Comparison of adiposity anthropometric indices and their associations with visceral fat levels determined by bioelectrical impedance analysis among diabetic patients

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Visceral fat (VF) and its effect on metabolic disorders have been extensively studied; nevertheless, there is a need for a simple and reliable index to equally assess VF in low-resource settings. This multihospital-based study was designed to compare the five adiposity anthropometric indices and their associations with VF levels determined by bioelectrical impedance analysis as the reference standard among diabetic patients. A pretested questionnaire was used to collect anthropometric, biochemical and hemodynamic data from 473 diabetic patients. Regression analysis was performed to determine the associations between the five adiposity anthropometric indices and VF levels. Receiver operating characteristic (ROC) curves were used to confirm the predictive capacities of the five adiposity anthropometric indices with VF levels. The waist-to-height ratio WHtR showed the greatest ROC value [area under the curve (AUC) = 0.745, \( p < 0.001 \)] in identifying diabetic patients with high VF levels compared to body mass index BMI [AUC = 0.584, \( p = 0.047 \)], waist circumference WC [AUC = 0.723, \( p < 0.001 \)], hip circumference HC [AUC = 0.647, \( p < 0.001 \)] and waist-to-hip ratio WHR [AUC = 0.711, \( p < 0.001 \)]. Likewise, the regression analysis of WHtR and VF levels revealed the strongest association [unadjusted odds ratio (UOR) = 21.49, \( p < 0.001 \)] compared to BMI [UOR = 6.77, \( p = 0.008 \)], WC [UOR = 6.37, \( p < 0.001 \)], HC [UOR = 5.93, \( p = 0.002 \)] and WHR [UOR = 13.17, \( p < 0.001 \)]. The optimal cut-off values to identify diabetic patients with high VF levels were > 0.5 for WHtR, > 25.7 kg/m\(^2\) for BMI, > 80.5 cm for WC, > 95.5 cm for HC and > 0.82 for WHR. WHtR was shown to have overpowered BMI, HC, WC and WHR in identifying diabetic patients with high VF levels. Therefore, the Ghana Health Service could recommend WHtR as a better diagnostic index for assessing VF levels due to its high predictive capacity.

Abbreviations

| WHtR | Waist to height ratio |
|------|-----------------------|
| WHR  | Waist to hip ratio    |
| BMI  | Body mass index       |
| HC   | Hip circumference     |
| WC   | Waist circumference   |
| VF   | Visceral fat          |
| ROC  | Receiver operating characteristics |
| UOR  | Unadjusted odds ratio |
| AOR  | Adjusted odds ratio   |
| WHO  | World Health Organization |
| CT   | Computed tomography   |

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Henceforth, considering the burden of visceral adiposity in Ghana among diabetic patients, this multihospital-index for the assessment of adiposity in Africa with different ethnicities, especially in Sub-Saharan Africa (SSA), is useful to other populations. Therefore, it is necessary to find appropriate cut-off values of each anthropometric impedance analysis (BIA) for estimating body composition (e.g., body fat and muscle mass). Compared to CT and MRI, it is safest, less expensive, noninvasive and simple. Nevertheless, it also requires little competency to operate. In addition, BIA outputs are affected by several factors, such as ethnicity, environment, phase of the menstrual cycle, dehydration, and underlying medical conditions.

The use of computed tomography (CT) and magnetic resonance imaging (MRI) in measuring VF provides valid and reliable estimates. However, they are expensive and require professional skills and exposure to radiation. These are not favourable for global and daily use. There is another device known as bioelectrical impedance analysis (BIA) for estimating body composition (e.g., body fat and muscle mass). Compared to CT and MRI, it is safest, less expensive, noninvasive and simple. Nevertheless, it also requires little competency to operate. In addition, BIA outputs are affected by several factors, such as ethnicity, environment, phase of the menstrual cycle, dehydration, and underlying medical conditions.

