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Association between sarcopenia and weight-adjusted waist index in male patients with type 2 diabetes

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Abstract

Background The Weight-adjusted-waist index (WWI) has emerged as a predictive factor for a range of metabolic disorders. To date, the predictive value of the WWI in relation to sarcopenia in individuals with diabetics has not been extensively explored. This study aims to investigate the impact of the WWI on the prevalence of sarcopenia among patients with type 2 diabetes mellitus (T2DM).

Method In this study, we enrolled 417 patients with T2DM from the Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University between Dec. 2023 and Apr. 2024. The relationship between the WWI and the prevalence of sarcopenia in T2DM patients was evaluated using multivariate logistic regression, subgroup analysis, restricted cubic spline (RCS) analysis, and receiver operating characteristic (ROC) curve analysis.

Results Among the 417 patients with T2DM, 76 (18.22%) were identified as having sarcopenia. The prevalence of sarcopenia across the WWI quartile categories, from the first to the fourth quartile, was 8.65%, 8.57%, 20.19% and 8.65% respectively. Multivariate logistic regression analysis revealed that, after adjusting for covariates, a higher WWI was an independent risk factor for sarcopenia in male T2DM patients (OR = 1.836, 95% CI: 1.216–2.772, $P = 0.004$). This association was not observed in female patients. Subgroup analysis further revealed a stronger correlation between WWI and sarcopenia among male patients with higher HbA1c levels. In males, RCS regression demonstrated a non-linear positive correlation, with an inflection point at a WWI of 10.42 cm/√kg. Finally, the area under the ROC curve (AUC) for the WWI was 0.612.

Conclusions WWI emerges as a robust and independent risk factor for sarcopenia in male patients with T2DM. WWI may serve as an accessible and cost-effective tool for identify sarcopenia in patients with diabetes.

Keywords Waist circumstance, Type 2 diabetes, Sarcopenia, Weight-adjusted-waist index

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Introduction

Age-related sarcopenia is characterized by a progressive loss of skeletal muscle mass, muscle strength, and physical performance, which heightens the risk of falls and fractures, impairs the quality of daily life, and increases the risk of accompanying diseases [1, 2]. The prevalence of sarcopenia varies depending on the criteria employed for its diagnosis. Globally, it is estimated that between 10 and 16% of the elderly population is affected by sarcopenia [3]. Diabetes, a metabolic disorder stemming from inadequate insulin secretion and/or utilization, is marked by hyperglycemia and encompasses a range of symptoms related to impaired carbohydrate, protein, and fat metabolism [4]. T2DM increases the risk of disabling diseases, including cardiovascular disease, retinopathy, renal failure, and peripheral vascular disease [5]. Compared to individuals with normal blood glucose levels, those with T2DM are at a greater risk of developing sarcopenia, primarily due to diminished muscle strength and physical performance [6–8]. Consequently, it is crucial to identify and evaluate sarcopenia in patients with diabetes.

Sarcopenia is typically diagnosed through intricate device-related measurements of muscle mass and function, such as computed tomography (CT), dual energy X-ray absorption (DXA), or bioelectrical impedance analysis (BIA), which can be time-consuming and costly

