and this relationship was nonlinear. This indicates that in T2D patients, maintaining WWI within the optimal range is crucial to effectively managing bone metabolism health. More prospective studies will be needed in the future to confirm these conclusions.

Abbreviations

OP	Osteoporosis
T2D	Type 2 diabetes
BMD	Bone mineral density
SO	Sarcopenic obesity
OSO	Osteosarcopenic obesity
BMI	Body mass index
WWI	Weight-adjusted waist index
WHO	World Health Organization
MetS	Metabolic syndrome
HbA1c	Glycated hemoglobin
TC	Total cholesterol
VID	25-hydroxy vitamin D
Cre	Serum creatinine
UA	Uric acid
FBG	Fasting blood glucose
TG	Triglyceride
HDL-C	High-density lipoprotein cholesterol
LDL-C	Low-density lipoprotein cholesterol
SD	Standard deviation
IQR	Interquartile range
OR	Odds radio
CI	Confidence interval
US	United States
BMSCs	Bone marrow mesenchymal stem cells

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13018-024-04991-7.

Supplementary Material 1

Acknowledgements

The authors acknowledge Jie Liu of the Department of Vascular and Endovascular Surgery, Chinese PLA General Hospital for his contribution to the statistical support, study design consultations, and comments regarding the manuscript.

Author contributions

RP performed data analysis and wrote the document. YL performed modifed the paper. RP interpreted data. YL designed the investigation and reviewed the document. All authors participated in the essay and accepted the submitted version.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
This study was approved by the Ethics Committee of the Cangzhou Central Hospital [Ethics Approval No. 2023-377-02] and was conducted following the Declaration of Helsinki guidelines. The committee waived the requirement of informed consent because of the retrospective nature of the study.

Consent for publication
I certify that this manuscript is a unique submission and is not being considered for publication, in part or in full, with any other source in any medium.

Competing interests
The authors declare no competing interests.

Received: 13 June 2024 / Accepted: 8 August 2024
Published online: 29 August 2024