Meanwhile, there should be a simple method that is less expensive and reliable to equally estimate VF levels in low-resource settings for clinical practice and epidemiological studies. Several studies, including the World Health Organization (WHO), have recommended the use of BMI, HC and WC for assessing adiposity. Another indicator, such as WHR, has also been proposed due to the effect of age, gender, and ethnic disparities on BMI and the low accuracy in identifying central obesity in some populations. Recently, a new index called WHtR has gained popularity and has been used extensively for assessing the risks of cardiometabolic diseases, adiposity and metabolic syndrome. It provides accurate information about adiposity status by considering height, gender and ethnicity disparities.

The majority of these studies that reported the cut-off values of the abovementioned anthropometric indices are largely based on data from Asian, European and American populations. These might not be accurately useful to other populations. Therefore, it is necessary to find appropriate cut-off values of each anthropometric index for the assessment of adiposity in Africa with different ethnicities, especially in Sub-Saharan Africa (SSA). Henceforth, considering the burden of visceral adiposity in Ghana among diabetic patients, this multihospital-based study was designed to compare the five adiposity anthropometric indices and their associations with VF levels determined by BIA as the reference standard to identify the best diagnostic index for assessing VF levels among diabetic patients in the Volta Region, Ghana.

Materials and methods
Study design and setting. This was a multihospital-based cross-sectional study conducted in the Volta Region, Ghana, between September 2019 and December 2019. Details of the study methodology, first and second papers, have been published. The final paper is different and unique in terms of content. It focused on a "comparison of adiposity anthropometric indices and their associations with VF levels determined by BIA among diabetic patients". The study protocol with an identification number (UHAS-REC No: A1 [16] 19–20) was approved by the Research Ethics Committee (REC) of the University of Health and Allied Sciences (UHAS), Ho, Volta Region, Ghana.

Study population and subject selection. Diabetic patients who visited the designated hospitals during their appointments were recruited through a systematic sampling technique. Patients who were medically stable and willing to participate in the study were interviewed face-to-face. Sick patients who were unable to talk, those who disagreed to participate and gestational diabetic patients were excluded from the study. A total of 473 diabetic patients were enrolled and were determined based on the study population (N = 1256) using Yamane’s formula; n = N/1 + N(e^2) where n = sample size, N = population size, e = margin of error (5%), plus 10% nonresponse.

Anthropometric, biochemical, hemodynamic and BIA measurements. The physical assessments of diabetic patients included height, body weight, WC, HC, fasting blood sugar (FBS), systolic blood pressure (SBP) and diastolic blood pressure (DBP). Weight was measured in a patient lightly dressed without shoes to the nearest 0.1 kg using a portable digital scale. Height was measured to the nearest 0.1 cm according to a standard method using a tape measure attached firmly to the wall. WC was measured at the umbilical position during the exhalation state while standing with a light dress and recorded to the nearest 0.1 cm. The HC was measured around the widest circumference of the buttock and recorded to the nearest 0.1 cm. The FBS, SBP and DBP data were retrieved from the patients’ folders. BMI was calculated as weight (kg) divided by squared height (m^2). WHR and WHtR were calculated by dividing WC (cm) by HC (cm) and height (cm), respectively. The BIA (Omron BF-511; Omron Healthcare Co., Ltd., Kyoto, Japan) was used to calculate the impedance of the body of each diabetic patient by imputing the age, gender and height. The BIA estimates the body composition by allow-
ing a small painless low-level electrical current through different kinds of body tissue\(^a\). The procedures were as follows: each patient was asked to step barefoot onto the BIA while on the ground and hold the display unit, which was the BIA handlers with both hands. While standing vertically, the patient was asked to extend the arms parallel to the floor at the same level as the shoulder. The BIA generated the VF value for each diabetic patient, which was used as the reference standard in the study.

