ESTIMATION OF VISCERAL ADIPOSE TISSUE (VAT) FROM ANTHROPOMETRY MEASUREMENTS IN SLOVAK WOMEN AND ITS RELATIONSHIP TO CARDIOMETABOLIC RISK

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Objective *The aim of the study was to evaluate the estimation of visceral adipose tissue (VAT) using anthropometric measurements and to examine its association with cardiometabolic risk in young Slovak women.*
Materials and Methods *This cross-sectional study included 100 women aged 18 - 25 years. Standardised anthropometric measurements were performed, including body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR), waist-to-height ratio (WHtR), and proximal thigh circumference (PTC). VAT was estimated using a validated anthropometric prediction equation. Statistical analysis included non-parametric tests, Spearman's correlation, multiple linear regression, and receiver operating characteristic (ROC) curve analysis using a VAT cut-off value of ≥100 cm².*
Results *The mean predicted VAT value was 65.94 ± 27.57 cm². VAT showed strong positive correlations with WC (rho = 0.790; p < 0.001) and WHtR (rho = 0.769; p < 0.001). Multiple regression analysis identified WHtR as the strongest determinant of estimated VAT. ROC analysis demonstrated the highest diagnostic precision for WHtR (AUC = 0.989) and WC (AUC = 0.980) in identifying increased visceral adiposity.*
Conclusion *WHtR and WC represent simple, non-invasive, and clinically applicable measures for early identification of individuals at increased risk of atherosclerosis and cardiometabolic diseases.*

Key words: visceral adipose tissue, anthropometry, cardiometabolic risk, atherosclerosis

Introduction

Obesity represents a major global public health problem and is strongly associated with an increased risk of cardiometabolic diseases. However, evidence indicates that fat distribution, rather than total body fat alone, is a key determinant of metabolic complications. Visceral adipose tissue (VAT), located within the abdominal cavity, plays a central role in metabolic disturbances due to its high metabolic activity and secretion of pro-inflammatory adipokines [6, 10, 17, 25]. Excess visceral fat significantly contributes to the development of atherosclerosis, which is the underlying cause of most cardiovascular diseases, including coronary artery disease and stroke. Excess visceral fat contributes to endothelial dysfunction, chronic low-grade inflammation, oxidative stress, and disorders of lipid metabolism, which are key mechanisms involved in the initiation and progression of atherosclerotic plaque formation [3, 11]. VAT is strongly associated with the main risk factors for atherosclerosis such as elevated low-density lipoprotein cholesterol, reduced high-density lipoprotein cholesterol, hypertension, insulin resistance, and metabolic syndrome [1, 14]. These risk factors accelerate arterial wall damage and promote atherogenesis even in young and apparently healthy individuals [11, 23]. Therefore, early identification of visceral adiposity using simple and accessible methods is essential for the prevention of atherosclerosis and its clinical consequences [3, 5].

Although imaging methods such as computed tomography and magnetic resonance imaging are considered gold standards for VAT quantification, their clinical use is limited by cost, accessibility, and technical demands [2, 16]. Consequently, anthropometric indicators have been widely investigated as practical alternatives. Waist circumference and sagittal abdominal diameter are among the strongest individual predictors of VAT and associated metabolic abnormalities, outperforming traditional indices such as waist-to-hip ratio [8, 15, 17]. In addition, multivariate anthropometric models that incorporate variables such as age, body weight, and regional circumference provide improved prediction of metabolic disturbances compared to body mass index alone [2, 13]. The assessment of visceral adiposity is particularly important in women, as fat distribution is influenced by hormonal status and changes throughout life. For example, menopause is associated with an increased accumulation of visceral fat and an elevated cardiometabolic risk independent of body weight [12, 20]. Although sex-specific indices and composite markers such as the Visceral Adiposity Index and the cardiometabolic index improve risk identification, their predictive precision varies between populations [4, 10]. Despite growing international evidence, data from Central and Eastern European populations, including Slovakia, remain limited. Previous Slovak studies have shown that anthropometric indicators can detect cardiometabolic risk more effectively than BMI alone and that the waist-to-height ratio can identify at-risk individuals even within normal BMI ranges [1, 6]. However, population-specific prediction models and representative data are still lacking. Given the known ethnic and regional differences in fat distribution, locally validated anthropometric tools are needed to improve VAT estimation and cardiometabolic risk assessment in Slovak women [2, 16]. The aim of this study is to evaluate the estimation of VAT using anthropometric measurements and to examine its relationship with cardiometabolic risk, with a particular focus on Slovak women.