References

1. Lyu FF, Ramoo V, Chui PL, et al. Prevalence rate of primary osteoporosis in China: a meta-analysis. BMC Public Health. 2024. https://doi.org/10.1186/s12889-024-18932-w.
2. Ensrud KE, Crandall CJ, Osteoporosis. Ann Intern Med. 2024. https://doi.org/10.7326/AITC202401160.
3. Migliorini F, Giorgino R, Hildebrand F, et al. Fragility fractures: risk factors and management in the Elderly. Medicina-Lithuania. 2021. https://doi.org/10.3390/medicina57101119.
4. Migliorini F, Colarossi G, Eschweiler J, et al. Antiresorptive treatments for corticosteroid-induced osteoporosis: a bayesian network meta-analysis. Brit Med Bull. 2022. https://doi.org/10.1093/bmb/ldac017.
5. Conti V, Russomanno G, Corbi G, et al. A polymorphism at the translation start site of the vitamin D receptor gene is associated with the response to anti-osteoporotic therapy in postmenopausal women from southern Italy. Int J Mol Sci. 2015. https://doi.org/10.3390/ijms16035452.
6. Migliorini F, Maffulli N, Colarossi G, et al. Effect of drugs on bone mineral density in postmenopausal osteoporosis: a bayesian network meta-analysis. J Orthop Surg Res. 2021. https://doi.org/10.1186/s13018-021-02678-x.
7. Migliorini F, Maffulli N, Spiezia F, et al. Potential of biomarkers during pharmacological therapy setting for postmenopausal osteoporosis: a systematic review. J Orthop Surg Res. 2021. https://doi.org/10.1186/s13018-021-02497-0.
8. Migliorini F, Maffulli N, Spiezia F, et al. Biomarkers as therapy monitoring for postmenopausal osteoporosis: a systematic review. J Orthop Surg Res. 2021. https://doi.org/10.1186/s13018-021-02474-7.
9. Migliorini F, Colarossi G, Baroncini A, et al. Pharmacological management of postmenopausal osteoporosis: a Level I evidence based - Expert Opinion. Expert Rev Clin Phar. 2021. https://doi.org/10.1080/17512433.2021.1851192.
10. Sheu A, Greenfield JR, White CP, et al. Contributors to impaired bone health in type 2 diabetes. Trends Endocrin Met. 2023. https://doi.org/10.1016/j.tem.2022.11.003.
11. Gadde KM, Martin CK, Berthoud HR, et al. Obesity: pathophysiology and management. J Am Coll Cardiol. 2018. https://doi.org/10.1016/j.jacc.2017.11.011.
12. Sampaio LG, Marques J, Petterle RR, et al. Association between fractures and traditional risk factors for osteoporosis and low bone mineral density in patients with obesity. Arch Endocrin Metab. 2021. https://doi.org/10.20945/2359-3997000000331.
13. Piñar-Gutierrez A, García-Fontana C, García-Fontana B, et al. Obesity and bone health: a complex relationship. Int J Mol Sci. 2022. https://doi.org/10.3390/ijms23158303.
14. Ross R, Neeland IJ, Yamashita S, et al. Waist circumference as a vital sign in clinical practice: a Consensus Statement from the IAS and ICCR Working Group on visceral obesity. Nat Rev Endocrinol. 2020. https://doi.org/10.1038/s41574-019-0310-7.
15. Ciudin A, Simó-Servat A, Palmas F, et al. Sarcopenic obesity: a new challenge in the clinical practice. Endocrinol Diab Nutr. 2020. https://doi.org/10.1016/j.endinu.2020.03.004.
16. Pellegrini M, Itani L, Rossi AP, et al. Approaching sarcopenic obesity in Young and Middle-aged female adults in Weight Management Settings: a narrative review. Healthcare-Basel. 2022. https://doi.org/10.3390/healthcare10102042.
17. De Lorenzo A, Itani L, Gualtieri P et al. Association between Sarcopenia and Reduced Bone Mass: Is Osteosarcopenic Obesity a New Phenotype to Consider in Weight Management Settings? *Life-Basel* 2023; https://doi.org/10.3390/life14010021
18. Compston JE, Flahive J, Hosmer DW, et al. Relationship of weight, height, and body mass index with fracture risk at different sites in postmenopausal women: the global longitudinal study of osteoporosis in women (GLOW). J Bone Min Res. 2014. https://doi.org/10.1002/jbmr.2051.
19. Romero-Corral A, Somers VK, Sierra-Johnson J, et al. Accuracy of body mass index in diagnosing obesity in the adult general population. Int J Obes. 2008. https://doi.org/10.1038/ijo.2008.11.
20. Kim NH, Park Y, Kim NH, et al. Weight-adjusted waist index reflects fat and muscle mass in the opposite direction in older adults. Age Ageing. 2021. https://doi.org/10.1093/ageing/afaa208.
21. Guo M, Lei Y, Liu X, et al. The relationship between weight-adjusted-waist index and total bone mineral density in adults aged 20–59. Front Endocrinol. 2023. https://doi.org/10.3389/fendo.2023.1281396.
22. Kim KJ, Son S, Kim KJ, et al. Weight-adjusted waist as an integrated index for fat, muscle and bone health in adults. J Cachexia Sarcopeni. 2023. https://doi.org/10.1002/jcsm.13302.
23. Lin Y, Liang Z, Zhang A, et al. Relationship between weight-adjusted Waist Index and osteoporosis in the Senile in the United States from the National Health and Nutrition Examination Survey, 2017–2020. J Clin Densitom. 2023. https://doi.org/10.1016/j.jocd.2023.02.002.
24. Wang X, Yang S, He G, et al. The association between weight-adjusted-waist index and total bone mineral density in adolescents: NHANES 2011–2018. Front Endocrinol. 2023. https://doi.org/10.3389/fendo.2023.1191501.
25. Zhang Y, Wu H, Li C, et al. Associations between weight-adjusted waist index and bone mineral density: results of a nationwide survey. Bmc Endocr Disord. 2023. https://doi.org/10.1186/s12902-023-01418-y.
26. Xu H, Wang Z, Li X, et al. Osteoporosis and Osteopenia among patients with type 2 diabetes aged ≥ 50: role of sex and clinical characteristics. J Clin Densitom. 2020. https://doi.org/10.1016/j.jocd.2019.04.004.
27. Drouin P, Blickle JF, Charbonnel B et al. [Diagnosis and classification of diabetes mellitus: the new criteria]. Diabetes Metab 1999.
28. Kanis JA, Melton LR, Christiansen C, et al. The diagnosis of osteoporosis. J Bone Min Res. 1994. https://doi.org/10.1002/jbmr.5650090802.
29. Park Y, Kim NH, Kwon TY, et al. A novel adiposity index as an integrated predictor of cardiometabolic disease morbidity and mortality. Sci Rep-Uk. 2018. https://doi.org/10.1038/s41598-018-35073-4.
30. Liu Y, Liu Y, Huang Y, et al. The effect of overweight or obesity on osteoporosis: a systematic review and meta-analysis. Clin Nutr. 2023. https://doi.org/10.1016/j.clnu.2023.10.013.
31. Kim JE, Choi J, Kim M, et al. Assessment of existing anthropometric indices for screening sarcopenic obesity in older adults. Brit J Nutr. 2023. https://doi.org/10.1017/S0007114522001817.
32. Lam BC, Koh GC, Chen C, et al. Comparison of body Mass Index (BMI), body adiposity index (BAI), Waist circumference (WC), Waist-To-Hip ratio (WHR) and Waist-To-Height ratio (WHtR) as predictors of cardiovascular disease risk factors in an adult population in Singapore. PLoS ONE. 2015. https://doi.org/10.1371/journal.pone.0122985.
33. De Laet C, Kanis JA, Odén A, et al. Body mass index as a predictor of fracture risk: a meta-analysis. Osteoporos Int. 2005. https://doi.org/10.1007/s00198-005-1863-y.
34. Atkins JL, Whincup PH, Morris RW, et al. Sarcopenic obesity and risk of cardiovascular disease and mortality: a population-based cohort study of older men. J Am Geriatr Soc. 2014. https://doi.org/10.1111/jgs.12652.
35. Sanada K, Chen R, Willcox B, et al. Association of sarcopenic obesity predicted by anthropometric measurements and 24-y all-cause mortality in elderly men: the Kuakini Honolulu Heart Program. Nutrition. 2018. https://doi.org/10.1016/j.nut.2017.09.003.
36. Kim JY, Choi J, Vella CA, et al. Associations between Weight-Adjusted Waist Index and Abdominal Fat and muscle Mass: multi-ethnic study of atherosclerosis. Diabetes Metab J. 2022. https://doi.org/10.4093/dmj.2021.0294.
37. Shi P, Hou A, Li C, et al. Continuous subcutaneous insulin infusion ameliorates bone structures and mechanical properties in type 2 diabetic rats by regulating bone remodeling. Bone. 2021. https://doi.org/10.1016/j.bone.2021.116101.