**Anthropometrics and VF classifications.** The BMI values were categorized according to the WHO classification: <18.5 kg/m\(^2\) (underweight), 18.5 to 24.9 kg/m\(^2\) (normal weight), 25 to 29.9 kg/m\(^2\) (overweight) and \(\geq 30\) kg/m\(^2\) (obese)\(^b\). The values of WC, HC, WHR, and WHR were classified into four quartiles (1st quartile = Q1, 2nd quartile = Q2, 3rd quartile = Q3 and 4th quartile = Q4) for regression analysis used by previous studies\(^c,d\). For WC, Q1 (<76 cm), Q2 (76–84 cm), Q3 (85–94 cm) and Q4 (\(\geq 95\) cm). For HC, Q1 (<92 cm), Q2 (92–99 cm), Q3 (100–108 cm) and Q4 (\(\geq 109\) cm). For WHR, Q1 (<0.79), Q2 (0.79–0.85), Q3 (0.86–0.90) and Q4 (\(\geq 0.91\)). For WHR, Q1 (<0.47), Q2 (0.47–0.52), Q3 (0.53–0.57) and Q4 (\(\geq 0.58\)). The VF values generated by the BIA were classified according to Omron BF-511; Omron Healthcare Co., Ltd., Kyoto, Japan manual as follows: (1–9) was “Normal” and (10–30) was “Very High” regardless of gender. However, in this study, VF values were reclassified into two categories: (1–9) was considered “Normal” and (10–30) was considered “High” and used as the reference standard.

**Data collection and quality assurance.** The data collection and measurements were performed by trained research assistants after validating and pretesting the structured questionnaire\(^e\). Data were collected systematically by dividing the study population (1256) with the estimated sample size (334) to obtain the fraction \(x = N/n = 1256/334 = 3.76\). The administration of the questionnaire and measurements commenced from the 1st diabetic patient to the 5th until the last patient was served\(^f\).

**Data analysis.** Analysis was performed by SPSS version 25.00. Categorical data were equated using Fisher’s exact test or the Chi-squared test. Student’s t-test for the comparison of continuous data. Three models were adapted for the regression analysis used in previous studies\(^c,d\). Model 1\(^g\) was unadjusted. Model 2\(^h\) was adjusted for SBP and DBP. Model 3\(^i\) was adjusted for gender, age, weight, height and FBS\(^j\). Regression analysis was performed to determine the associations between the five adiposity anthropometric indices and VF levels. The regression analysis focused only on the odds ratio (OR) for BMI (normal versus obese) and WC, HC, WHR and WHR (1st quartile versus 4th quartile)\(^j\). ROC curves were used to confirm the predictive capacities of the five adiposity anthropometric indices with VF levels\(^k\). Youden’s index was calculated to determine the optimum cut-off points of the five adiposity anthropometric indices\(^l\). A \(p\) value < 0.05 was considered significant in all analyses.

**Ethics approval and consent to participate.** Ethical clearance was obtained from the Research Ethics Committee (REC) of the University of Health and Allied Sciences (UHAS), Ho, with ethical approval number (UHAS-REC No: A.1[16]19–20). Additionally, approval was obtained from the health facilities administration. For this study, informed consent was obtained from all subjects and/or their legal guardian(s) before the aims of the study were explained to them in the languages they understood. All methods were carried out following relevant guidelines and regulations. Privacy and confidentiality were confirmed by filling out the questionnaire singly and without special credentials.

**Results**

**Baseline characteristics of diabetic patients stratified by visceral fat levels.** The prevalence of high VF levels was 88.8% (\(n = 420\)), determined by BIA as the reference standard among 473 diabetic patients (\(p = 0.485\)). The total average age was 50.8 ± 0.7 years. No significant differences were found between the VF levels for age, weight, height and FBS (\(p > 0.05\)). Other anthropometric and hemodynamic parameters were statistically significant (\(p < 0.05\)). The means for BMI, WC, HC, WHR and WHR into quartiles, when compared to the 1st quartile, greater proportions of diabetic patients with high VF levels were found in the 4th quartile: WC (19.5 vs. 30.0%), HC (23.1 vs. 27.4%), WHR (19.5 vs. 32.1%) and WHR (17.9 vs. 29.5%) (see Table 1).