Table 1 Study population characteristics stratified by gender and sarcopenia

	Male		*P*-value	Female		*P*-value
	Sarcopenia	Non-sarcopenia		Sarcopenia	Non-sarcopenia	
N	48	213		28	128	
WWI, cm/√kg	10.80 ± 1.00	10.35 ± 1.01	0.006	11.14 ± 1.22	10.95 ± 1.28	0.46
Age, years	67.21 ± 12.04	56.60 ± 10.01	< 0.001	68.93 ± 9.54	63.79 ± 10.37	0.017
Body mass index, Kg/m2	22.86 ± 3.08	25.20 ± 3.06	< 0.001	20.94 ± 2.73	25.30 ± 3.71	< 0.001
Systolic blood pressure, mmHg	133.08 ± 23.82	131.76 ± 17.16	0.716	130.64 ± 20.05	135.80 ± 21.99	0.256
Diastolic blood pressure, mmHg	73.29 ± 11.24	76.54 ± 10.16	0.051	69.11 ± 10.87	71.99 ± 10.78	0.202
Smoking, %			0.028			
Never	77.1	57.7		100	100	
Ever	10.4	11.7		0	0	
Current	12.5	30.5		0	0	
Drinking,%			0.020			0.008
Never	85.4	66.7		92.9	98.4	
Ever	0	8.5		7.1	0	
Current	14.6	24.9		0	1.6	
Hypertension			0.171			0.048
Yes	66.7	55.9		50	69.5	
No	33.3	44.1		50	30.5	
Hyperlipidemia			0.102			0.653
Yes	54.2	66.7		57.1	61.7	
No	45.8	33.3		42.9	31.4	
CHD			< 0.001			0.079
Yes	20.8	4.7		10.7	96.9	
No	79.2	95.3		89.3	3.1	
Hb, g/L	128.67 ± 17.90	141.31 ± 18.38	< 0.001	115.79 ± 14.86	126.08 ± 15.43	0.002
Prealbumin, mg/L	252.49 ± 58.31	270.75 ± 50.12	0.028	219.10 ± 58.01	232.09 ± 54.85	0.264
Albumin, g/L	37.91 ± 5.05	40.75 ± 4.71	< 0.001	38.02 ± 3.52	39.29 ± 3.92	0.117
Globulin, g/L	27.83 ± 4.51	26.39 ± 4.50	0.046	28.62 ± 3.83	28.12 ± 4.52	0.589
Creatinine, umol/L	100.81 ± 59.66	81.24 ± 39.94	0.034	65.18 ± 21.08	62.95 ± 33.95	0.739
TC, mmol/L	4.49 ± 1.48	4.99 ± 1.80	0.074	4.86 ± 1.67	4.76 ± 1.47	0.739
TG, mmol/L	1.35 ± 0.67	2.43 ± 4.18	< 0.001	1.51 ± 0.77	1.65 ± 0.92	0.438
HDL, mmol/L	1.15 ± 0.33	1.15 ± 0.30	0.963	1.32 ± 0.41	1.21 ± 0.30	0.192
LDL, mmol/L	2.85 ± 1.06	3.52 ± 5.49	0.397	3.08 ± 1.36	3.04 ± 1.10	0.871
FBG, mmol/L	9.34 ± 5.73	8.47 ± 4.14	0.224	10.14 ± 6.88	8.34 ± 4.05	0.193
HbA1c,%	9.54 ± 2.67	9.45 ± 2.12	0.815	10.16 ± 2.95	9.46 ± 2.04	0.249
UA, umol/L	358.74 ± 104.96	356.65 ± 92.31	0.891	303.21 ± 86.82	307.01 ± 82.98	0.828
WC, cm	85.65 ± 10.32	87.70 ± 9.88	0.197	78.29 ± 9.37	86.12 ± 11.61	0.001

WWI, weight-adjusted-waist index; CHD, coronary heart disease; TC, total cholesterol; TG, total glyceride; HDL, high density lipoprotein; LDL, low density lipoprotein; FBG, fasting blood glucose; HbA1c Glycosylated hemoglobin Alc; UA, uric acid; WC, waist circumstance

Table 2 Association of the Sarcopenia with WWI

	Crude model		Model I		Model II	
	OR (95% CI)	***P***	**OR (95% CI)**	***P***	**OR (95% CI)**	***P***
Male	1.537 (1.122, 2.106)	0.007	1.667 (1.150, 2.418)	0.007	1.836 (1.216, 2.772)	0.004
WWI						
Q1	Ref		Ref		Ref	
Q2	0.983 (0.345, 2.797)	0.974	1.256 (0.376, 4.200)	0.711	1.235 (0.329, 4.634)	0.755
Q3	2.792 (1.090, 6.833)	0.032	2.638 (0.880, 7.907)	0.083	3.442 (1.031, 11.492)	0.044
Q4	1.956 (0.759, 5.043)	0.165	3.052 (0.986, 9.445)	0.053	4.583 (1.303, 16.115)	0.018
Female						
WWI	1.128 (0.820, 1.552)	0.458	1.110 (0.746, 1.654)	0.606	1.059 (0.632, 1.775)	0.827
Q1	Ref		Ref		Ref	
Q2	2.345 (0.719, 7.649)	0.158	2.881 (0.642, 12.930)	0.167	2.516 (0.418, 15.147)	0.314
Q3	1.000 (0.265, 3.772)	1	1.322 (0.272, 6.424)	0.729	1.869 (0.307, 11.378)	0.497
Q4	1.755 (0.519, 5.937)	0.366	1.503 (0.336, 6.729)	0.594	1.034 (0.161, 6.651)	0.972