Materials and methods

Study population

This cross-sectional study included 100 Slovak women between the ages of 18 and 25 years. Participants were recruited from university students and the general population.

Inclusion criteria were:

- female sex
- between 18 and 25 years of age
- apparently in a healthy state

Exclusion criteria included:

- pregnancy
- diagnosed cardiovascular disease
- diabetes mellitus
- chronic metabolic disorders
- endocrine disorders affecting body composition

All participants provided their informed consent prior to inclusion in the study. The study was approved by the Prešov University Ethical Committee (Approval ID: ECUP092023PO, dated 12/09/2022).

Anthropometric measurements

Anthropometric measurements were made according to standardised procedures. Body height was measured to the nearest 0.1 cm using a wall-mounted stadiometer, with the participants standing barefoot. Body weight was measured to the nearest 0.1 kg using a calibrated digital scale, with the participants wearing light clothing.

Body mass index (BMI) was calculated using the standard formula:

$$BMI = \text{body weight (kg)} / \text{body height (m}^2\text{)}$$

Waist circumference (WC) was measured at the midpoint between the lowest rib and the iliac crest at the end of normal expiration. Hip circumference (HC) was measured at the level of the highest gluteal protuberance. The circumference of the proximal thigh (PTC) was measured just below the gluteal fold of the right leg. All circumferences were measured using a non-elastic anthropometric tape to the nearest 0.1 cm. All measurements were performed by the same trained investigator to minimise inter-observer variability.

Waist-to-hip ratio (WHR) was calculated as:

$$WHR = WC / HC$$

Waist-to-height ratio (WHtR) was calculated as:

$$WHtR = WC / \text{height}$$

VAT estimation

VAT was estimated using a validated anthropometric prediction equation developed by Samouda et al. [18]:

$$VAT\ (\text{cm}^2) = 2.15 \times WC - 3.63 \times PTC + 1.46 \times Age + 6.22 \times BMI - 92.713$$

Based on available clinical evidence, VAT quantification is widely applied for the identification of cardiometabolic risk. A VAT area of 100 cm² is commonly considered a threshold for elevated visceral obesity -related risk, while values ≥130 cm² are associated with a substantially higher probability of cardiometabolic abnormalities. The applied predictive equation has been demonstrated to provide a valid estimate of VAT compared to computed tomography measurements [19]. Subsequently, participants were stratified into visceral adiposity risk categories according to their calculated VAT values.

Importantly, the present study should be interpreted as a pilot investigation in a specific population of young Slovak women, which may limit generalisability.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics software (Version 22, IBM Corp., Armonk, NY, USA). Data normality was assessed using the Shapiro–Wilk test. As most variables were not normally distributed, non-parametric statistical methods were applied. Differences between groups were analysed using: Mann–Whitney U test and Kruskal–Wallis test. The correlations between VAT and anthropometric parameters (BMI, WC, WHR, WHtR) were assessed using Spearman's rank correlation coefficient rho. Multiple linear regression analysis was performed to identify determinants of the estimated VAT. For the analysis of the ROC curve, visceral adiposity using a threshold of ≥ 100 cm² was dichotomised into normal and increased/high risk. Statistical significance was defined as $p < 0.05$.

Results

The basic anthropometric and body composition characteristics of the study population are presented in Table 1. The mean age of participants was 22.07 ± 2.26 years. The mean body weight was 69.99 ± 12.02 kg and the mean body height was 166.83 ± 5.86 cm. The average body mass index indicated a borderline overweight population (25.13 ± 4.03 kg/m²). The mean waist circumference was 78.81 ± 8.57 cm, while the mean hip circumference was 99.19 ± 9.09 cm. The mean circumference of the proximal thigh was 54.90 ± 5.61 cm. The mean waist-to-hip ratio and waist-to-height ratio were 0.795 ± 0.045 and 0.473 ± 0.054, respectively. The mean predicted VAT value was 65.94 ± 27.57 cm². A wide range of VAT values was observed, indicating variability in visceral adiposity within the study population.

