# Association of a novel anthropometric equation with visceral adipose tissue: An analysis of NHANES data

## Viseral yağ dokusu ile yeni bir antropometrik denklemin ilişkisi: NHANES verilerinin analizi

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**Abstract**

**Aim:** Obesity is a major risk factor for cardiometabolic diseases, and the amount of visceral adipose tissue (VAT) is a key determinant of this risk. The waist-to-hip ratio (WHR), a common indicator of body fat distribution, can yield similar results in individuals with both high and low waist and hip circumferences, making it insufficient for accurately assessing VAT. Developing measurements that can better predict VAT magnitude would be beneficial for primary prevention.

**Methods:** This cross-sectional study analyzed data from 878 adults (NHANES 2017–2018). VAT was measured via dual-energy X-ray absorptiometry (DEXA). Anthropometric data (height, weight, waist, and hip circumference) were used to calculate body mass index (BMI), WHR, and waist-to-height ratio (WHtR). We introduced a new equation, W2HR, defined as WHR × waist circumference. Pearson correlation analysis assessed the associations between these metrics and VAT. ROC analysis determined their ability to distinguish increased VAT (>130 $cm^2$) from normal VAT, with AUC values calculated.

**Results:** The mean age of participants was 40.10 ± 11.69 years, and 50.6% were male. All indices showed a positive correlation with VAT (p<0.001). W2HR demonstrated the highest correlation coefficient (r = 0.773, 95% CI: 0.745–0.801), followed by waist circumference (r = 0.763, 95% CI: 0.732–0.792) and WHtR (r = 0.749, 95% CI: 0.714–0.783). Among both sexes, W2HR exhibited the highest discriminative ability for increased VAT (AUC in males = 0.885, 95% CI: 0.852–0.913; AUC in females = 0.903, 95% CI: 0.872–0.929). In males, W2HR showed a significantly better performance than BMI, waist circumference, and WHtR (p<0.001, p<0.001, and p=0.002, respectively). In females, W2HR was significantly superior to BMI and WHR (both p<0.001).

**Conclusion:** W2HR is strongly correlated with VAT and easy to apply, highlighting the need for further research on its link to cardiometabolic risk.

**Keywords:** Adiposity; NHANES; obesity

**Öz**

**Amaç:** Obezite, kardiyometabolik hastalıklar için major risk faktörüdür ve viseral yağ dokusu (VAT) miktarı bu riskin en önemli belirleyicisidir. Vücut yağ dağılımının göstergesi olan bel-kalça oranı (WHR), bel çevresi ve kalça çevresinin her ikisinin birden yüksek veya düşük olduğu durumlarda benzer sonuçlar vermektedir ve viseral adipoz dokunun miktarı hakkında yeterli bilgi sağlamamaktadır. VAT miktarını öngörebilen ölçümlerin geliştirilmesi, birincil koruma için faydalı olacaktır.

**Yöntemler:** Bu kesitsel çalışma Ulusal Sağlık ve Beslenme İnceleme Anketi (NHANES) 2017-2018 dönemine ait 878 kişinin verileri ile gerçekleştirildi. Dual-enerji X-Ray absorbsiyometri (DEXA) ile ölçülen VAT değerleri kullanıldı. NHANES antropometri veri setindeki boy, vücut ağırlığı, bel ve kalça çevresi bilgileri kullanılarak vücut kitle indeksi (VKİ), WHR ve bel-boy oranı (WHtR) hesaplandı. Yeni geliştirdiğimiz denklem olan W2HR, WHR ile bel çevresinin çarpımı olarak tanımlandı. Tüm ölçümlerin VAT ile ilişkileri Pearson korelasyon analizi ile incelendi. Bu ölçümlerin, her iki cinsiyette artmış VAT (>130 cm2)'ı, normal VAT'tan ayırt etme başarılarını belirlemek için alıcı işlem karakteristiği (ROC) analizi kullanılarak eğri altında kalan alanlar (AUC) hesaplandı.

**Bulgular:** Katılımcıların ortalama yaşı 40.10 ± 11.69 ve %50.6'sı erkekti. Ölçümlerin hepsi VAT ile pozitif yönlü ilişkili bulundu (p<0.001). W2HR en yüksek korelasyon katsayısına sahipti (r = 0.773, 95% CI: 0.745–0.801), bunu bel çevresi (r = 0.763, 95% CI: 0.732–0.792) ve WHtR (r = 0.749, 95% CI: 0.714–0.783) takip etti.