Crude model: adjusted for none

Model I: adjusted for age and BMI

Model II: adjusted for age, BMI, SBP, DBP, smoking, drinking, Hb, albumin, creatinine, TC, TG, HDL, LDL, FBG, UA

Male 9.6949, 10.4468, 11.1717

Female 10.1440, 10.8630, 11.7658

[1]. There is a need for a simple, efficient, and cost-effective method for screening and diagnosing sarcopenia.

It has been identified that certain biomarkers may be linked to the development and progression of sarcopenia, positioning them as potential biomarkers for the condition [1]. The WWI is a currently proposed anthropometric measure that evaluates obesity by standardized waist circumference (WC). The WWI is calculated by dividing the WC in centimeters by the square root of body weight (kg) (cm/√ kg) [9]. Obesity can independently lead to reduced muscle mass and function, which may originate from adipose tissue-related metabolic disorders such as oxidative stress, inflammation, and insulin resistance [10, 11]. Individuals with obesity are at an increased risk of developing chronic, non-communicable illnesses, which can negatively impact metabolic processes including both synthesis and catabolism [10]. Sarcopenia can directly contribute to fat accumulation by reducing overall energy use. Consequently, the combined effects of obesity and sarcopenia may exacerbate the detrimental cycle of fat gain and muscle lose [12]. Although BMI is widely used for assessing obesity due to its simple calculation, it does not distinguish between abdominal/visceral fat and fat/muscle mass [13, 14]. Measurement of WC serves as a reliable indicator of abdominal obesity. Furthermore, an earlier study involving Korean cohorts revealed a notable link between the WWI and an increase in fat mass coupled with a reduction in muscle mass [15]. The newly developed WWI, an anthropometric measure that normalizes WC and weight, has proven effective in forecasting cardiovascular death, type 2 diabetes [9, 14, 16], chronic kidney disease [17], stroke [18], and hyperuricemia [19]. However, the association between WWI and sarcopenia in patients with T2DM has not been previously documented. Therefore, we aimed to investigate the correlation between WWI and the prevalence of sarcopenia in T2DM patients.

The primary goals of this research are to evaluate the prevalence of sarcopenia across both genders. Subsequently, we aim to examine the association between the WWI and the occurrence of sarcopenia. Finally, we seek to determine the diagnostic utility of WWI for identifying sarcopenia.

Table 3 Subgroup analysis of the correlation between WWI and Sarcopenia

	OR (95%CI) *p* value	***P* for interaction**
Age		0.547
<65 years	1.577 (0.964, 2.578) 0.07	
≥65 years	1.242 (0.806, 1.915) 0.326	
BMI		0.295
Non-obesity	1.504 (1.069, 2.118) 0.019	
Obesity	2.049 (0.752, 5.585) 0.161	
FBG		0.335
<6.1mmol/L	1.172 (0.656, 2.095) 0.591	
6.1-7.0mmol/L	2.443 (0.774, 7.709) 0.591	
>7.0mmol/L	1.639 (1.084, 2.479) 0.019	
HbA1c		0.0152
<7.0%	0.941 (0.452, 1.959) 0.871	
≥7.0%	1.672 (1.169, 2.393) 0.005	
Hypertension		0.522
Yes	1.296 (0.899, 1.869) 0.165	
No	2.193 (1.206, 3.987) 0.01	
CHD		0.7911
Yes	1.187 (0.533, 2.644) 0.675	
No	1.619 (1.142, 2.294) 0.007	

