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Weight-adjusted waist index as a new predictor of osteoporosis in postmenopausal patients with T2DM

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This study aimed to investigate the predictive value of the weight-adjusted waist index (WWI) for osteoporosis in postmenopausal patients with type 2 diabetes mellitus (T2DM). This cross-sectional study included 229 postmenopausal patients with T2DM (mean age 64.53 ± 7.4 years). Collect anthropometric data. Bone mineral density (BMD) of the lumbar spine and femoral necks was measured using dual-energy X-ray absorptiometry. Calculate WWI and Osteoporosis Self-Assessment Tool for Asians (OSTA). Use SPSS 25.0 to analyze data employing binary logistic regression and the receiver operating characteristic (ROC) curve. WWI in osteoporosis group was significantly higher than that in non-osteoporosis group (11.54 ± 0.82 vs. 11.07 ± 0.73, $P = 0.000$), while the OSTA was significantly lower in osteoporosis group compared to non-osteoporosis group (– 1.40 (– 2.8, 0.40) vs. 0.10 (– 1.45,1.80), $P = 0.000$). Binary logistic regression analysis indicated that the risk of osteoporosis in WWI ≥ 11.55 group was 3.158 times higher than that in WWI < 11.55 group (95% CI 1.714–5.820, $P = 0.000$). The risk in OSTA ≤ – 1 group was 3.935 times higher than that in OSTA > – 1 group (95% CI 2.168–7.141, $P = 0.000$). The area under the ROC curve for OSTA and WWI in predicting the risk of osteoporosis in postmenopausal patients with T2DM aged over 70 was 0.761 and 0.808, respectively, with sensitivities of 0.429 and 0.714. In postmenopausal patients with T2DM, WWI is closely associated with osteoporosis and negatively correlates with BMD. Among postmenopausal T2DM patients aged over 70, WWI may be superior to OSTA in predicting osteoporosis.

Keywords Osteoporosis, WWI, OSTA, Postmenopausal, T2DM

Abbreviations

AUC	Area under the curve
BMD	Bone mineral density
BMI	Body mass index
DBP	Diastolic blood pressure
DXA	Dual-energy X-ray absorptiometry
FPG	Fasting plasma glucose
HbA1c	Glycosylated hemoglobin A1c
HDL-C	High density lipoprotein cholesterol
LDL-C	Low density lipoprotein cholesterol
OSTA	Osteoporosis Self-Assessment Tool for Asians
ROC	Receiver operating characteristic curve
SBP	Systolic blood pressure
TC	Total cholesterol
TG	Triglycerides
T2DM	Type 2 diabetes mellitus
WC	Waist circumference

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| WHO | World Health Organization |
| WWI | Weight-adjusted waist index |

Osteoporosis is a chronic bone disease characterized by decreased bone mass and altered bone microstructure, with age and female gender identified as independent risk factors[1–3]. Diabetes mellitus, another chronic disease associated with aging, has been linked to osteoporosis. Research conducted in Japan indicates that elderly female patients with type 2 diabetes mellitus (T2DM) face the highest risk of bone loss and osteoporosis[4]. This increased risk is attributed to the sudden decline in estrogen levels and the redistribution of fat in postmenopausal women, which increases the risk of T2DM[5] and osteoporosis[6]. Patients with T2DM often exhibit normal or elevated bone mineral density (BMD), but they face an increased risk of fractures attributed to a deteriorated bone quality[7,8]. Therefore, it is of profound significance to focus on the high-risk groups of co-morbidity between T2DM and osteoporosis, and to implement early screening and preventative measures for osteoporosis in order to reduce the incidence of osteoporotic fractures.

The current gold standard for osteoporosis diagnosis remains dual-energy X-ray absorptiometry (DXA); however, its accessibility is limited[9]. The Osteoporosis Self-Assessment Tool for Asians (OSTA) is a straightforward and effective predictive screening tool that estimates osteoporosis risk in postmenopausal women based on age and body weight. Nevertheless, the OSTA employs a limited number of indicators, resulting in insufficient specificity, which diminishes its effectiveness in diagnosing postmenopausal osteoporosis within the Chinese population[10–13]. A study by Liu et al. found that the OSTA did not perform well in patients with diabetes, exhibiting a low predictive value and a sensitivity of only 44.8%[10].