Her iki cinsiyette artmış VAT'ı ayırt etme başarısı en yüksek ölçüm W2HR bulundu (erkeklerde AUC = 0.885, 95% CI: 0.852–0.913; kadınlarda AUC = 0.903, 95% CI: 0.872–0.929). Erkeklerde W2HR ile VKİ, bel çevresi ve WHtR arasındaki farklar anlamlıydı (sırası ile p<0.001, p<0.001 ve p=0.002). Kadınlarda W2HR ile VKİ ve WHR arasındaki fark anlamlıydı (her ikisi için p<0.001)

**Sonuç:** Yeni geliştirdiğimiz formülün VAT ile güçlü ilişkili bulunması ve kolay uygulanabilir olması bu formülün kardiyometabolik risk ile ilişkisini inceleyecek kapsamlı çalışmalara olan ihtiyacı vurgulamaktadır.

**Anahtar Sözcükler:** Adiposite; NHANES; obezite

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## INTRODUCTION

Obesity is a global public health concern and a significant risk factor for cardiometabolic diseases (1). Vague's landmark study first demonstrated that body fat distribution plays a crucial role in obesity-related risk (2). Among different fat depots, visceral adipose tissue (VAT) has been strongly associated with insulin resistance, and numerous studies have highlighted its central role in the pathogenesis of cardiometabolic diseases (3-5).

While computed tomography (CT) and magnetic resonance imaging (MRI) are considered the gold standards for VAT measurement, studies have shown that dual-energy X-ray absorptiometry (DEXA) provides a comparable assessment (6,7). However, factors such as limited accessibility, radiation exposure, and high costs restrict the widespread use of imaging modalities for visceral obesity screening. As a result, these methods have been reserved for research purposes rather than routine clinical practice.

For decades, body mass index (BMI) has been widely used to classify obesity and remains an essential tool in epidemiological research. However, BMI does not differentiate between lean and adipose tissue and primarily reflects overall obesity rather than fat distribution. Due to its limitations in predicting cardiometabolic risk, waist circumference-based measurements and formulas have gained prominence (8).

Ashwell et al. were among the first to demonstrate the relationship between waist-to-hip ratio (WHR) and VAT (9). Subsequently, epidemiological studies established that WHR—beyond BMI—was associated with an increased risk of cardiometabolic diseases (10,11). However, later studies indicated that waist circumference had a stronger predictive ability for diabetes and cardiovascular disease than WHR, leading to its inclusion in the metabolic syndrome criteria as a key determinant of obesity-related risk (12,13).

In the early 2000s, the concept of hypertriglyceridemic waist was introduced, based on the pathophysiology of VAT, which predominantly drains into the portal vein and contributes to the increased production of triglyceride-rich lipoproteins (14). With the widespread use of CT and MRI, large-scale patient data enabled the development of various equations, some based on hypertriglyceridemic waist circumference and others on body roundness, which were shown to be effective in estimating VAT magnitude (15,16). However, due to the complexity of these equations and the reliance on multiple anthropometric measurements and laboratory tests, they have not been widely adopted for routine visceral adiposity screening in clinical practice. Instead, simpler metrics such as BMI, waist circumference, WHR, and waist-to-height ratio (WHtR) continue to be commonly used.

In this study, we aimed to compare the associations of these measurements with DEXA-derived VAT and their ability to predict increased VAT using National Health and Nutrition Examination Survey (NHANES) data. Additionally, we sought to evaluate a newly developed, easily calculable equation in comparison with existing measures.

## MATERIAL AND METHODS

### *Data collection*

This study utilized data from the National Health and Nutrition Examination Survey (NHANES), conducted by the National Center for Health Statistics (NCHS). The NCHS Research Ethics Review Board approved the data collection and public release, ensuring compliance with ethical standards and participant privacy (http://www.cdc.gov/nchs/nhanes/) (17). Written informed consent was obtained from all adult participants before data collection; therefore, the authors did not obtain consent directly. Since hip circumference measurements were not available in NHANES cycles before 2017, data from the earliest available cycle thereafter were used.

### *Study population*

Data were obtained from the NHANES 2017-2018 cycle. Participants were included if they met the following criteria: (1) age ≥ 20 years, (2) availability of complete anthropometric data, and (3) presence of VAT measurements and relevant covariates. The inclusion and exclusion process is illustrated in Figure 1. Prior to the analysis, a power calculation was performed using G*Power software (version 3.1.9.7), which indicated that a minimum of 716 participants would be required to detect a moderate correlation (r = 0.30) between anthropometric indices and VAT with a power of 0.90

and a significance level of α = 0.05. Our final sample size of 878 participants exceeded this requirement.