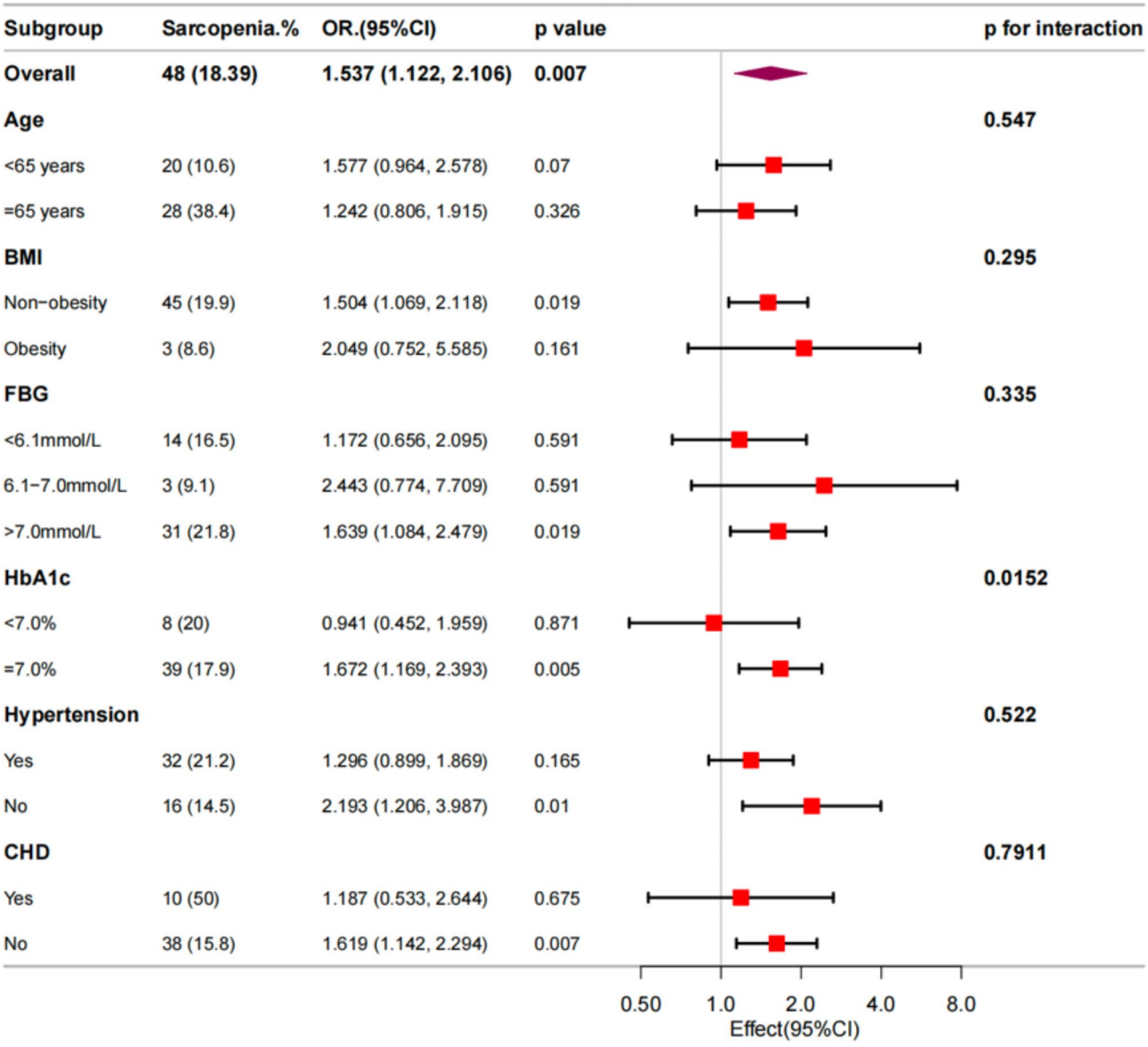

Fig. 1 Forest plot of the subgroup analysis of the correlation between WWI and sarcopenia

Methods

Study participants

A total of 417 participants diagnosed with T2DM at the Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University between Dec. 2023 and Apr. 2024 were enrolled in this cross-sectional study. Patients with diabetes were excluded if they presented with at least one of the following conditions: (1) type 1 diabetes, (2) other forms of diabetes, (3) diabetes ketoacidosis, (4) hyperglycemic hyperosmolar status, (5) acute infections, including pulmonary infection, urinary system infection, and hepatobiliary system infection, (6) prolonged bed rest, (7) nutritional disorders such as cancer, severe renal failure, heart failure, or respiratory failure, (8) incomplete data for DXA or WC measurements.