Osteoporosis and obesity are closely related conditions. Previous studies have suggested that obesity and being overweight may serve as independent protective factors for osteoporosis, a phenomenon often referred to as the 'obesity paradox'[14–17]. Notably, abdominal obesity is more prevalent among Chinese patients with T2DM[18], and early research indicated a positive correlation between body mass index (BMI), waist circumference (WC) and BMD[19–24]. However, in recent years, an increasing number of studies have challenged the notion that obesity serves as a protective factor against osteoporosis. Elevated levels of WC and visceral fat area have been found to negatively correlate with BMD[25,26], while abdominal obesity has been associated with an increased risk of hip fractures, which poses a significant threat to bone health[27–29]. The weight-adjusted waist index (WWI) is a novel obesity assessment metric proposed by Park et al. in 2018[30]. This index standardizes WC relative to body weight[30], thereby combining the advantages of waist circumference while minimizing its association with BMI[31]. WWI exhibits greater accuracy in evaluating muscle and fat mass compared to conventional metrics, such as BMI and WC, and is capable of reflecting changes in abdominal composition with age, including the loss of muscle mass and the retention or gain of fat mass[32]. Additionally, several studies have demonstrated the relationship between WWI and bone density or osteoporosis across different age groups[33–35].

This study aimed to investigate whether WWI, an assessment indicator closely associated with abdominal obesity, could serve as a predictive screening indicator for osteoporosis in postmenopausal women with T2DM. We selected postmenopausal female patients with T2DM who were admitted to the hospital, with the objective of evaluating the effectiveness of WWI compared to OSTA in predicting the risk of developing osteoporosis across various age groups.

Material and methods
Study design and participants
This study is a small sample cross-sectional study. Data comes from the database of hospitalized patients with T2DM in the Department of Endocrinology at the First Hospital of Qinhuangdao from September 2020 to September 2022.

The inclusion criteria encompassed postmenopausal women diagnosed with T2DM who possessed basic communication skills, comprehension abilities and full behavioral capacity. Additionally, they had relatively stable and standardized physical activity levels and dietary calcium intake. Exclusion criteria included patients with a history of severe physical impairment, such as uncorrected acute complications of diabetes mellitus, acute cerebrovascular disease, gastrointestinal bleeding, acute renal failure, severe hepatic abnormalities and severe osteoarthritic or neuromuscular disorders that impact activities of daily living. Additionally, patients with acute infectious diseases, malignant tumors, inflammatory diseases, a history of endocrine disorders affecting bone metabolism (e.g., thyroid disease, hypopituitarism, Addison's disease, Cushing's syndrome, pituitary adenomas, parathyroid disease or hypogonadism) and patients taking medications that influence bone metabolism were also excluded. This study also excluded sedentary and bedridden patients and populations with missing data. This study finally involved a total of 229 postmenopausal patients with T2DM.

Data collection
In this study, the general information, anthropometric data and laboratory data of the enrolled patients were collected. Collect the age, history of diabetes, history of smoking and history of drinking of each patient. Anthropometric data include height, weight, WC, systolic blood pressure (SBP), diastolic blood pressure (DBP) and BMD. These data were measured by well-trained medical staff. BMI was calculated by dividing weight (kg) by the square of height (m). WWI was calculated by dividing the waist circumference (cm) by the square root of weight (kg). OSTA was calculated based on the formula: (weight (kg) − age(years)) × 0.2. BMD of the lumbar spine and bilateral femoral necks was measured using DXA equipment from MEDILINK, France.

Laboratory data was obtained from the hospital information system. Blood tests were performed after at least 9 h of fasting. Glycosylated hemoglobin A1c (HbA1c), fasting plasma glucose (FPG), triglycerides (TG), total cholesterol (TC), high density lipoprotein cholesterol (HDL-C), low density lipoprotein cholesterol (LDL-C) were measured by direct methods on an automated biochemical analyzer (Hitachi LST008 Tokyo, Japan).

Diagnostic criteria

The diagnostic criteria for T2DM adhered to the 1999 World Health Organization (WHO) criteria[36]. The diagnostic criteria for osteoporosis adhered to the WHO diagnostic criteria[37]: T-scores ≤ − 2.5 were defined as osteoporosis, − 2.5 < T-scores ≤ − 1.0 were defined as osteopenia, T-scores > -1.0 were defined as normal BMD. Patients with osteopenia and normal BMD are considered non-osteoporosis.