### VAT measurement and anthropometric equations

VAT was assessed using dual-energy X-ray absorptiometry (DEXA) at the L4-L5 intervertebral level with Hologic APEX 4.0 software, reported in $cm^2$. The following anthropometric indices were calculated:

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

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

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

W$^2$HR = (Waist circumference (cm))$^2$ / Hip circumference (cm)

### Covariates

The NHANES dataset includes demographic, anthropometric, lifestyle, and health-related variables. In this study, covariates included age, sex, race, and education level. Health conditions such as diabetes, hypertension, and coronary artery disease (CAD) were determined through physician diagnoses or self-reports.

Metabolic syndrome was defined based on the National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP III) criteria (13).

### Evaluation of anthropometric equations for predicting VAT

The predictive performance of anthropometric indices for VAT was assessed by examining their correlations with VAT and their ability to identify elevated VAT. A commonly accepted threshold of 130 $cm^2$ was used to define increased VAT. Cutoff values were determined separately for men and women.

### Statistical analysis

Descriptive statistics were presented as means and standard deviations (SD) for continuous variables and as frequencies (n, %) for categorical data. Pearson correlation analysis was used to evaluate association between anthropometric indices and VAT. Receiver operating characteristic (ROC) analysis was performed to compare the ability of these indices for identifying increased VAT. The DeLong method was used to test for differences in area under the curve (AUC) values.

Statistical analyses were conducted using SPSS version 26.0 (IBM Corp., Armonk, NY, USA), and ROC analysis was performed with MedCalc version 13.0 (MedCalc Software, Mariakerke, Belgium). A significance level of $p < 0.05$ was considered for all tests.

## RESULTS

### Baseline characteristics

A total of 878 participants (50.6% male) were included in the analysis, with a mean age of 40.10 ± 11.69 years. The majority (63%) had an education level above high school. Regarding racial distribution, 32.7% of participants were non-Hispanic white, followed by 22.2% non-Hispanic black, 14.4% Mexican American, and 9.1% other Hispanic individuals.

The mean BMI was 28.96 ± 6.76 kg/$m^2$, and the mean waist circumference was 97.31 ± 16.55 cm. The mean VAT was 102.53 ± 56.45 $cm^2$, while the mean subcutaneous adipose tissue was 339.69 ± 170.08 $cm^2$. Metabolic syndrome was present in 39.1% of participants, while 20.8% had hypertension, 6.9% had diabetes mellitus, and 0.7% had coronary artery disease. Detailed characteristics of participants are presented in Table 1.

### Correlations and predictive performance of anthropometric equations

As presented in Table 2, all anthropometric indices showed significant positive correlations with VAT ($p < 0.001$ for all). Among them, W$^2$HR exhibited the highest correlation with VAT (r = 0.773, 95% CI: 0.745–0.801), followed by WC (r = 0.763, 95% CI: 0.732–0.792) and WHtR (r = 0.749, 95% CI: 0.714–0.783). BMI and WHR demonstrated weaker correlations (r = 0.672 and r = 0.640, respectively).

The results of the ROC analysis are shown in Table 3. The analysis revealed that all indices effectively identified individuals with increased VAT (≥130 $cm^2$). In men, W$^2$HR demonstrated the highest discriminatory power (AUC = 0.885, 95% CI: 0.852–0.913), followed by WHR (AUC = 0.873, 95% CI: 0.838-0.902) and waist circumference (AUC = 0.864, 95% CI: 0.829-0.895). Similarly, in women, W$^2$HR had the highest AUC (0.903, 95% CI: 0.872–0.929), followed by WHtR (AUC = 0.894, 95% CI: 0.824-0.890) and waist circum-