This study design was approved by the Institutional Review Board of the Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University, and has been performed in accordance with ethical standards laid down in the Declaration of Helsinki. The written informed consent of all subjects was obtained following the Declaration of Helsinki.

Data collecting

Medical history and baseline characteristic data, including age, height, weight, blood pressure, presence of diabetic nephropathy, diabetic retinopathy, diabetic peripheral neuropathy, tobacco and alcohol consumption, medication use, and laboratory parameters such as hemoglobin, prealbumin, albumin, globulin, creatinine,

total triglycerides, total cholesterol, high-density lipoprotein, low-density lipoprotein, fasting blood glucose, HbA1c, and urea acid, were abstracted from individual medical records. Anthropometric measurements were conducted on the first day of admission. Sarcopenia was designed as the primary outcome measure. The diagnosis of sarcopenia was based on the Chinese expert consensus on prevention and intervention for sarcopenia in the elderly (2023). Patients with type 2 diabetes were diagnosed with sarcopenia when they exhibited reduced muscle mass (men < 7.0 kg/m2, women < 5.4 kg/m2) and decreased muscle strength (men < 28 kg, women < 18 kg). The criteria for diagnosing conditions such as hypertension [20], hyperlipidemia [21], and coronary heart disease [22] were adopted from previous studies. Based on tobacco and alcohol consumption patterns, participants were categorized into three types: currently users, past users, and those who have never used.

Statistical analysis

Notably, there were gender differences in the WWI and ASM/height2, necessitating separate analyses for males and females. Continuous variables are reported as means and standard deviations, whereas categorical variables are presented as percentages. The t-test was used to assess the differences between groups based on continuous variables, and the chi-square test was used for categorical variables. Multivariate logistic regression analysis was conducted to investigate the association between WWI and sarcopenia, with adjusted odds ratios (OR) and 95% confidence intervals (CI) reported. In the crude model, no covariates were adjusted. In model1, adjustments were made for age and BMI. Building on Model1, SBP, DBP, smoking, drinking, Hb, albumin, creatinine, TC, TG, HDL, LDL, FBG and UA were included as covariates in Model 2. Subgroup analysis was performed to explore the relationship between the WWI and sarcopenia, stratified by age group (< 65 years/ ≥ 65 years), BMI categories (non-obese /obese), fasting blood glucose levels (< 6.1 mmol/L/ 6.1-7.0 mmol/L/ >7.0mmol/L), HbA1c (< 7.0%/ ≥7.0%), hypertension (yes/no) and coronary heart disease (yes/no), considering these factors as predefined potential influencing factors. To assess the potential modification of effects within subgroups, interaction terms between subgroup indicators were added, and likelihood ratio tests were conducted. ROC curve analysis was used to evaluate the predictive ability of WWI for sarcopenia. Statistical analyses were conducted using IBM SPSS Statistics Version 29.0 (IBM Corp., Armonk, NY, USA). Statistical significance was set at a two-sided P value < 0.05.

Table 4 The results of ROC analysis of WWI for the diagnosis of Sarcopenia

Nutritional indices	Cut-off	Sensitivity (%)	Specificity (%)	AUC	95% CI
Male					
WWI	10.59511	0.564	0.723	0.612	(0.528, 0.696)

Results

Patient baseline characteristics

The baseline characteristics of the diabetes patients are shown in Table 1. The study comprised 417 patients, of which 62.59% were male. The prevalence of sarcopenia among males and females were 18.39% and 17.95%, respectively. In the male group, WWI, age, globulin levels, and creatinine were all significantly higher in patients with sarcopenia compared to those without. Conversely, T2DM patients with sarcopenia showed lower levels of BMI, hemoglobin and albumin while there was no such difference in females in WWI, globulin, creatinine and albumin.