Table 1 Descriptive characteristics of the study population [Source: Own processing]

Variable	Mean ± SD	Min–Max
Age	22.07 ± 2.26	18 - 25
Body weight (kg)	69.99 ±12.02	51.5 - 128.9
Body height (cm)	166.83 ± 5.86	152.8 - 178.0
BMI (kg/m²)	25.13 ± 4.03	20.1 - 43.3
WC (cm)	78.81 ± 8.57	66.0 - 127.0
HC (cm)	99.19 ± 9.09	82.0 - 145.0
PTC (cm)	54.90 ± 5.61	47.0 - 80.0
WHR	0.795 ± 0.045	0.69 - 0.96
WHtR	0.473 ± 0.054	0.39 - 0.74
VAT (predicted)	65.94 ± 27.57	39.58 - 194.10

BMI = body mass index, WC = waist circumference, HC = hip circumference, PTC = proximal thigh circumferen-

ce, WHR = waist-to-hip ratio, WHtR = waist-to-height ratio, VAT = visceral adipose tissue

The distribution of the participants according to the categories of BMI, WC, WHR, WHtR, and predicted VAT is shown in Table 2. Based on BMI classification, 64 % of participants had normal body weight, 27 % were overweight, and 9 % were classified as obese. According to waist circumference, increased cardiometabolic risk was present in 24 % of participants, while 11 % were classified as having high risk. Abdominal obesity based on WHR was identified in 16 % of participants, whereas WHtR classified 24 % of participants as having abdominal obesity. Based on predicted visceral adipose tissue, 9 % of participants were classified as having increased or high visceral adiposity risk.

Table 2 Distribution of participants according to the risk categories for anthropometric and visceral adiposity [Source: Own processing]

Variable	Category	N (%)
BMI	Healthy weight	64
	Overweight	27
	Obesity	9
WC	Normal value	65
	Increased risk	24
	High risk	11
WHR	Normal value	84
	Abdominal obesity	16
WHtR	Normal value	76
	Abdominal obesity	24
VAT (predicted)	Normal value	91
	Increased risk	6
	High risk	3

BMI = body mass index, WC = waist circumference, WHR = waist-to-hip ratio, WHtR = waist-to-height ratio, VAT = visceral adipose tissue

The correlations between VAT and the anthropometric parameters are presented in Table 3. VAT showed a strong positive correlation with waist circumference (rho = 0.790, $p < 0.001$) and waist-to-height ratio (rho = 0.769, $p < 0.001$). A moderate positive correlation was observed between VAT and body mass index (rho = 0.641, $p < 0.001$), as well as waist-to-hip ratio (rho = 0.546, $p < 0.001$). Among all anthropometric parameters, waist circumference showed the strongest correlation with visceral adipose tissue, closely followed by the waist-to-height ratio.

Multiple linear regression analysis was performed to identify determinants of the estimated VAT value (Tab. 4). The general regression model was statistically significant and explained 88.2 % of the variability in ($R^2 = 0.882$, adjusted $R^2 = 0.877$, $p < 0.001$). Waist-to-height ratio was identified as the strongest independent predictor of VAT ($\beta = 0.364$, $p = 0.003$), followed by waist circumference ($\beta = 0.326$, $p = 0.012$), body mass index ($\beta = 0.202$, $p = 0.026$), and waist-to-hip ratio ($\beta = 0.145$, $p = 0.003$). All anthropometric parameters remained statistically significant predictors in the model. The regression model showed excellent predictive accuracy ($R = 0.939$, $R^2 = 0.882$).