**Table 1.** Demographic and clinical features of participants

| | Patients (n=878) |
|---|---|
| Age | 40.10±11.69 |
| Gender, male | 444 (50.6%) |
| Education | |
| High school or below | 325 (37%) |
| Above high school | 553 (63%) |
| Race | |
| Mexican American | 126 (14.4%) |
| Other Hispanic | 80 (9.1%) |
| Non-Hispanic white | 287 (32.7%) |
| Non-Hispanic black | 195 (22.2%) |
| Other race | 190 (21.6%) |
| Body mass index (kg/m$^2$) | 28.96±6.76 |
| Waist circumference (cm) | 97.31±16.55 |
| Hip circumference (cm) | 105.57±13.31 |
| Waist to hip ratio | 0.92±0.08 |
| Waist to height ratio | 0.58±0.10 |
| W$^2$HR | 90.41±21.72 |
| Fasting glucose (mg/dl) | 108.75±35.55 |
| HDL-Cholesterol (mg/dl) | 52.72±15.06 |
| Triglyceride (mg/dl) | 112.33±123.60 |
| Visceral adipose tissue (cm$^2$) | 102.53±56.45 |
| Subcutaneous adipose tissue (cm$^2$) | 339.69±170.08 |
| Metabolic syndrome | 343 (39.1%) |
| Hypertension | 183 (20.8%) |
| Diabetes Mellitus | 61 (6.9%) |
| Coronary artery disease | 6 (0.7%) |

W$^2$HR: Waist circumference squared divided by hip circumference, n: Number, %: Percent, HDL: High density lipoprotein.
Results are presented as mean ± standard deviation or percentage.

**Table 2.** Association of anthropometric equations with visceral fat area

| | Pearson's r (95% CI) | p value |
|---|---|---|
| BMI | 0.672 (0.636-0.708) | <0.001 |
| WC | 0.763 (0.732-0.792) | <0.001 |
| WHR | 0.640 (0.600-0.676) | <0.001 |
| WHtR | 0.749 (0.714-0.783) | <0.001 |
| W$^2$HR | 0.773 (0.745-0.801) | <0.001 |

BMI: Body mass index, WC: Waist circumference, WHR: Waist-to-hip ratio, WHtR: Waist-to-height tatio, W$^2$HR: Waist circumference squared divided by hip circumference, CI: Confidence interval.

ference (AUC = 0.892, 95% CI: 0.859-0.920). BMI had the lowest AUC values in both sexes (Figures 2 and 3).

Pairwise comparisons, presented in Table 4, indicated that in men, W$^2$HR was significantly superior to BMI (p<0.001), WC (p<0.001), and WHtR (p=0.002). In women, W$^2$HR showed significantly better performance than WHR and BMI (p < 0.001), while its superiority over WC and WHtR was not statistically significant.

**Table 3.** Predictive ability of anthropometric equations in identifying increased visceral fat area

| | Cut-off value | AUC (95% CI) |
|---|---|---|
| Male | | |
| BMI | 28.40 | 0.829 (0.790-0.862) |
| WC | 99.70 | 0.864 (0.829-0.895) |
| WHR | 0.96 | 0.873 (0.838-0.902) |
| WHtR | 0.57 | 0.859 (0.824-0.890) |
| $W^2HR$ | 97.61 | 0.885 (0.852-0.913) |
| Female | | |
| BMI | 27.80 | 0.847 (0.810-0.879) |
| WC | 95.90 | 0.892 (0.859-0.920) |
| WHR | 0.91 | 0.826 (0.787-0.861) |
| WHtR | 0.59 | 0.894 (0.861-0.921) |
| $W^2HR$ | 91.84 | 0.903 (0.872-0.929) |

AUC: Area under the curve, CI: Confidence interval, BMI: Body mass index, WC: Waist circumference, WHR: Waist-to-hip ratio, WHtR: Waist-to-height tatio; $W^2HR$: Waist circumference squared divided by hip circumference

**Table 4.** P-values obtained as a result of comparing the AUC values of the adiposity indices

| | Equations | BMI | WC | WHR | WHtR | $W^2HR$ |
|---|---|---|---|---|---|---|
| Male | BMI | | <0.001 | 0.037 | 0.003 | <0.001 |
| | WC | | | 0.585 | 0.575 | <0.001 |
| | WHR | | | | 0.380 | 0.287 |
| | WHtR | | | | | 0.002 |
| Female | BMI | | <0.001 | 0.438 | <0.001 | <0.001 |
| | WC | | | 0.002 | 0.770 | 0.063 |
| | WHR | | | | 0.001 | <0.001 |
| | WHtR | | | | | 0.226 |

AUC: Area under the curve, BMI: Body mass index, WC: Waist circumference, WHR: Waist-to-hip ratio, WHtR: Waist-to-height tatio; $W^2HR$: Waist circumference squared divided by hip circumference

## DISCUSSION

In this study, all anthropometric measurements were found to be significantly associated with VAT magnitude as measured by DEXA, with $W^2HR$ showing the strongest correlation with VAT, while BMI and WHR demonstrated moderate correlations. When evaluating the ability to predict increased VAT, $W^2HR$ emerged as the best index in both genders; however, its superiority over WHR in men and over WC and WHtR in women did not reach statistical significance.