Groups

Based on the diagnostic criteria for BMD, the population was categorized into osteoporosis and non-osteoporosis groups, allowing for a comparison of indicators between these two groups. The analysis was further stratified by WWI tertiles to examine the relationship between WWI and both BMD and the risk of osteoporosis. Additionally, the population was divided by age groups to investigate the correlation between WWI and BMD of each site.

Statistical analysis

Continuous variables that follow a normal distribution are expressed as mean ± standard deviation ($\bar{x} \pm s$), and comparisons between two groups are conducted using the t-test. In contrast, continuous variables that do not adhere to a normal distribution are expressed as median (interquartile range) [M (P25, P75)], and comparisons between groups are conducted using the rank sum test. Categorical variables are expressed as counts, frequencies or percentages (%), and the chi-square test is utilized for comparisons between groups. Binary logistic regression was employed to analyze the factors influencing osteoporosis in postmenopausal patients with T2DM. The receiver operating characteristic (ROC) curve for the subjects was plotted, and the area under the curve (AUC) was utilized to assess the predictive capability of WWI and OSTA regarding the risk of osteoporosis in postmenopausal T2DM patients over the age of 70. All statistical analyses were conducted using SPSS version 25.0(SPSS Inc., Chicago, IL, USA), with differences considered statistically significant at $P < 0.05$.

Ethic declarations

This study was approved by the Ethics Committee of the First Hospital of Qinhuangdao and was conducted according to the Helsinki Declaration guidelines, including all relevant details. Due to the retrospective nature of the study, the Ethics Committee of the First Hospital of Qinhuangdao waived the need of obtaining informed consent.

Results

Characteristics of the subjects in osteoporosis and non-osteoporosis groups

In this study, we selected 229 eligible postmenopausal patients with T2DM, who were hospitalized and had a mean age of 64.53 ± 7.4 years. Among these patients, 79 (34.50%) were diagnosed with osteoporosis. The age and WWI of the osteoporosis group were significantly higher than those of the non-osteoporosis group ($P < 0.05$), while the OSTA was significantly lower in the osteoporosis group compared to the non-osteoporosis group ($P < 0.05$), as presented in Table 1. No statistically significant differences were observed in other indicators between the two groups ($P > 0.05$).

Association between WWI and the risk of osteoporosis

In the tertile subgroups of WWI, as the WWI increased from low to high, there was a corresponding decrease in BMD of the lumbar spine, right femoral neck and left femoral neck ($P < 0.05$). Concurrently, the detection rate of osteoporosis increased in conjunction with the rise in WWI, with these differences being statistically significant (21.1% vs. 29.9% vs. 52.6%, $X^2 = 17.869$, $P = 0.000$), as shown in Table 2.

WWI and BMD were analyzed across different age subgroups, as illustrated in Fig. 1. In group T (total population), WWI exhibited a negative correlation with lumbar spine BMD (r = − 0.218, $P = 0.002$), right femoral neck BMD (r = − 0.171, $P = 0.015$) and left femoral neck BMD (r = − 0.149, $P = 0.035$). In group A (aged 50–60), no correlation was found between WWI and both lumbar spine BMD and femoral neck BMD ($P > 0.05$). In group B (aged 60–70), a negative correlation was observed between WWI and lumbar spine BMD (r = − 0.237, $P = 0.015$), while no correlation was noted with femoral neck BMD ($P > 0.05$). In group C (aged over 70), WWI exhibited a negative correlation with lumbar spine BMD (r = − 0.450, $P = 0.019$), right femoral neck BMD (r = − 0.427, $P = 0.026$) and left femoral neck BMD (r = − 0.480, $P = 0.011$).

Comparison of the predictive efficacy of WWI and OSTA in assessing the risk of osteoporosis   A binary logistic regression analysis was conducted, where the dependent variable was defined as the presence of osteoporosis (no osteoporosis = 0; osteoporosis = 1). The independent variables included age, WWI stratification (WWI < 11.55 = 0; WWI ≥ 11.55 = 1) and OSTA stratification (OSTA > − 1 = 0; OSTA ≤ − 1 = 1). The results indicated that the risk of osteoporosis was 3.158 times higher (95% CI 1.714–5.820, $P = 0.000$) in the WWI ≥ 11.55 group compared to the WWI < 11.55 group. Additionally, the risk was 3.935 times higher (95% CI 2.168–7.141, $P = 0.000$) in the OSTA ≤ − 1 group compared to the OSTA > − 1 group (Table 3).

