RESEARCH ARTICLE

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Weight-Adjusted Waist index as an Independent Predictor of Sarcopenia in Patients with type 2 Diabetes Mellitus

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Abstract

Introduction: Diabetes, and sarcopenia frequently co-occur and adversely affect muscular strength, body composition, and functional performance in adults. Identifying anthropometric markers that effectively distinguish individuals with and without these conditions is crucial for early screening and intervention. **Methods:** We compared diabetic and non-diabetic groups on physical attributes—handgrip strength, calf circumference (CC), and six-meter walk test (6MWT). We evaluated anthropometric indices, including waist-to-height ratio (WHtR), waist circumference (WC), waist-to-hip ratio (WHR), and weight-adjusted waist index (WWI), using Receiver Operating Characteristic (ROC) curves (AUC) and Youden's J statistic. **Results:** We found WWI showed the highest discriminative ability with an AUC of 0.745 (95% CI: 0.630–0.859) and the highest Youden Index (0.445), indicating the best overall balance between sensitivity and specificity. WHtR demonstrated the highest sensitivity (0.806), while WHR achieved the highest specificity (0.977) and the best positive predictive value (PPV = 0.857). WWI also provided the highest negative predictive value (NPV = 0.767). Collectively, these findings highlight WWI as the strongest overall predictor, with WHtR and WHR showing complementary strengths in sensitivity and specificity, respectively. **Conclusion:** Establishing simple, cost-effective anthropometric cutoffs for sarcopenia in Indian diabetics may facilitate early diagnosis in routine clinical and community settings, enabling timely intervention and improved outcomes. WWI may be considered to be included in clinical and public health screening programs targeting individuals at risk for diabetes, sarcopenia related functional decline.

Keywords: Sarcopenic, Type 2 diabetes mellitus, Anthropometry, Weight-adjusted waist index, Indian population

Índice de cintura ajustado al peso como predictor independiente de sarcopenia en pacientes con diabetes mellitus tipo 2

Resumen

Introducción: La diabetes y la sarcopenia frecuentemente coexisten y afectan adversamente la fuerza muscular, la composición corporal y el rendimiento funcional en adultos. Identificar marcadores antropométricos que distingan efectivamente a individuos con y sin estas condiciones es crucial para la detección e intervención tempranas. **Métodos:** Comparamos grupos diabéticos y no diabéticos en atributos físicos: fuerza de prensión manual, circunferencia de pantorrilla (CC) y prueba de caminata de seis metros (6MWT). Evaluamos índices antropométricos, incluyendo la relación cintura-talla (WHtR), circunferencia de cintura (WC), relación cintura-cadera (WHR) e índice de cintura ajustado al peso (WWI), usando curvas de Característica Operativa del Receptor (ROC) (AUC) y la estadística J de Youden. **Resultados**: Encontramos que WWI mostró la capacidad discriminativa más alta con un AUC de 0.745 (IC del 95%: 0.630–0.859) y el índice de Youden más alto (0.445), lo que indica el mejor equilibrio general entre sensibilidad y especificidad. El WHtR demostró la mayor sensibilidad (0,806), mientras que el WHR alcanzó la mayor especificidad (0,977) y el mejor valor predictivo positivo (VPP = 0,857). El WWI también proporcionó el mayor valor predictivo negativo (VPN = 0,767). En conjunto, estos hallazgos destacan al WWI como el predictor general más sólido, con el WHtR y el WHR mostrando fortalezas complementarias en sensibilidad y especificidad, respectivamente. **Conclusión:** Establecer puntos de corte antropométricos simples y rentables para la sarcopenia en diabéticos indios puede facilitar el diagnóstico temprano en entornos clínicos y comunitarios de rutina, lo que permite una intervención oportuna y mejores resultados. El WWI puede considerarse para su inclusión en programas de cribado clínico y de salud pública dirigidos a personas con riesgo de diabetes y deterioro funcional relacionado con la sarcopenia.