The significant positive correlation of all measurements—including BMI—with VAT is unsurprising, given the strong interrelationship among these indices. However, we found that BMI had a lower predictive ability for increased VAT compared to other methods. Kuk et al. demonstrated in a study of 256 participants with VAT measurements obtained via MRI that while BMI exhibited a significant positive association with VAT, similar to our findings, this relationship became negative after adjusting for waist circumference (18). This finding supports the notion that while BMI is a reliable surrogate for general obesity, it may be inadequate for assessing visceral adiposity.

In our study, WHR showed only a moderate correlation with VAT, and in women, its ability to predict increased VAT was comparable to BMI but weaker than all other indices. Kissebah et al., building upon Vague's classification of android and gynoid obesity, proposed WHR as a reflection of fat distribution, sug-

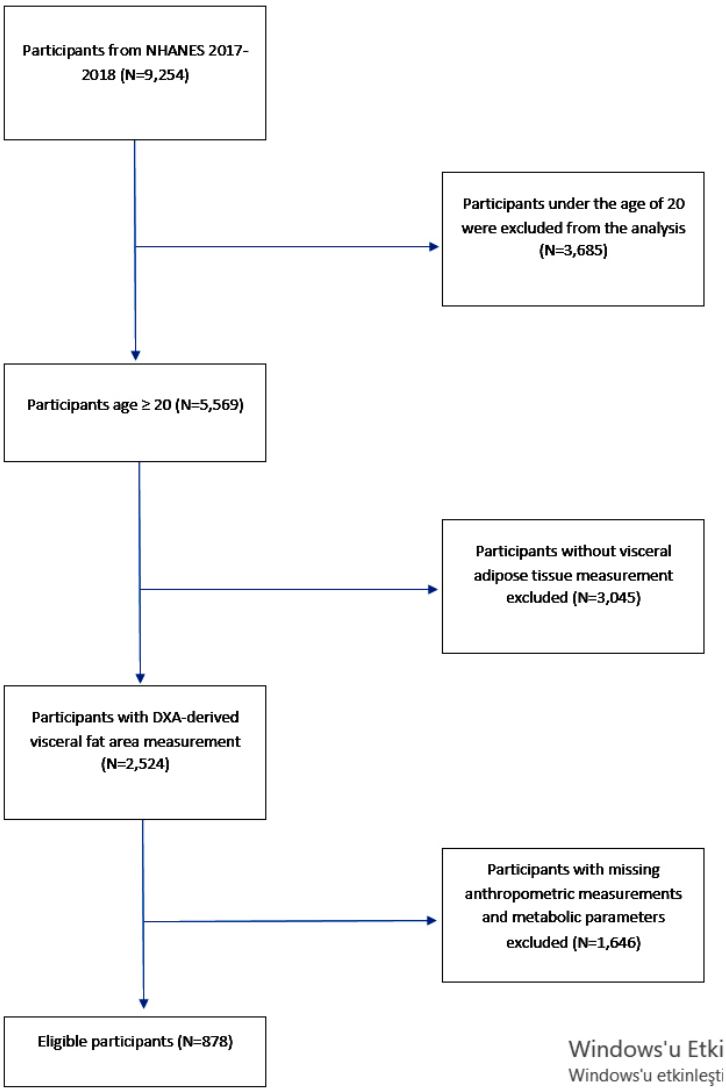



**Figure 1.** Study flow diagram

gesting it would be the best predictor of cardiometabolic risk associated with obesity (19). However, later evidence indicated that waist circumference alone was more strongly associated with absolute visceral adipose tissue magnitude (20,21). A study that measured adipose tissue via MRI before and after weight loss in obese individuals further supported this, showing that changes in WHR were not significantly related to absolute reductions in visceral fat (22). The inability of WHR to reliably reflect visceral adiposity may be attributed to the fact that individuals with both high and low waist and hip circumferences can have the same WHR, meaning that while WHR provides insight into fat distribution, it does not predict the magnitude of VAT. Consequently, WHR is not ideal for use in epidemiological studies or routine monitoring but may still be useful in selected populations.