ROC curves were plotted using the presence of osteoporosis as the status variable (no osteoporosis = 0; osteoporosis = 1), with WWI and OSTA serving as the test variables (Fig. 2). The results indicated that the AUC for OSTA and WWI in predicting the occurrence of osteoporosis in postmenopausal patients with T2DM aged over 70 years was 0.761 (95% CI 0.636–0.886) and 0.808 (95% CI 0.688–0.927), respectively, with sensitivities of 0.429 and 0.714 (Table 4).

Variables	Non-osteoporosis group (n = 150)	Osteoporosis group (n = 79)	t or X^2	P
Age(years)	62.99 ± 7.60	67.46 ± 6.03	− 4.862	0.000
History of diabetes (years)	8(3,16)	10(3,15)	− 0.911	0.363
History of smoking(%)	4.7%	6.3%	0.045	0.831
History of drinking(%)	4%	1.3%	1.380	0.502
WC(cm)	88.77 ± 8.17	89.83 ± 9.72	− 0.876	0.382
BMI (kg/m^2)	25.35 ± 3.25	24.62 ± 3.54	1.573	0.117
WWI(cm/√kg)	11.07 ± 0.73	11.54 ± 0.82	− 4.409	0.000
OSTA	0.10(− 1.45,1.80)	− 1.40(− 2.8,0.40)	4.752	0.000
SBP (mmHg)	143.58 ± 21.04	141.82 ± 17.45	0.634	0.527
DBP (mmHg)	82.31 ± 12.10	79.54 ± 10.45	1.715	0.088
HbA1c	8.89 ± 1.99	8.85 ± 2.06	0.120	0.904
FPG (mmol/L)	8.63 ± 3.50	9.31 ± 4.16	− 1.243	0.216
TG (mmol/L)	1.93 ± 0.91	2.03 ± 1.26	− 0.602	0.548
TC (mmol/L)	5.61 ± 1.52	5.48 ± 1.17	0.700	0.485
HDL-C(mmol/L)	1.12 ± 0.23	1.10 ± 0.27	0.746	0.456
LDL-C(mmol/L)	3.07 ± 1.08	2.97 ± 0.82	0.772	0.441

Table 1. Baseline characteristics of the subjects in osteoporosis and non-osteoporosis groups. Numerical data are expressed as mean ± standard deviation (SD) or indicates the median value (P25, P75). For differences in proportions, the numbers in parenthesis denote the percentage. WC: waist circumference; BMI: body mass index; WWI: weight-adjusted waist index; OSTA: osteoporosis self-assessment tool for Asians; SBP: systolic blood pressure; DBP: diastolic blood pressure; HbA1c: glycosylated hemoglobin A1c; FPG: fasting plasma glucose; TG: triglycerides; TC: total cholesterol; HDL-C: high density lipoprotein cholesterol; LDL-C: low density lipoprotein cholesterol.

	WWI(cm/√kg)			F/X^2	P
	Q_1(n = 76) (≤ 10.83)	Q_2(n = 77) (10.83–11.55)	Q_3(n = 76) (≥ 11.55)		
Age(years)	64.22 ± 7.62	63.71 ± 7.18	65.66 ± 7.36	1.422	0.243
Lumbar spine BMD(g/cm2)	0.88 ± 0.15	0.84 ± 0.15	0.78 ± 0.16▲♦	8.152	0.000
Right femoral neck BMD(g/cm2)	0.76 ± 0.13	0.76 ± 0.13	0.68 ± 0.16▲♦	8.303	0.000
Left femoral neck BMD(g/cm2)	0.77 ± 0.14	0.75 ± 0.12	0.69 ± 0.15▲♦	5.684	0.004
Osteoporosis(%)	21.1%	29.9%	52.6%	17.869	0.000

Table 2. Association between WWI tertile subgroups and bone mineral density and the comparison of osteoporosis detection rates. Continuous variables that a normal distribution: mean ± standard deviation ($\bar{x} \pm s$), using the t-test; continuous variables that do not follow a normal distribution: median (interquartile range) [M (P25, P75)], using the rank sum test; categorical variables: counts, frequencies or percentages (%), using chi-square test. ▲compared with Q1, ♦compared with Q2.BMD: bone mineral density.