**Regression analysis showing the associations of BMI, WC, HC, WHR and WHR with VF levels in diabetic patients.** The study showed that BMI, WC, HC, WHR and WHR were significantly associated with VF levels. In Model 1\(^g\), diabetic patients classified as obese were more likely to possess high VF levels compared to normal BMI [(UOR) = 6.77, (95% CI 1.65–27.79), \(p = 0.008\)], those in the 4th quartile compared to the 1st quartile were more likely to possess high VF levels, WC [(UOR) = 6.37, (95% CI 2.66–15.21), \(p < 0.001\)], HC [(UOR) = 5.93, (95% CI 1.96–17.93), \(p = 0.002\)], WHR [(UOR) = 13.17, (95% CI 3.85–45.11), \(p < 0.001\)], and WHR [(UOR) = 21.49, (95% CI 4.96–93.16), \(p < 0.001\)]. In Model 2\(^h\), obese diabetic patients were more likely to possess high VF levels than those with normal BMI adjusted odds ratio (AOR) = 5.16, (95%, CI 1.22–21.87), \(p = 0.026\), and diabetic patients in the 4th quartile were more likely to possess high VF levels than those in the 1st quartile, WC [AOR = 5.24, (95%, CI 4.08–13.23), \(p < 0.001\)], HC [AOR = 4.85, (95% CI 1.57–15.00), \(p = 0.006\)], WHR [AOR = 11.23, (95% CI 3.23–38.99), \(p < 0.001\)] and WHR [AOR = 18.68, (95% CI 4.07–85.73), \(p < 0.001\)]. In Model 3\(^i\), this study showed that WHR has the greatest predictive capacity in identifying diabetic patients.
with high VF levels [Q4 vs. Q1, (AOR) = 51.15, (95% Cl 9.22–283.82) p < 0.001] followed by BMI [AOR = 43.31, (95% Cl 1.91–981.73), p = 0.018], WC [AOR = 20.41, (95% Cl 5.66–73.64), p < 0.001], WHR [AOR = 12.45, (95% Cl 3.59–43.24), p < 0.001) and HC [AOR = 11.94, (95% Cl 2.84–50.22), p = 0.001] (see Table 2).

The ROC curves showed that WHtR might be a better anthropometric index for identifying diabetic patients with high VF levels than other anthropometric indices. The areas under the ROC curves were as follows: WHtR (AUC = 0.75, 95% CI 0.68–0.81), BMI (AUC = 0.58, 95% CI 0.51–0.66), WC (AUC = 0.72, 95% CI 0.65–0.79), HC (AUC = 0.65, 95% CI 0.57–0.72) and WHR (AUC = 0.71, 95% CI 0.64–0.78) (see Fig. 1 and Table 3). The optimum cut-off values of > 25.7 kg/m² for BMI (sensitivity, 60.2%; specificity, 49.1%), > 80.5 cm for WC (sensitivity, 72.4%; specificity, 39.6%), > 95.5 cm for HC (sensitivity, 67.6%; specificity, 43.4%), > 0.82 for WHR (sensitivity, 72.6%; specificity, 35.8%) and > 0.5 for WHtR (sensitivity, 67.6%; specificity, 32.1%) were determined by ROC curves to identify diabetic patients with high VF levels. The highest sensitivity (72.6%) for VF levels was shown by WHR, while the sensitivity of BMI (60.2%) was the lowest. Furthermore, the highest and lowest specificities were shown for BMI (49.1%) and WHtR (32.1%) (see Table 3).