An analysis of the receiver operating characteristic (ROC) curve was performed to evaluate the diagnostic performance of selected anthropometric indices to identify increased visceral adiposity, defined according to VAT classification criteria (Tab. 5). VAT served as the reference variable in the ROC analysis. The waist-to-height ratio demonstrated the highest diagnostic accuracy, with an area under the curve (AUC) of 0.989, indicating outstanding discriminatory ability. Waist circumference also showed excellent performance, with an AUC of 0.980. Body mass index demonstrated excellent diagnostic accuracy (AUC = 0.946), while waist-to-hip ratio showed good predictive ability (AUC = 0.816). These findings indicate that waist-to-height ratio and waist circumference are the most accurate anthropometric predictors of increased visceral adiposity in Slovak women.

Table 3 Spearman correlation analysis between VAT and anthropometric indices [Source: Own processing]

Variable	VAT (rho)	p value
BMI	0.641	< 0.001
WC	**0.790**	**< 0.001**
WHR	0.546	< 0.001
WHtR	**0.769**	**< 0.001**

BMI = body mass index, WC = waist circumference, WHR = waist-to-hip ratio, WHtR = waist-to-height ratio, VAT = visceral adipose tissue

Table 4 Multiple linear regression analysis showing determinants of the estimated VAT [Source: Own processing]

Variable	B	Standardised β	p value
BMI	1.384	0.202	0.026
WC	1.048	0.326	0.012
WHR	88.935	0.145	0.003
WHtR	186.468	0.364	0.003

BMI = body mass index, WC = waist circumference, WHR = waist-to-hip ratio, WHtR = waist-to-height ratio

Table 5 ROC curve analysis of anthropometric predictors of VAT [Source: Own processing]

Variable	AUC	Diagnostic precision
BMI	0.946	Excellent
WC	0.980	Outstanding
WHR	0.816	Good
WHtR	0.989	Outstanding

BMI = body mass index, WC = waist circumference, WHR = waist-to-hip ratio, WHtR = waist-to-height ratio

Discussion

The present study evaluated VAT estimated using anthropometric measurements and its association with cardiometabolic risk in young Slovak women. The main findings indicate that VAT is strongly associated with anthropometric indicators of abdominal obesity, particularly waist circumference and waist-to-height ratio. In addition, the waist-to-height ratio demonstrated the highest predictive ability and diagnostic accuracy to identify increased visceral adiposity. These findings confirm the importance of simple anthropometric measurements as practical tools for assessing visceral fat and cardiometabolic risk. Visceral fat contributes to a pro-atherogenic environment. This includes chronic inflammation, increased production of pro-inflammatory cytokines, endothelial dysfunction, and adverse changes in the lipid profile, which promote the formation and progression of atherosclerotic plaques [3, 11, 19]. Anthropometric indicators such as waist circumference and waist-to-height ratio reflect central fat accumulation and therefore indirectly reflect the burden of atherosclerosis-related risk [1, 5]. The mean predicted value of VAT in our study was 65.94 ± 27.57 cm², with substantial inter-individual variability despite the relatively young age of the participants. This finding is consistent with previous studies showing that visceral adiposity may vary considerably even among young and apparently healthy individuals and may not always correspond directly to general obesity defined by body mass index [6, 13]. Visceral fat is considered metabolically active and plays an important role in the development of cardiometabolic disorders through its association with insulin resistance, dyslipidaemia, and cardiovascular risk factors [25].