Notably, in our study, despite WHR's moderate correlation with VAT and its low predictive ability for increased VAT in women, it performed comparably to other indices—and better than BMI—in identifying increased VAT in men. A recent study we conducted in apparently healthy individuals, 75% of whom were either normal weight or overweight, assessed CT-derived VAT and its association with widely used anthropometric indices. That study found that, in women, four out of six indices were significantly superior to WHR in identifying increased VAT, while in men, no

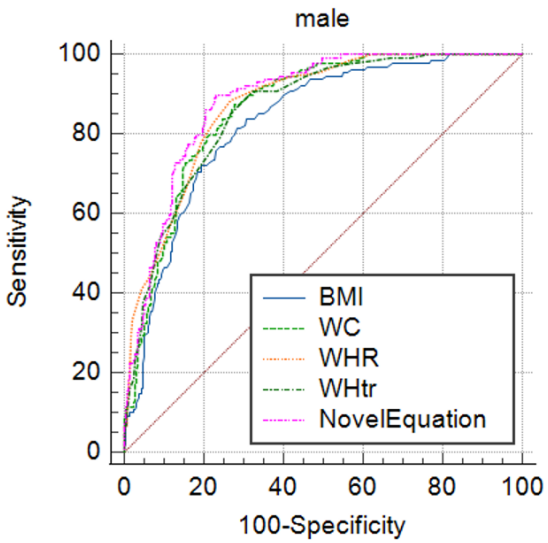



**Figure 2.** Predictive abilities of anthropometric equations for increased visceral adipose tissue in males
(BMI: Body mass index, WC: Waist circumference, WHR: Waist-to-hip ratio, WHtR: Waist-to-height tatio)

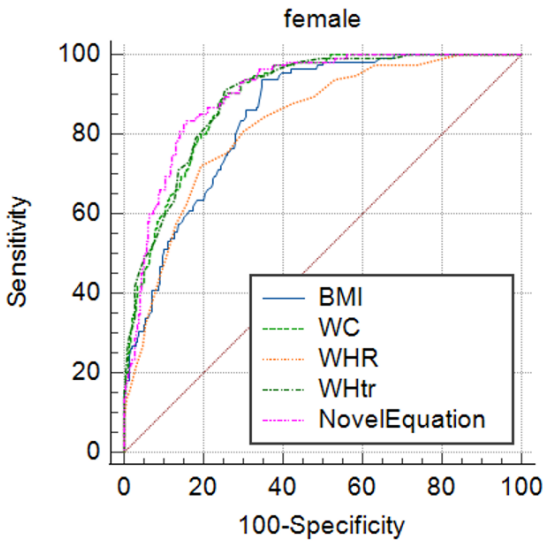



**Figure 3.** Predictive abilities of anthropometric equations for increased visceral adipose tissue in females
(BMI: Body mass index, WC: Waist circumference, WHR: Waist-to-hip ratio, WHtR: Waist-to-height tatio)

index was significantly superior to WHR (23). Similarly, Gadekar et al. demonstrated in a cross-sectional study of young, healthy adults with an average BMI of 24 that WHR had a strong correlation with VAT in both sexes, albeit slightly stronger in men (24). Taken together, these findings suggest that while WHR may be useful for identifying increased VAT in normal-weight and overweight men, its role in visceral obesity screening in the general population may be misleading.

Despite WHR's utility in assessing fat distribution, its inability to account for VAT magnitude presents a significant limitation (25). To address this, we developed $W^2HR$, an equation not previously described in the literature. This concept stems from the idea that individuals with the same WHR may have vastly different VAT levels—and, consequently, cardiometabolic risk profiles. By reintroducing waist circumference as a multiplier, $W^2HR$ aims to differentiate these individuals more effectively. In our study, $W^2HR$ demonstrated a stronger association with VAT than existing equations and better predicted increasing VAT in both genders.

This study has some limitations. First, due to the extended study period, potential measurement errors in both anthropometric and biochemical assessments may have introduced inaccuracies in our findings. Second, we did not validate our newly developed equation in patient groups with different characteristics. However, given that NHANES data provide a robust representation of diverse ethnic, demographic, and sociocultural populations, we believe that $W^2HR$ is likely to maintain a strong association with VAT across various study populations.

In conclusion, we demonstrated that $W^2HR$, a modified version of WHR designed to better capture VAT magnitude, exhibited a strong association with VAT and outperformed traditional anthropometric indices in predicting increased VAT. The simplicity and ease of application of $W^2HR$, combined with its promising predictive ability, highlight the need for further prospective and large-scale validation studies to confirm its utility in different populations.

### *Conflict-of-interest and financial disclosure*

The authors declare that they have no conflict of interest to disclose. The authors also declare that they did not receive any financial support for the study.

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