Discussion

This cross-sectional study included 229 postmenopausal patients with T2DM. Our findings indicate a detection rate of 34.5% for osteoporosis among postmenopausal patients with T2DM. The prevalence of postmenopausal osteoporosis varies significantly, ranging from 10.75 to 32.1%[38–41], which can be attributed to differences in population characteristics and diagnostic methods.

Our study found that, within the tertile subgroups of WWI, BMD of the lumbar spine, right femoral neck and left femoral neck in postmenopausal T2DM patients gradually decreased with increasing WWI, while the detection rate of osteoporosis correspondingly rose. A significant negative correlation was observed between WWI and both lumbar spine and femoral neck BMD, with this relationship being more pronounced in postmenopausal T2DM patients over 70 years. This aligns with results from several studies utilizing the NHANES and KNHANES databases[16,33–35,42]. In the correlation analysis between WWI and BMD across different age subgroups, a negative correlation was observed between WWI and BMD of both the lumbar spine and femoral neck only in the age group of over 70 years. In contrast, no correlation was found in the age group of 50–60 years. This finding suggests a significant relationship between WWI and aging, indicating a potential non-linear relationship between WWI and the risk of osteoporosis. A cross-sectional study conducted by Li et al.[14] reported that no association was detected between WWI and osteoporosis when WWI < 11.14 cm/√kg. However, a significant positive correlation was identified between WWI and an increased risk of osteoporosis when WWI ≥ 11.14 cm/√kg, as well as a non-linear relationship between WWI and osteoporosis within the T2DM population. Additionally, a study involving individuals aged 65 years and older in the United States[34]
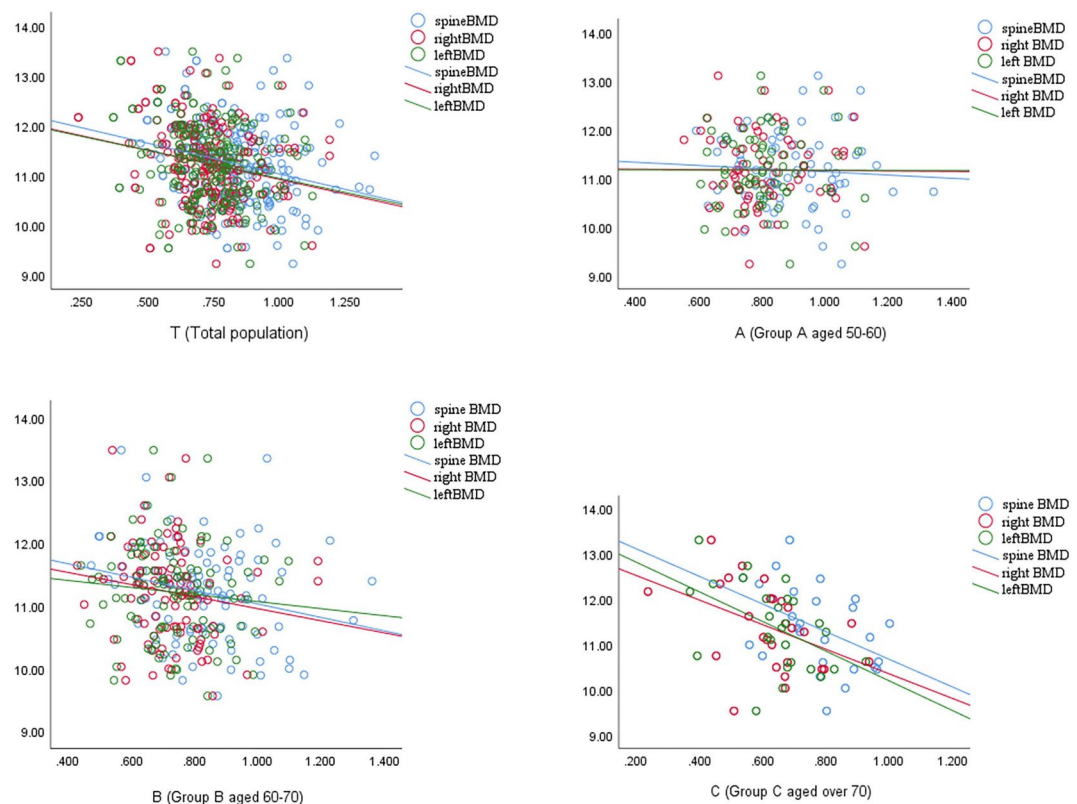
Fig. 1. (**T**) Correlation between WWI and BMD at each site in the total population; (**A**) Correlation between WWI and BMD at each site in group A(aged 50–60); (**B**) Correlation between WWI and BMD at each site in group B(aged 60–70); (**C**) Correlation between WWI and BMD at each site in group C(aged over 70).