Association of the Sarcopenia with WWI

To investigate the relationship between sarcopenia and WWI, we developed three multiple regression models (Table 2). The crude model, which is the unadjusted model, revealed a statistically significant positive correlation between WWI and the risk of sarcopenia. This association persisted after adjusting for all covariates in Model 2 (OR = 1.836, 95%CI 1.216–2.772, $p = 0.004$). Compared to individuals in the lowest WWI quartile, those in the highest WWI quartile experienced a substantial increase in the risk of sarcopenia (OR: 4.583, 95% CI 1.303, 16.115; $P < 0.05$).

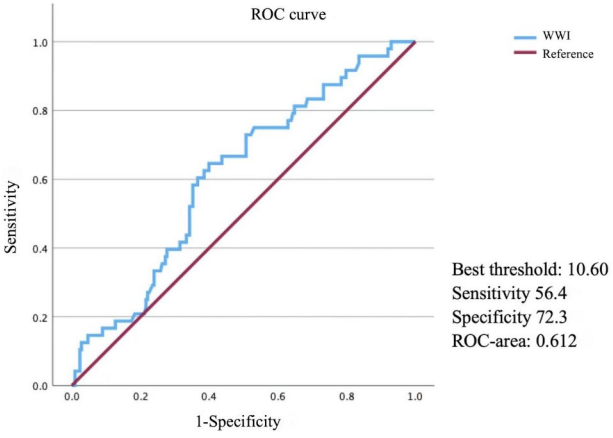

Fig. 2 The results of ROC analysis of WWI for the diagnosis of sarcopenia

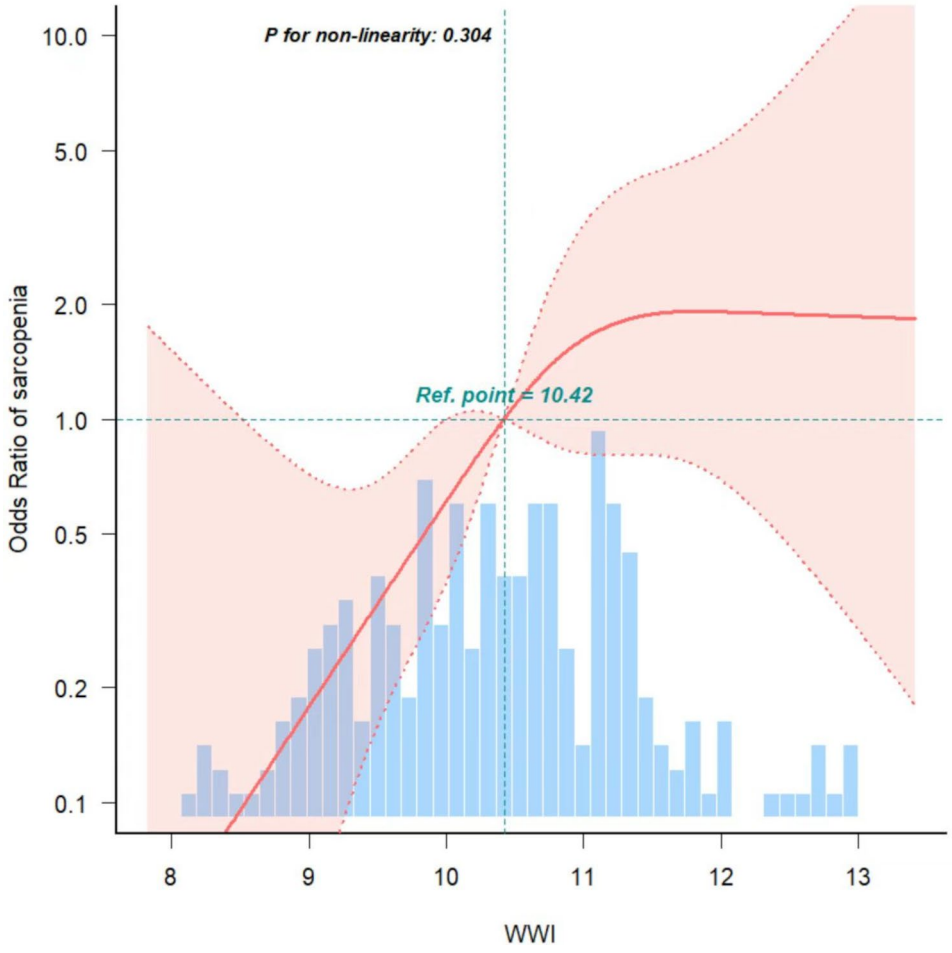

Fig. 3 Restricted cubic spline and threshold effect analysis

Subgroup analysis

We conducted subgroup analysis and interactive testing, focusing on age, BMI, fasting blood glucose, HbA1c, hypertension and coronary heart disease, to examine the association between the WWI and sarcopenia in different stratified populations (Table 3; Fig. 1). Notably, significant differences in the association were observed between subgroups stratified by HbA1c levels, whereas no such differences were found between subgroups based on the other factors.

The predictive capacity of WWI for Sarcopenia

Figure 2 displays the ROC curve, illustrating the predictive ability of the WWI for diagnosed sarcopenia. In males, the AUC was 0.612 (95%CI 0.528–0.696). Sarcopenia can be effectively diagnosed using a WWI at 10.60 cm/√ kg in males (sensitivity: 56.4%, specificity: 72.3%). The WWI demonstrates a good predictive ability for sarcopenia, which could be a valuable tool for the diagnosis of sarcopenia in clinical practice.

Restricted cubic spline and threshold effect analysis

The findings revealed that the threshold effect value of the WWI and sarcopenia for male participants was 10.42 cm/√ kg (Fig. 3). When the WWI is below 10.42 cm/√ kg, the effect value is 1.582 (95%CI 0.601–4.169, $p = 0.353$). Conversely, when the WWI exceeds 10.42 cm/√ kg, the effect value changed to 1.265 (95%CI 0.693–2.310, $p = 0.443$).

Discussion