Table 1. Baseline characteristics of diabetic patients stratified by visceral fat levels. Data are presented as frequencies with percentages in parentheses and means ± standard errors of the means. Where appropriate, categorical data were compared using Fisher’s exact test or the Chi-squared test, and continuous data were compared using Student’s t-test.

| Parameter | Total | Normal | High | p-value |
|-----------|-------|--------|------|---------|
| Gender (F) | 349 (73.8) | 37 (69.8) | 312 (74.3) | 0.485 |
| Age (years) | 50.80 ± 0.68 | 53.15 ± 1.82 | 50.50 ± 0.73 | 0.180 |
| Weight (kg) | 71.58 ± 0.66 | 69.91 ± 1.91 | 71.79 ± 0.71 | 0.358 |
| Height (m) | 1.63 ± 0.00 | 1.66 ± 0.01 | 1.63 ± 0.00 | 0.105 |
| BMI (kg/m²) | 26.82 ± 0.24 | 25.55 ± 0.64 | 26.98 ± 0.25 | 0.042 |
| BMI classification | | | | 0.038 |
| Underweight | 22 (4.7) | 5 (9.4) | 17 (4.0) | |
| Normal | 119 (25.2) | 16 (30.2) | 103 (24.5) | |
| Overweight | 236 (49.9) | 28 (52.8) | 208 (49.5) | |
| Obese | 96 (20.3) | 4 (7.5) | 92 (21.9) | |
| WC (cm) | 86.12 ± 0.63 | 77.32 ± 1.47 | 87.23 ± 0.67 | < 0.001 |
| WC according to quartile | | | | < 0.001 |
| 1st quartile | 111 (23.5) | 29 (54.7) | 82 (19.5) | |
| 2nd quartile | 117 (24.7) | 13 (24.5) | 104 (24.8) | |
| 3rd quartile | 112 (23.7) | 4 (7.5) | 108 (25.7) | |
| 4th quartile | 133 (28.1) | 7 (13.2) | 126 (30.0) | |
| HC (cm) | 101.02 ± 0.66 | 95.94 ± 1.43 | 101.66 ± 0.72 | 0.001 |
| HC according to quartile | | | | 0.007 |
| 1st quartile | 117 (24.7) | 20 (37.7) | 97 (23.1) | |
| 2nd quartile | 119 (25.2) | 16 (30.2) | 103 (24.5) | |
| 3rd quartile | 118 (24.9) | 13 (24.5) | 105 (25.0) | |
| 4th quartile | 119 (25.2) | 4 (7.5) | 115 (27.4) | |
| WHR | 0.85 ± 0.00 | 0.81 ± 0.01 | 0.86 ± 0.00 | < 0.001 |
| WHR according to quartile | | | | < 0.001 |
| 1st quartile | 106 (22.4) | 24 (45.3) | 82 (19.5) | |
| 2nd quartile | 130 (27.5) | 16 (30.2) | 114 (27.1) | |
| 3rd quartile | 99 (20.9) | 10 (18.9) | 89 (21.2) | |
| 4th quartile | 138 (29.2) | 3 (5.7) | 135 (32.1) | |
| WHtR | 0.53 ± 0.00 | 0.47 ± 0.01 | 0.54 ± 0.00 | < 0.001 |
| WHtR according to quartile | | | | < 0.001 |
| 1st quartile | 101 (21.4) | 26 (49.1) | 75 (17.9) | |
| 2nd quartile | 135 (28.5) | 15 (28.3) | 120 (28.6) | |
| 3rd quartile | 111 (23.5) | 10 (18.9) | 101 (24.0) | |
| 4th quartile | 126 (26.6) | 2 (3.8) | 124 (29.5) | |
| FBS (mmol/L) | 9.95 ± 0.24 | 8.99 ± 0.65 | 10.07 ± 0.25 | 0.125 |
| SBP (mmHg) | 120.66 ± 0.93 | 114.15 ± 1.71 | 121.48 ± 1.02 | < 0.001 |
| DBP (mmHg) | 76.69 ± 0.48 | 72.83 ± 1.08 | 77.18 ± 0.52 | < 0.001 |