Palabras Clave: Sarcopénico, Diabetes mellitus tipo, Antropometría, Índice de cintura ajustado al peso, Población India

Introduction

Sarcopenia in diabetes is defined as existence of reduced muscle mass, a condition associated with higher morbidity and mortality (Kalyani et al., 2014; Seok et al., 2007). It is increasingly recognised as a significant health burden in patients with type 2 diabetes mellitus (T2DM), where insulin resistance, chronic inflammation, and altered body composition create a vicious cycle of muscle loss (Andersen et al., 2004).

Despite its importance, sarcopenia lacks standardised diagnostic criteria, particularly for anthropometric cutoffs in Indian populations. Gold-standard body composition tools such as Dual-energy X-ray Absorptiometry (DXA) and Computed Tomography (CT), though accurate, are costly and impractical for large-scale or community-based studies (Batsis & Villareal, 2018). Anthropometric measures provide a simple, cost-effective approach for identifying sarcopenia, particularly in settings where advanced imaging modalities are not feasible. Among them, calf circumference has long been recommended as a surrogate marker of muscle mass, with values <31 cm shown to predict low muscle mass and sarcopenia-related disability (Kawakami et al., 2015; Rolland et al., 2003). Mid-arm circumference and arm muscle area also correlate with skeletal muscle mass and functional decline (Tsai et al., 2012). More recently, central adiposity-related indices, such as ratio waist-to-height ratio (WHtR) and waist-to-hip ratio (WHR), have been linked with sarcopenia, reflecting the redistribution of fat and muscle with aging (Martone et al., 2025). Importantly, the Weight-adjusted waist index (WWI) has emerged as a strong anthropometric predictor of sarcopenia, with studies demonstrating its superior diagnostic accuracy compared to BMI and WHtR (Park et al., 2023). Anthropometric measures such as BMI, waist circumference (WC), WHR, WHtR, and the newer WWI provide simple, low-cost alternatives with established links to cardiometabolic risks (Belfield et al., 2024). However, their utility for identifying sarcopenia remains poorly studied in Indian patients with diabetes. Based on the above backdrops this study aimed to determine whether WHR, WHtR, and WWI are significant independent predictor of sarcopenia in type 2 diabetes mellitus.

Materials and Methods

Study Design

This hospital-based cross-sectional study was conducted over a period of twelve months in the Department of Physiology, All India Institute of Medical Sciences (AIIMS), Kalyani. Seventy-four participants with type 2 diabetes were recruited after having informed consent. Participants were excluded if they had type 1 diabetes mellitus, chronic systemic diseases such as hypertension, ischemic heart disease, renal failure, or cancer, pregnant or lactating, or had a recent history of musculoskeletal injury. The study was approved by the All India Institute of Medical Sciences Institutional Ethics Committee (Ref. No. IEC/AIIMS/Kalyani/certificate/2024/148) and the study protocol was aligned with Declarations of Helsinki.

Anthropometric Measurements

Anthropometric measurements were conducted according to the International Society for the Advancement of Kinanthropometry (ISAK) protocols (ISAK manual 2024). Height, body weight, waist and hip circumferences were measured using a stadiometer, a digital scale and a non-stretchable anthropometric tape.

Body Mass Index (BMI), Waist Hip Ratio (WHR), Waist Height Ratio (WHR), Waist Weight Ratio (WWT) were calculated using the following equations:

BMI = Weight (kg) / Height^2 (m)

WHR = Waist Circumference (cm) / Hip Circumference (cm)

WHR = Waist circumference (cm) / Height (cm)

WWI = Waist circumference (cm) / $\sqrt{}$ weight (kg)