38. Contreras-Hernández IF, Vargas-De-León C, García-Cortes LR, et al. Comparison of ten surrogate insulin resistance and obesity markers to identify metabolic syndrome in Mexican adults. Metabolites. 2024. https://doi.org/10.3390/metabo14070358.
39. Hu K, Deya EE, Zhuo W et al. Understanding the Consequences of Fatty Bone and Fatty Muscle: How the Osteosarcopenic Adiposity Phenotype Uncovers the Deterioration of Body Composition. *Metabolites* 2023; https://doi.org/10.3390/metabo13101056
40. Ali D, Tencerova M, Figeac F, et al. The pathophysiology of osteoporosis in obesity and type 2 diabetes in aging women and men: the mechanisms and roles of increased bone marrow adiposity. Front Endocrinol. 2022. https://doi.org/10.3389/fendo.2022.981487.
41. JafariNasabian P, Inglis JE, Reilly W, et al. Aging human body: changes in bone, muscle and body fat with consequent changes in nutrient intake. J Endocrinol. 2017. https://doi.org/10.1530/JOE-16-0603.
42. Paintin J, Cooper C, Dennison E, Osteosarcopenia. Brit J Hosp Med. 2018. https://doi.org/10.12968/hmed.2018.79.5.253.
43. Bonewald L. Use it or lose it to age: a review of bone and muscle communication. Bone. 2019. https://doi.org/10.1016/j.bone.2018.11.002.
44. Epsley S, Tadros S, Farid A, et al. The effect of inflammation on bone. Front Physiol. 2020. https://doi.org/10.3389/fphys.2020.511799.
45. Bathina S, Armamento-Villareal R. The complex pathophysiology of bone fragility in obesity and type 2 diabetes mellitus: therapeutic targets to promote osteogenesis. Front Endocrinol. 2023. https://doi.org/10.3389/fendo.2023.1168687.
46. Sebo ZL, Rendina-Ruedy E, Ables GP, et al. Bone marrow adiposity: Basic and Clinical implications. Endocr Rev. 2019. https://doi.org/10.1210/er.2018-00138.
47. Yoon KH, Lee JH, Kim JW, et al. Epidemic obesity and type 2 diabetes in Asia. Lancet. 2006. https://doi.org/10.1016/S0140-6736(06)69703-1.
48. Pannacciulli N, Cantatore FP, Minenna A, et al. C-reactive protein is independently associated with total body fat, central fat, and insulin resistance in adult women. Int J Obes Relat Metab Disord. 2001. https://doi.org/10.1038/sj.ijo.0801719.
49. Tahimic CG, Wang Y, Bikle DD. Anabolic effects of IGF-1 signaling on the skeleton. Front Endocrinol. 2013. https://doi.org/10.3389/fendo.2013.00006.
50. Yoshimura N, Muraki S, Oka H, et al. Prevalence of knee osteoarthritis, lumbar spondylosis, and osteoporosis in Japanese men and women: the research on osteoarthritis/osteoporosis against disability study. J Bone Min Metab. 2009. https://doi.org/10.1007/s00774-009-0080-8.
51. Horii C, Asai Y, Iidaka T, et al. Differences in prevalence and associated factors between mild and severe vertebral fractures in Japanese men and women: the third survey of the ROAD study. J Bone Min Metab. 2019. https://doi.org/10.1007/s00774-018-0981-5.
52. Yamamoto Y, Matsuba R, Nagasaka T, et al. Age and sex are excellent predictors of bone complications in patients with type 2 diabetes with no history of osteoporotic fracture or treatment for osteoporosis. J Int Med Res. 2024. https://doi.org/10.1177/03000605241246743.

Publisher's Note