	B	Odds Ratio	95%CI	P
WWI	1.150	3.158	1.714–5.820	0.000
OSTA	1.370	3.935	2.168–7.141	0.000

Table 3. Logistic regression analysis of influencing factors of osteoporosis in postmenopausal patients with T2DM. *Y: the presence of osteoporosis (assignment: no osteoporosis = 0; osteoporosis = 1); X: WWI(assignment: < 11.55 = 0; ≥ 11.55 = 1), OSTA (assignment: > − 1 = 0; ≤ − 1 = 1). WWI: weight-adjusted waist index; OSTA: osteoporosis self-assessment tool for Asians.

revealed a U-shaped relationship between WWI and osteoporosis. Our further logistic regression analysis confirmed that a WWI exceeding 11.55 cm/√kg significantly increased the risk of osteoporosis by 3.158-fold compared to the group with a WWI below 11.55 cm/√kg. This finding is in proximity to the cut-off value of 11.14 cm/√kg reported in the study by Li et al.[14].

We found a 3.935-fold increased risk of developing osteoporosis in logistic regression analysis for subjects with an OSTA below − 1. However, the ROC curve revealed that the AUC of the OSTA for predicting osteoporosis risk in postmenopausal individuals with T2DM over the age of 70 was 0.761. Despite the limited sample size of postmenopausal T2DM patients aged over 70, the AUC of the WWI was 0.808. This indicates a higher sensitivity compared to the OSTA, suggesting that the WWI may serve as a more effective screening tool for predicting the risk of osteoporosis in postmenopausal patients with T2DM.

To analyze the possible reasons for the differences between these two screening metrics, we first selected postmenopausal T2DM patients for our study. This population is significantly impacted by the rapid decline in physiological estrogen levels, which affects overall body composition including bone, muscle and fat. Consequently, it is essential to consider the effects of fat and muscle composition on bone mass when assessing it. In contrast, OSTA focuses solely on age and body weight, failing to differentiate between fat and muscle mass and lacking the ability to interpret their relationship with bone metabolism and bone mass. Secondly, abdominal obesity is a common somatotype among patients with T2DM[18], particularly among the elderly population in China[43]. WWI serves as an effective indicator for assessing the presence of abdominal obesity by standardizing WC relative to body weight. This approach combines the advantages of WC while minimizing the association with BMI[31], thereby reflecting the complex condition of sarcopenic obesity[14,42]. Existing literature indicates a
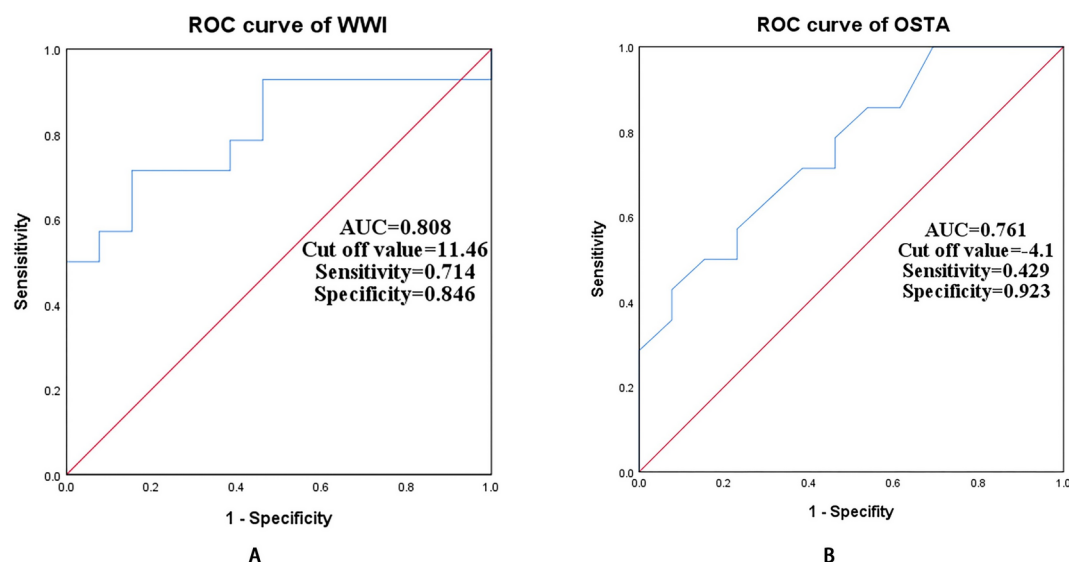
Fig. 2. (**A**) ROC curve of WWI predicting the risk of osteoporosis in patients with T2DM over 70; (**B**) ROC curve of OSTA predicting the risk of osteoporosis in patients with T2DM over 70.