ROC curve analysis for comparison of BMI, WC, HC, WHR and WHtR in determining VF levels in diabetic patients. The ROC curves showed that WHtR might be a better anthropometric index for identifying diabetic patients with high VF levels than other anthropometric indices. The areas under the ROC curves were as follows: WHR (AUC = 0.75, 95% CI 0.68–0.81), BMI (AUC = 0.58, 95% CI 0.51–0.66), WC (AUC = 0.72, 95% CI 0.65–0.79), HC (AUC = 0.65, 95% CI 0.57–0.72) and WHR (AUC = 0.71, 95% CI 0.64–0.78) (see Fig. 1 and Table 3). The optimum cut-off values of > 25.7 kg/m² for BMI (sensitivity, 60.2%; specificity, 49.1%), > 80.5 cm for WC (sensitivity, 72.4%; specificity, 39.6%), > 95.5 cm for HC (sensitivity, 67.6%; specificity, 43.4%), > 0.82 for WHR (sensitivity, 72.6%; specificity, 35.8%) and > 0.5 for WHtR (sensitivity, 67.6%; specificity, 32.1%) were determined by ROC curves to identify diabetic patients with high VF levels. The highest sensitivity (72.6%) for VF levels was shown by WHR, while the sensitivity of BMI (60.2%) was the lowest. Furthermore, the highest and lowest specificities were shown for BMI (49.1%) and WHtR (32.1%) (see Table 3).
Table 2. Regression analysis showing the associations of BMI, WC, HC, WHR and WHtR with VF levels in diabetic patients. † Unadjusted. ‡ Adjusted for SBP and DBP. § Adjusted for gender, age, weight, height and FPS. 1: reference.

| Parameter and model | Adiposity anthropometric indices classifications | p value |
|---------------------|-----------------------------------------------|---------|
| **BMI**             | Underweight                                |   1.89 (0.61–5.85) |   0.008 |
|                     | Normal                                      |   2.19 (0.75–6.39) |         |
|                     | Overweight                                  |   6.77 (1.65–27.79) |
| **WC**              | 1st quartile                                |   2.83 (1.38–5.79) | < 0.001 |
|                     | 2nd quartile                                |   9.55 (3.23–28.23) |
|                     | 3rd quartile                                |   6.37 (2.66–15.21) |
|                     | 4th quartile                                | < 0.001 |
| **HC**              | 1st quartile                                |   1.33 (0.65–2.71) |   0.002 |
|                     | 2nd quartile                                |   2.83 (1.38–5.79) |         |
|                     | 3rd quartile                                |   9.55 (3.23–28.23) |
|                     | 4th quartile                                |   6.37 (2.66–15.21) |
| **WHR**             | 1st quartile                                |   2.09 (1.04–4.17) | < 0.001 |
|                     | 2nd quartile                                |   2.61 (1.18–5.78) |         |
|                     | 3rd quartile                                |   13.17 (3.85–45.11) |
|                     | 4th quartile                                | < 0.001 |
| **WHtR**            | 1st quartile                                |   2.23 (1.10–4.54) | < 0.001 |
|                     | 2nd quartile                                |   2.84 (1.23–6.55) |         |
|                     | 3rd quartile                                |   12.45 (3.59–43.24) |
|                     | 4th quartile                                | < 0.001 |

Figure 1. ROC curve analysis for comparison of BMI, WC, HC, WHR and WHtR in determining VF levels in diabetic patients.
and the healthy Iranian population, respectively. Dou et al.29 reported that WHtR had the maximum ROC values (AUC = 0.67 and AUC = 0.68, respectively) in predicting these anthropometric indices might be valuable for assessing VF levels. However, the regression analysis of the present study showed that WHtR [UOR = 21.49, \( p < 0.001 \)] might be a better anthropometric index for identifying diabetic patients with high VF levels than BMI [UOR = 6.77, \( p = 0.008 \)], WC [UOR = 6.37, \( p < 0.001 \)], HC [UOR = 5.93, \( p = 0.002 \)] and WHR [UOR = 13.17, \( p < 0.001 \)] (see Table 2).