Assessment of Sarcopenia

Sarcopenia was diagnosed according to the Asian Working Group for Sarcopenia (AWGS) 2019 consensus (Chen et al., 2020). Muscle strength was assessed by handgrip dynamometry, with cutoffs of <28 kg in men and <18 kg in women indicating low strength. Physical performance was evaluated by gait speed over a 6-m walk, with values <1.0 m/s classified as low. Muscle mass was measured using bioelectrical impedance analysis (BIA) to calculate skeletal muscle mass index (SMI), with cutoffs of <7.0 kg/m² for men and <5.7 kg/m² for women. Calf circumference was also measured, with thresholds of <34 cm in men and <33 cm in women, suggesting reduced muscle mass (Álvarez-Bustos et al., 2024). Standardised precaution was taken during BIA measurements. Subjects were asked to come in fasting condition followed by avoid eating or drinking (especially caffeinated or alcoholic beverages) for at least 4–8 hours before the test. Excessive water intake just before the test was forbidden to avoid distended bladder condition. Subjects were instructed to avoid strenuous exercise for at least 12 hours prior to testing, and a 10-minute rest in a seated posture was recommended to stabilize fluid distribution.

Statistical analysis

All statistical analyses and visualizations were performed in R (version 4.5.1; R Foundation for Statistical Computing, Vienna, Austria) using the packages *ggplot2*, *pROC*, *patchwork*, and *dplyr*. Continuous variables were expressed as mean ± standard deviation (SD) for normally distributed data. Between-group comparisons were performed using the independent Student's T-test with effect size. The relationship between anthropometric indices and sarcopenia were examined using binomial logistic regression to analyse independent predictor in model. Receiver operating characteristic (ROC) curve analysis was used to determine optimal cutoff values for and to assess their diagnostic accuracy by calculating sensitivity, specificity, and the area under the curve (AUC). A p-value <0.05 was considered statistically significant throughout the study.

Results

Anthropometric, physiological and body composition descriptive characteristics

Baseline characteristics of all the anthropometric measurements and physiological indices followed by physical performance markers were represented in Table 1, Figure 1 and 2. Individuals with sarcopenia exhibited lower height, weight and BIA-derived muscle mass index at a significant level (height & BIA=p<0.001; weight=p<0.01; Figure 1a), indicating reduced overall body mass.

Table 1. Descriptive characteristics of participants with and without sarcopenia; ** = p<0.01, ***= p<0.001

Variable	No Sarcopenia (n=43)	Sarcopenia (n=31)
Age (years)	45.14 ± 9.75	44.55 ± 11.16
Height (cm)	159.30 ± 8.92	151.72 ± 7.79***
Weight (kg)	68.28 ± 13.43	60.55 ± 10.19**
BMI (kg/m²)	26.87 ± 4.24	26.38 ± 4.67
BIA (kg/m²)	7.00 ± 0.92	5.98 ± 0.88***
Calf circumference (cm)	34.84 ± 3.21	31.99 ± 2.93***
Hip circumference (cm)	97.79 ± 8.73	94.89 ± 9.42
Waist circumference (cm)	93.38 ± 9.94	91.82 ± 10.25
Duration of DM (months)	28.65 ± 18.66	28.29 ± 19.65
PPBS (mg/dL)	221.96 ± 71.08	225.51 ± 72.52
FBS (mg/dL)	142.26 ± 39.55	144.88 ± 58.06
HbA1c (%)	7.54 ± 1.54	7.53 ± 1.51
Gait Speed (m/s)	1.02 ± 0.167	0.90 ± 0.14**
Handgrip (kg)	28.73 ± 6.88	18.30 ± 4.84***