The primary objective of this study was to evaluate the prevalence of sarcopenia in patients with T2DM and to investigate its connection to the WWI. Furthermore, a positive correlation between WWI and sarcopenia was observed among males, whether WWI was treated as a continuous factor or categorized into quartiles. Within the male subgroup analysis, with the exception of the HbA1c subgroup, the correlation between WWI and sarcopenia did not significantly vary across other subgroups. The Restricted Cubic Spline (RCS) analysis indicated a non-linear positive correlation between WWI and sarcopenia, with a threshold value identified at 10.42 cm/√kg.

The optimal WWI threshold for diagnosing sarcopenia, as indicated by the ROC curve, is 10.60 for males, with a sensitivity of 56.4% and a specificity of 72.3%.

The connection between various indicators of obesity and sarcopenia continues to be a topic of debate. This research pinpointed elevated WWI as a contributing factor to sarcopenia. Previous research suggests that a higher BMI may act as a protective factor against sarcopenia, while a greater percentage of body fat is considered a risk factor [23–25]. These indices suggest that obesity rates increase as their values rise. While a high BMI is commonly seen as detrimental to health, it serves as a safeguard against sarcopenia. There may be a reason for this since these studies focus primarily on older adults, who experience age-related changes in body composition, the accumulation of fat tissue and the loss of muscle tissue are examples. This implies that the Body Mass Index (BMI) remains constant as the percentage of body fat rises [26]. As fat mass increases and muscle mass decreases, there is a shift in the distribution of fat, manifesting as a transition from subcutaneous fat to abdominal/visceral fat [27–29]. Elevated levels of visceral fat may increase the likelihood of developing sarcopenia [30]. Visceral fat accumulation has a reciprocal effect on skeletal muscle loss [31]. Sarcopenia can lead to decreased physical activity, reduced energy use, and an heightened risk of obesity [32]. Additionally, an increase in visceral fat can cause inflammation, which may lead to sarcopenia [33, 34]. The application of BMI may be limited because it does not differentiate between fat and muscle mass. WC has a direct correlation with visceral fat and serves as an uncomplicated measure to assess visceral fat [35, 36], disregarding personal weight. This study demonstrates that the combined assessment utilizing WC and weight exhibits its superior predictive capability compared to WC and BMI. This conclusion is supported by the observation that the WWI yields a larger area under the ROC curve for sarcopenia compared to WC and BMI.