	AUC (95% CI)	Cut-off	Sensitivity	Specificity	P
WWI	0.808(0.688–0.927)	11.46	0.714	0.846	0.007
OSTA	0.761(0.636–0.886)	−4.1	0.429	0.923	0.001

Table 4. Comparison of WWI and OSTA in predicting osteoporosis risk in postmenopausal T2DM patients over 70 years. AUC: area under the curve; WWI: weight-adjusted waist index; OSTA: osteoporosis self-assessment tool for Asians.

positive correlation between WWI and body fat mass, alongside a negative correlation with muscle mass[32,42]. Elevated WWI suggest that individuals with larger WC possess higher fat mass and lower muscle mass compared to those with the same weight but smaller WC. Furthermore, WWI demonstrates minimal variation across different racial groups, making it broadly applicable in multiracial contexts[14].

In our study, we found that the negative correlation between WWI and BMD in the postmenopausal population with T2DM was more pronounced in individuals over 70 years. We inferred that this phenomenon may be attributed to the influence of abdominal obesity on bone metabolism, which leads to a reduction in bone mass; furthermore, abdominal obesity is more prevalent among the elderly population[43]. However, disease states and sensitive indicators may vary across different populations. Osteoporosis is influenced by a wide range of etiological factors and risk factors. As an indicator related to abdominal obesity, WWI considers only two parameters: WC and body weight[30]. Consequently, its applicability may be limited across diverse populations. Nevertheless, the validity of the WWI in younger age groups has been established[33,44]. Therefore, further studies are necessary to assess the sensitivity and applicability of the WWI in non-diabetic populations. Additionally, more appropriate cut-off value of WWI should be investigated. The strength of the present study lies in its focus on the relationship between WWI and the risk of osteoporosis in postmenopausal patients with T2DM, an area that has been underexplored in previous studies, which predominantly focused on bone health in the general population. However, this study also has certain limitations. Firstly, being a cross-sectional retrospective study, it failed to reveal a causal relationship between WWI and the risk of osteoporosis. Secondly, this study was conducted at a single center with a small sample size, which limited the ability to determine a more appropriate cut-off value for WWI. Thirdly, the population of this study was restricted to hospitalized postmenopausal individuals with T2DM, and no healthy control group was included. Consequently, we will continue to expand our sample size, particularly among the non-diabetic population aged over 70 years, to obtain clearer statistical evidence of the superiority of WWI over OSTA in screening for osteoporosis. Additionally, further prospective studies and causal inference analyses are necessary to corroborate our findings.

Conclusion

The results of this study demonstrate that in postmenopausal patients with T2DM, WWI is closely associated with osteoporosis and negatively correlates with BMD. Furthermore, among postmenopausal T2DM patients over 70 years, WWI may be more effective than OSTA in predicting osteoporosis. We anticipate that WWI will serve as a predictive screening indicator for osteoporosis, enabling early intervention to mitigate its adverse consequences.

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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Author contributions

GD, LZ and JL wrote the main manuscript text and prepared Tables 1-4 and Figs. 1 and 2. JL, XW and LS collected and analyzed the data. DF, NW and LL contributed to the study design. BL and FY organized the study and revised the manuscript. All authors read and approved the final manuscript.

Declarations

Competing interests

The authors declare no competing interests.

Additional information

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