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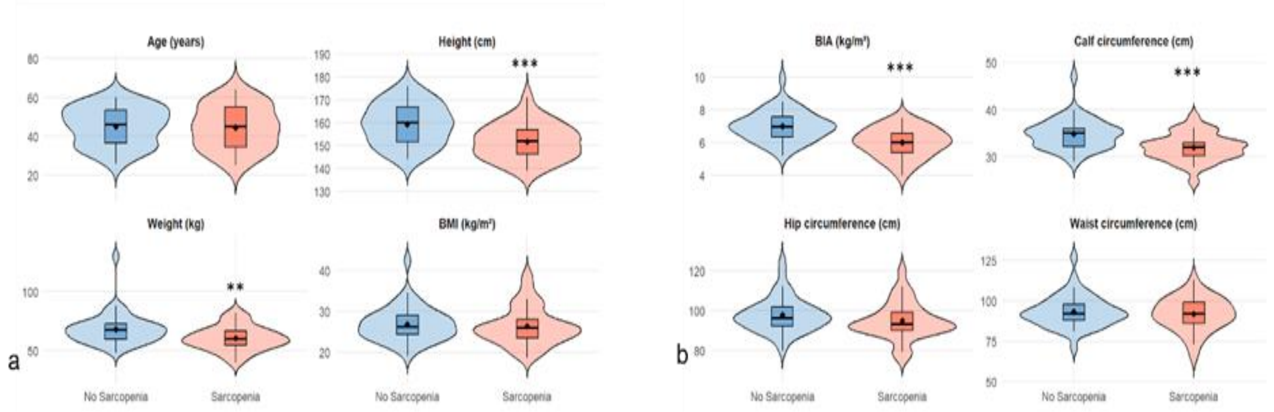

Figure 1. Violin plots displaying group differences and distributions (a) in age (years), height (cm), weight (kg), and body mass index (BMI, kg/m²) between participants with and without sarcopenia. (b) bioimpedance analysis (BIA, kg/m²), calf circumference (cm), hip circumference (cm), and waist circumference (cm). Black dots indicate medians, thick bars represent interquartile ranges, and violin shapes show data density. **=p<0.01, ***=p<0.001

Calf circumference of sarcopenic individuals were significantly lower than non-sarcopenic (p<0.001;Figure 1b), whereas hip and waist circumferences were insignificant within the groups. These findings suggest that sarcopenia is associated with generalized reductions in body mass and peripheral muscle bulk, most notably in the lower limbs. Both fasting blood sugar (FBS) and postprandial blood sugar (PPBS) were higher in patients with sarcopenia, though differences were insignificant accompanied by insignificant HbA1c levels. Duration of diabetes in both the groups possess insignificant difference.

Functional Outcomes-Gait Speed and Handgrip Strength

Figure 2 shows violin plots illustrating the distribution of gait speed and handgrip strength by sarcopenia status. Gait speed was significantly lower in the sarcopenia group (median ≈ 0.9 m/s) compared with non-sarcopenia (median ≈ 1.1 m/s) (p<0.01). Handgrip strength was markedly reduced in sarcopenia (median ≈ 18 kg) compared with non-sarcopenia (median ≈ 29 kg) (p<0.001; Table 1 and Figure 2c &d).