Likewise, the ROC curves of the anthropometric indices confirmed that WHtR showed the greatest predictive capacity [AUC = 0.745, \( p < 0.001 \)] compared to BMI [AUC = 0.584, \( p = 0.047 \)], WC [AUC = 0.723, \( p < 0.001 \)], HC [AUC = 0.647, \( p = 0.001 \)] and [AUC = 0.711, \( p < 0.001 \)] in identifying diabetic patients with high VF levels (see Table 3 and Fig. 1). The findings are innovative and added to the literature. For the first time, this study revealed the accuracy of using WHtR in identifying diabetic patients with high VF levels. It is, however, inconsistent with a study performed in Ghana by Eghan et al.2, who reported that both WC and HC had the largest ROC value [AUC = 0.79] in estimating VF among type II diabetic patients (T2DM) compared to BMI [AUC = 0.67], WHR [AUC = 0.53] and triceps skinfold thickness [AUC = 0.58]. The discrepancy could be the study setting and methodology.

There are inadequate studies performed for direct comparisons; however, many studies3,4,10,20,21,28–28, including two meta-analyses7,18 conducted globally in different study populations and ethnicities, have reported WHtR as the best anthropometric index. Those studies have focused on determining the accuracy of using anthropometric indices to predict adiposity, cardiometabolic risk factors and metabolic syndrome. Studies have reported an association between high VF and the risk of diabetes complications, cardiometabolic diseases, and metabolic abnormalities in diabetic patients6–10; hence, assessing an individual’s body composition using appropriate indices is significant.

Despite gender differences associated with diabetes incidence, some studies have proposed that BMI2,4,10–12, WC3,11, HC1 and WHR2,10,20 might be useful indices to predict adiposity, cardiovascular risk factors and metabolic syndrome. Studies have reported an association between high VF and the risk of diabetes complications, cardiometabolic diseases, and metabolic abnormalities in diabetic patients6–10; hence, assessing an individual’s body composition using appropriate indices is significant.

Discussion

The likely reasons are as follows: first, individuals with shorter heights have remarkably greater quantities of body fat compared to taller heights with the same BMI13,14. Second, individuals with similar WCs but different heights do not have the same quantities of body fat14. Third, being short in stature was associated with a higher accumulation of VF compared to being tall14. Additionally, studies have reported WC as a cardiometabolic risk factor compared to weight14. Finally, height alone predicts hypertension and diabetes, and the percentage of body fat associated with WC is an independent risk factor for cardiovascular disease4.

Although BMI also includes height measurement in the calculation, it is unable to differentiate between body fat and lean mass3–4 compared to WHtR, which is more reflective of body fat, particularly VF3–4. Studies have shown that BMI independently contributes to the prediction of VF12,32; which coincided with the present study. Therefore, BMI might be a possible index in identifying diabetic patients with high VF levels; however, the association of BMI and VF [UOR = 6.77, \( p = 0.008 \)] and the precision [AUC = 0.584, \( p = 0.047 \)] in identifying
diabetic patients with high VF levels at cut-off > 25.7 kg/m² were lower compared to WHtR (see Table 2, Table 3 and Fig. 1). The WHO has proposed that the BMI cut-offs at which substantial cardiometabolic risk is established vary depending on the country. A prior study suggested that different BMI cut-off points must be reviewed and reintroduced among ethnic populations for better sensitivity and specificity.

Many studies have emphasized that WC might be a better index for cardiometabolic risk factors. Other studies have reported an inverse association between height and cardiometabolic risk factors leading to morbidity and mortality. The association of WC with VF [UOR = 6.37, \( p < 0.001 \)] and the accuracy [AUC = 0.723, \( p < 0.001 \)] in identifying diabetic patients with high VF levels at cut-offs > 80.5 cm were lower than those of WHtR (see Tables 2, 3 and Fig. 1). Therefore, WC might be a possible index in identifying diabetic patients with high VF; however, it ignores the effect of height; hence, it might underestimate and overestimate the levels of VF in shorter and taller people. Furthermore, Hernández-Vásquez et al. reported that height is very important in some populations, especially Peruvian, who have shorter heights worldwide. In Peruvian adults, WHtR has been shown to have the strongest association with hypertension in both genders.