In the present study, waist circumference showed the strongest correlation with visceral adipose tissue, closely followed by waist-to-height ratio. These findings are consistent with previous research that shows that waist circumference is one of the most reliable anthropometric indicators of VAT accumulation and cardiometabolic risk [8, 17]. Similarly, the waist-to-height ratio has been identified as a sensitive marker of visceral adiposity and an effective screening tool for detecting people with increased cardiometabolic risk [2, 5]. In contrast, the body mass index showed a weaker association with visceral adipose tissue, which confirms its limitations as an indicator of fat distribution and metabolic risk, since it does not distinguish between fat mass and lean body mass [2, 20]. The results of multiple regression analysis further confirmed that the anthropometric indicators of central obesity determinants of the estimated VAT value. Waist-to-height ratio was identified as the strongest predictor, followed by waist circumference, body mass index, and waist-to-hip ratio. These findings are consistent with previous studies showing that anthropometric prediction models that incorporate abdominal measurements provide accurate estimates of visceral adiposity and are strongly associated with cardiometabolic risk factors [2, 15]. VAT predicted with anthropometric measures has been shown to correlate well with imaging-based measurements and metabolic biomarkers, supporting its clinical applicability [13]. The ROC curve analysis demonstrated excellent diagnostic performance of waist-to-height ratio and waist circumference, confirming their usefulness as screening tools for visceral adiposity. These results are in agreement with previous studies that demonstrate that anthropometric parameters can effectively identify people with increased visceral fat and cardiometabolic risk [16, 18]. Although the waist-to-hip ratio also showed a significant predictive capacity, its diagnostic precision was lower, corresponding to previous findings suggesting that the waist-to-hip ratio is less sensitive to detect visceral adiposity compared to other anthropometric indicators [24]. Importantly, despite the young age of the study population, a proportion of participants already showed an increase in visceral adiposity and cardiometabolic risk according to anthropometric indices. This observation supports previous findings indicating that unfavourable fat distribution and cardiometabolic risk factors may be present even in young adults and individuals of normal-weight [21, 22]. Therefore, early identification of individuals at increased risk is essential for implementing preventive strategies aimed at reducing future cardiovascular and metabolic complications.

This study contributes to the limited data on the estimation of visceral adiposity in Central European populations, particularly in Slovak women. Previous studies conducted in similar populations have also confirmed the usefulness of anthropometric indicators in assessing visceral fat and cardiometabolic risk [6, 22]. From a clinical perspective, anthropometric measurements represent valuable tools not only to estimate visceral adiposity but also to identify individuals at increased risk of developing atherosclerosis. Central obesity has been consistently associated with early vascular changes, including arterial stiffness, endothelial dysfunction, and subclinical atherosclerosis [7, 9, 23]. Therefore, anthropometric parameters can serve as indirect markers of early atherosclerotic risk and can be used effectively in preventive screening, especially in young populations where clinical manifestations of atherosclerosis are not yet present [1, 23]. Early identification of at-risk individuals allows the implementation of preventive strategies aimed at reducing visceral fat and slowing the progression of atherosclerotic disease [3, 11]. Given the simplicity, low cost, and non-invasive nature of anthropometric measurements, their use in clinical practice and preventive screening may represent an effective approach for early risk identification.

The present study has several strengths, including a standardised anthropometric assessment and the use of a validated anthropometric equation to estimate visceral adipose tissue. However, several limitations should be acknowledged. First, VAT was estimated indirectly using an anthropometric prediction model rather than directly measured using imaging methods such as computed tomography or dual-energy X-ray absorptiometry, which are considered reference methods [13, 16]. Second, the cross-sectional design does not allow causal relationships to be established. Although the ROC analysis demonstrated extremely high diagnostic accuracy (AUC values approaching 0.99), these findings should be interpreted with caution. Such high values may indicate potential overfitting of the model or interdependence between variables. In particular, WHtR includes waist circumference in its calculation, which may introduce collinearity and artificially increase predictive performance.

Conclusion

This study demonstrated that anthropometric measurements are effective tools for estimating VAT and assessing cardiometabolic risk in young Slovak women. Waist-to-height ratio and waist circumference showed the strongest associations with VAT and the highest diagnostic accuracy, highlighting the importance of central obesity indicators over BMI. Despite the young and apparently healthy population, some participants already exhibited increased visceral adiposity, suggesting that cardiometabolic risk may emerge early in adulthood. Anthropometric measures are simple, non-invasive, and cost-effective tools suitable for routine clinical practice and preventive screening. They may also support early identification of individuals at risk of atherosclerosis, as visceral fat is a key modifiable factor in its development. In clinical practice, a WHtR cut-off value of ≥ 0.5 may serve as a practical screening threshold. The routine use of WHtR and waist circumference could improve early risk stratification and support preventive interventions aimed at reducing future cardiometabolic disease.

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