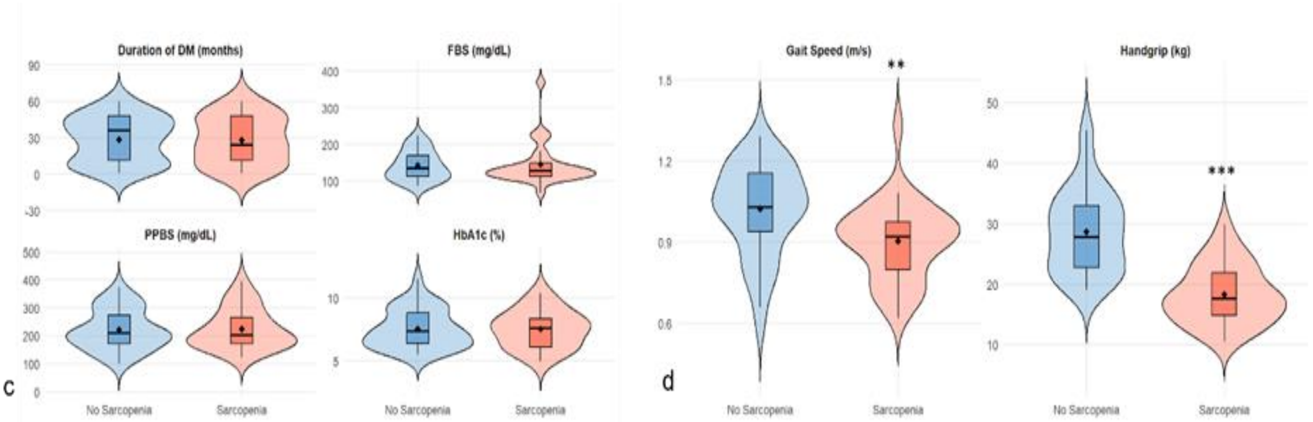

Figure 2. Violin plots comparing (c) =duration of diabetes mellitus (months), fasting blood glucose (FBS, mg/dL), postprandial blood glucose (PPBS, mg/dL), and HbA1c (%) between participants with and without sarcopenia. (d) Gait speed (m/s) and Handgrip (kg). Black dots represent medians and thick bars represent interquartile ranges. **=p<0.01, ***=p<0.001

Group Comparison between Anthropometric and Functional performance

Between-group comparisons (Table 2 and Figure 2) showed that participants with sarcopenia had significantly higher WWI compared with non-sarcopenic individuals (mean difference = –0.1431, 95% CI –1.371, –0.403, *p* < 0.001, effect size = –0.8899).

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Table 2. Group comparison between participants with and without Sarcopenia

Variable	p-value	Mean difference	Effect Size	95% CI (Lower, Upper)
WHR	0.405	–0.0139	–0.2159	–0.678, 0.248
WHtR	0.15	–0.0187	–0.2620	–0.725, 0.203
WWI	<0.001	–0.1431	–0.8899	–1.371, –0.403
Handgrip (kg)	<0.001	10.4284	1.7040	1.161, 2.238
Gait Speed (m/s)	<0.001	0.1187	0.7504	0.270, 1.226

Table 3. Logistic regression model for predictors of sarcopenia

Variable	Estimate (β)	SE	p-value	Odds Ratio (OR)	McFadden's R^2
Intercept	–10.444	4.54	0.022	2.91×10^{-5}	0.137
WWI	5.474	1.76	0.002	238.4	
WHR	0.946	4.26	0.824	2.58	
WHtR	1.986	3.82	0.604	7.29	

Table 4. ROC curve analysis of anthropometric predictors for sarcopenia

Predictor	AUC	95% CI (Lower–Upper)	Bootstrap SE	Bootstrap Ratio	Threshold	Sensitivity	Specificity	PPV	NPV	Youden Index
WWI	**0.745**	**0.630 – 0.859**	0.059	12.72	1.497	0.677	0.767	0.677	**0.767**	**0.445**
WHtR	0.599	0.463 – 0.735	0.069	8.64	0.566	**0.806**	0.442	0.51	0.76	0.248
WHR	0.557	0.419 – 0.696	0.071	7.87	1.041	0.194	**0.977**	**0.857**	0.627	0.17