Eghan et al. reported HC to be a potential predictor of VF estimates in diabetic patients, which is consistent with the present study. However, there were low to moderate associations between HC and VF levels compared to WHtR (see Table 2). The association of HC and VF [UOR = 5.93, \( p = 0.002 \)] and the relative ability [AUC = 0.647, \( p < 0.001 \)] to correctly identify diabetic patients with high VF levels at cut-off > 95.5 cm was good; however, that of WHtR was better (see Table 2, Table 3 and Fig. 1). WHR incorporates the height of the individual in the calculation, hence increasing the accuracy of the estimation of risks. Additionally, Moosaei et al. reported WHR as a more accurate tool for predicting hypertension in patients with T2DM.

Other studies have acknowledged WHR association with VF estimates and diabetes; however, Eghan et al. have called for further study to appraise the efficacy of WHR. At a cut-off > 0.82 cm, WHR produced a relatively high sensitivity (72.6%) and a weak specificity (35.8%), with [AUC = 0.711, \( p = 0.001 \)] (see Table 3 and Fig. 1). This implies that diabetic patients with higher WHR than normal are likely to have more accumulation of VF, which is risky for their health. Based on the present study, WHR might be a possible index in identifying diabetic patients with high VF; however, the greater AUC for WHtR compared to WHR and its usefulness in diverse ethnicities recommend it as a better index for predicting adiposity.

WHtR showed higher efficacy than the other four anthropometric indices in identifying diabetic patients with high VF levels. First, it overpowered most of the limitations of BMI, WC, HC and WHR when adjusted (see Table 2). Second, WHtR has been recommended in several studies and provides a global cut-off value that is equally useful to both genders, ethnicities and different ages against other variables of abdominal adiposity. WHtR shown to be a simple and reliable index to predict metabolic syndrome, cardiometabolic risk factors and adiposity at a cut-off > 0.5, which is the best index for identifying diabetic patients with high VF levels reported in the present study. These benefits have been brief in the following public health motto: "keep your waist circumference to less than half of your height". Finally, the advantages WHtR has over the four anthropometric indices are easiest to memorize for counselling patients, although it has no standard classification yet.

Strengths and limitations. The strengths of this study exist in the study population, and it provides information for further study. Second, the measurements of the anthropometric variables were carried out by trained research assistants through dual assessments per a standard protocol to reduce recall and social desirability bias. Nonetheless, this study has some limitations. First, the diabetic patients were enrolled from one region out of sixteen regions in Ghana and limited to the selected hospitals; therefore, care should be taken when generalizing the findings. Second, information on diet, physical activity and lifestyle were not included in the analysis due to their scarcity; hence, adjusting for these covariates might affect the results of the regression analysis. Third, some of the biochemical and hemodynamic data were not available and recorded for all patients due to their appointment times. Furthermore, the five adiposity anthropometric indices were not analysed, presented and discussed according to gender using different cut-off values due to the insignificance of the analysed data according to gender. Finally, the use of BIA as the reference standard in this study was not classified according to gender; therefore, care should be taken when deducing and generalizing the findings to the population.

Conclusion

In the absence of BIA in low-resource settings for clinical practice and epidemiological studies, WHtR was shown to have overpowered BMI, HC, WC and WHR in identifying diabetic patients with high VF levels. Therefore, the Ghana Health Service could recommend WHtR as a better diagnostic index for assessing VF levels due to its high predictive capacity.

Data availability

The data used to support the findings of this study are available from the author upon request.

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Author contributions
L.S.T. conceptualized and designed the study. L.S.T. coordinated and participated in the data collection. L.S.T. drafted and wrote the manuscript. The author reviewed the manuscript for intellectual content and approved the final manuscript.

Competing interests
The author declares no competing interests.

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