To the best of our knowledge, this article is the first to assess the relationship between WWI and sarcopenia among T2DM individuals. WWI has been found to be inversely related to both appendicular lean mass and abdominal muscle mass in middle-aged and older individuals in general [15, 37, 38]. Earlier research has shown a direct association between WWI and sarcopenic obesity in individuals with certain medical conditions, such as type 2 diabetes or those undergoing hemodialysis [14, 39]. This research indicates that increased WWI levels pose a risk for sarcopenia in males with type 2 diabetes. The lack of a correlation between WWI and sarcopenia in women with type 2 diabetes may be due to the limited sample size. The condition of sarcopenia is associated with aging [2, 40]. The emergence and progression of sarcopenia are linked to obesity [41], diabetes [42, 43], hypertension [44, 45], and coronary heart disease [46, 47]. The subgroup analysis further established a correlation between WWI and sarcopenia across different age, BMI, fasting blood glucose, hypertension, and coronary heart disease categories. Diabetes exacerbates sarcopenia through multiple mechanisms, including hyperglycemia, chronic inflammation, and oxidative stress. These factors may explain the stronger association between sarcopenia and WWI in the poorly controlled diabetic cohort [48]. The subgroup analysis of WWI and sarcopenia further reveals a distinct association between them, suggesting WWI as a possible predictor of sarcopenia.

This study has several advantages. Firstly, we have investigated a widely accessible and cost-effective parameter, WWI, which demonstrates the potential to be used in diverse clinical settings. Furthermore, the reliability of the research findings has been enhanced through the modification of covariates and the analysis of subgroups. However, there are several limitations to the research. The correlation between WWI and sarcopenia in female patients was not found to be statistically significant, possibly due to the limited sample size. The cross-sectional nature of the study prevents us from determining a precise association between WWI and sarcopenia. The AUC of WWI for predicting sarcopenia is only 0.612, possibly due to the small sample size or the limited predictive value of a single factor. Consequently, it's vital to carry out longitudinal studies with more substantial sample sizes to clarify the causal links. Regarding the diagnosis of sarcopenia, our data collection involved T2DM patients in China, which led us to select the consensus of Chinese experts on sarcopenia prevention and intervention (2023). The relationship between WWI and sarcopenia may be influenced by different diagnostic standards.

Conclusion

In this study, we observed that male patients with T2DM and higher WWI values were more likely to be affected by sarcopenia, with this association being more pronounced in those with suboptimal glycemic control. While these findings suggest that WWI may serve as a useful adjunct indicator for identifying individuals at increased risk of sarcopenia, the threshold value of 10.60 cm/√kg for men should be interpreted with caution. Its clinical utility, generalizability, and potential integration into routine practice need to be further validated by larger, more diverse, and longitudinal studies.

Abbreviations

WWI	Weight-adjusted-waist index
T2DM	Type 2 diabetes mellitus
RCS	Restricted cubic spline
ROC	Receiver operating characteristic
AUC	Area under the curve
CT	Computed tomography
DXA	Dual energy X-ray absorption

BIA	Bioelectrical impedance analysis
WC	Waist circumference
HbA1c	Glycosylated hemoglobin Alc
BMI	Body Mass Index

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Author contributions
Y.P., J.X., J.W. and C.W. made substantial contributions to the conception, study design, and review of the manuscript. Y.X. and J.X. performed statistical analyses. Y.X. prepared the manuscript. Y.X. and Z.W. collected and organized data.

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study design was approved by the Institutional Review Board of the Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University, and has been performed in accordance with ethical standards laid down in the Declaration of Helsinki. The written informed consent of all subjects was obtained following the Declaration of Helsinki.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Clinical trial number
Not applicable.

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