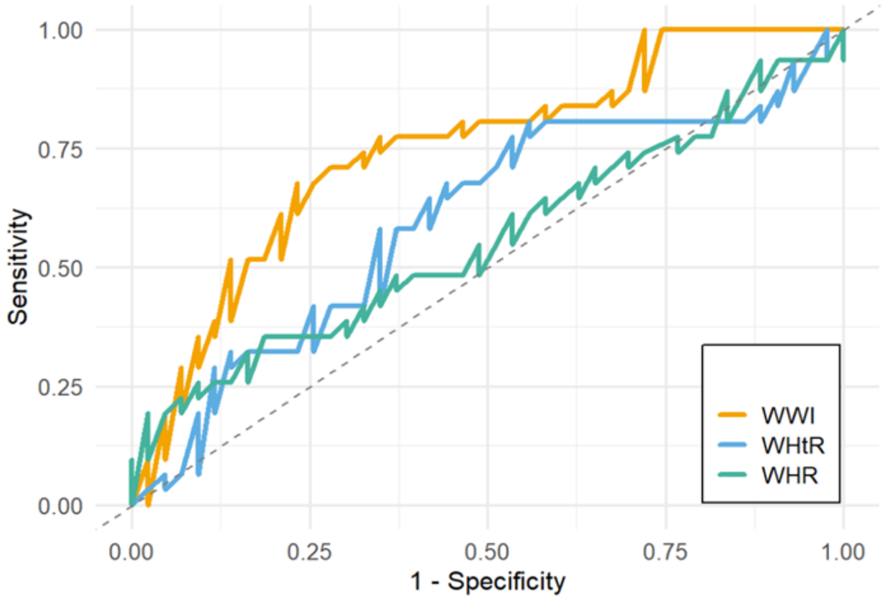

Figure 3. ROC curves comparing the predictive performance of weight-adjusted waist index (WWI), waist-to-height ratio (WHtR), and waist-to-hip ratio (WHR) for sarcopenia. The diagonal dashed line represents the null classifier.

In contrast, WHR (p = 0.405, effect size=–0.2159) and WHtR (p = 0.150, effect size=–0.2620) did not differ significantly between groups.

Functional parameters demonstrated strong discriminatory power. Sarcopenic participants exhibited substantially lower handgrip strength (mean difference = 10.428, 95% CI 1.161, 2.238, p < 0.001, effect size = 1.7040) and slower gait speed (mean difference = 0.1187, 95% CI 0.060–0.200, p < 0.001, effect size = 0.7504).

Receiver operating characteristic (ROC) analysis showed that the WWI had the highest discriminative ability for sarcopenia (AUC = 0.745, 95% CI: 0.630–0.859), followed by WHtR (AUC = 0.599, 95% CI: 0.463–0.735) and WHR (AUC = 0.557, 95% CI: 0.419–0.696) (Table 4, Figure 3). At the optimal cut-off value (WWI = 1.497), WWI demonstrated sensitivity = 0.677, specificity = 0.767, PPV = 0.677, NPV = 0.767, with a Youden Index of 0.445, outperforming WHtR (Youden Index = 0.248) and WHR (Youden Index = 0.170). Logistic regression further supported these findings (Table 3), where WWI was a significant predictor of sarcopenia (β = 5.47, OR = 238.4, p = 0.002), WHR (OR = 2.58, p = 0.824) and WHtR (OR = 7.29, p = 0.604) were not significant. The overall model explained 13.7% of variance (McFadden's R^2 = 0.137).

Discussion

The present study demonstrates that diabetes with sarcopenia exert synergistic adverse effects on physical performance and anthropometric indices. We observed that sarcopenic diabetic subjects had significantly lower handgrip strength, reduced calf circumference, and poorer gait speed compared with non-sarcopenic. Previous reports indicate that T2DM accelerates muscle mass decline and impairs contractile function through mechanisms of insulin resistance, mitochondrial dysfunction, and low-grade chronic inflammation, and our study results were aligned with the study. These mechanisms compromise protein synthesis, enhance proteolysis, and contribute to a phenotype of reduced muscle quality despite preserved or increased adiposity (Volpato et al., 2012).

The burden of sarcopenia in T2DM is substantial, 18–23% overall, higher than the ~10% prevalence in the general older-adult population (Ai et al., 2021). One meta-analyses confirms that T2DM increases the risk of sarcopenia by nearly two-fold (Kim & Choi, 2013). Higher prevalence in Southeast Asia; may relate to body composition, nutrition, and physical activity differences. Routine sarcopenia screening in older adults with diabetes is justified (Mesinovic et al., 2019).

Anthropometric indicators such as calf circumference (CC), CC adjusted for BMI, and the waist-to-calf ratio (WCR) have been proposed as simple screening tools for sarcopenia. CC has been validated as a surrogate for appendicular skeletal muscle mass and is widely used in community and clinical settings (Dhar et al., 2022). Similarly, WCR has emerged as a strong predictor of diabetes risk and muscle-fat imbalance, outperforming waist circumference in discriminating metabolic risk (Liu et al., 2023). In our analysis, lower calf circumference and higher waist-based indices were consistently associated with sarcopenia, highlighting the importance of integrating such measures into screening algorithms for at-risk populations, particularly in low-resource settings.

Functional performance tests remain critical for identifying clinically relevant sarcopenia. Handgrip strength has been established as a robust predictor of morbidity and mortality in older adults, while impaired gait speed reflects both muscular and cardiopulmonary compromise (Khader et al., 2019; Qiao et al., 2021). Our findings of significantly reduced handgrip and walking endurance among sarcopenic are in line with evidence that functional decline precedes overt disability and is a key determinant of health outcomes in diabetes. Notably, recent studies have also emphasized that lower-limb function tests, such as the chair stand test, may capture sarcopenia in obese diabetic adults more accurately than handgrip strength alone (Batsis et al., 2014). Thus, a multidimensional assessment incorporating both upper- and lower-extremity measures is recommended.

In the present study, WWI emerged as the strongest anthropometric predictor of sarcopenia, with an AUC of 0.75, outperforming both WHtR and WHR. This finding is consistent with recent reports suggesting that WWI, by adjusting waist circumference for body weight, better captures abdominal adiposity independent of overall body size, thereby reflecting sarcopenic changes more accurately (9). In contrast, WHtR demonstrated only moderate predictive value (AUC = 0.60), characterized by high sensitivity but poor specificity, which may lead to over-identification of at-risk individuals. WHR performed the least effectively (AUC = 0.56), which aligns with evidence indicating that hip circumference introduces confounding from gluteofemoral muscle and fat mass, reducing its discriminatory ability in sarcopenia detection (Bohannon, 2008).

The superior performance of WWI in our diabetic cohort is noteworthy, as diabetes is frequently associated with central adiposity, insulin resistance, and accelerated muscle loss. Traditional ratios such as WHR may inadequately capture this complex interplay, whereas WWI appears more sensitive to body composition imbalances characteristic of diabetic sarcopenia. From a clinical perspective, WWI offers a simple24, non-invasive tool with both reasonable sensitivity and specificity, making it potentially valuable for screening in resource-limited settings.

From a clinical perspective, our findings underscore the need for early detection and intervention. Simple anthropometric and functional tools such as CC, CC/BMI, WCR, handgrip strength, and gait speed could be feasibly incorporated into primary care and endocrinology clinics to stratify risk. Multimodal interventions combining resistance exercise, adequate protein intake (particularly leucine-rich supplementation), and optimised glycaemic control have been shown to mitigate muscle loss while managing adiposity (Yoo et al., 2022).

Conclusion

This study adds to the growing evidence that sarcopenia coexist frequently in T2DM and jointly impair functional performance and anthropometric health. WWI emerges as a significant independent reliable anthropometric predictor for adverse metabolic and functional outcomes. Mechanistically, this may be explained by the fact that sarcopenia is not merely a loss of muscle mass, but is often accompanied by redistribution of adiposity, particularly visceral fat accumulation. Because WWI isolates the contribution of abdominal fat from overall body mass, it may capture this imbalance between muscle loss and fat accumulation more effectively than traditional indices. Given its ease of measurement, global applicability, and demonstrated robustness, WWI may be prioritised in clinical and public health screening programs targeting individuals at risk for diabetes, sarcopenia. Multimodal interventions (exercise, protein-rich diet, vitamin D supplementation, glycaemic optimization) should be integrated into diabetes care to minimize the catabolic outcome of sarcopenia.

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