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Bioimpedance Body Composition Analysis in Estimating Insulin Resistance in Women with Overweight and Obesity (LUCAS 1.1): A Retrospective Analysis

ABSTRACT

Objective: Insulin resistance (IR) is a disruption in glucose homeostasis characterized by decreased tissue sensitivity to insulin. One of the main causes of IR is considered to be obesity, a significant problem in contemporary medicine. It can be diagnosed using easily measurable parameters such as body mass index (BMI), waist circumference (WC), or waist-to-hip ratio (WHR). In this study, we aimed to compare the effectiveness of conventional obesity markers with parameters obtained from bioimpedance body composition analysis in assessing the severity of insulin resistance in individuals with overweight and obesity

Materials and methods: A retrospective analysis of 702 patients, including 557 women (79%) with overweight and obesity, was conducted, focusing on metrics like BMI, WC, visceral fat rating (VFR), and indirect indicators of insulin resistance: Quantitative Insulin Sensitivity Check Index (QUICKI), Homeostatic Model Assessment of Insulin Resistance (HOMA-IR), and triglyceride to high-density lipoprotein ratio (TG/HDL ratio).

Results: Due to significant differences in body composition, men and women were analyzed separately. Because of the high number of male patients with insulin resistance, only the female group was analyzed. Both BMI and WC had a greater AUC than VFR. Analyzing the Youden graph, a cutoff point value for VFR, suggested to be 16% body fat (PBF), showed limited predictive value.

Conclusions: The VFR could serve as a valuable additional biomarker in assessing insulin resistance in female patients with obesity. (Clin Diabetol 2025; 14, 1: 5–11)

Keywords: obesity; visceral fat rating; insulin resistance; bioimpedance; body composition

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Introduction

Obesity has become an increasingly significant health problem worldwide. According to the World Health Organization (WHO), in 2016 1.9 billion adults aged 18 years and older were overweight, with 650 million of them classified as persons with obesity [1]. The statistics mentioned above clearly indicate the need to raise public awareness about obesity, its consequences, early detection, and the search for newer therapeutic methods. One method for detecting and monitoring this condition is utilization of the body mass index (BMI) indicator. Calculating this indicator requires easily measurable parameters: height in centimeters and weight in kilograms. Unfortunately, it does not take into account the distribution of body fat, which can lead to inaccurate results. Subcutaneous fat tissue, despite representing the highest percentage of mass and surface area of all fat tissue in the body, is not as metabolically active as visceral fat tissue. Excessive accumulation of visceral fat is associated with numerous cardiometabolic complications. Therefore, it is crucial to use methods in measurements that allow for differentiation between them [2, 3].

The amount of visceral fat tissue can be estimated using densitometry (DXA), computed tomography (CT), or magnetic resonance imaging (MRI). However, these methods are expensive, less accessible, or require radiation exposure, prohibiting their wide in clinical practice [4]. Due to the significant diagnostic and prognostic benefits of assessing visceral fat tissue, it is necessary to find another indicator that is easily accessible, cost-effective, and does not expose the patient to additional radiation. Promisingly, the use of the bioimpedance method appears to be suitable for this purpose [5]. This method is based on measuring the body's electrical response after introducing a low-level alternating current, allowing for the estimation of body composition [5]. Visceral obesity leads to insulin resistance (IR), characterized by decreased sensitivity of cells to insulin despite its elevated levels in the bloodstream [6]. The Lublin Comorbidity of Adiposity Study (LUCAS) is a project initiated by the Department of Endocrinology, Diabetology, and Metabolic Diseases at the Medical University of Lublin. Its aim is to determine the correlations between anthropometric parameters and various metabolic disorders as well as other consequences of obesity in a large population sample. The aim of this study, which is a part of this project, was to investigate the correlation between visceral obesity measured using bioimpedance and elevated IR indices.

Materials and methods

Study design and patients

This cross-sectional study was carried out at the Department of Endocrinology, Diabetology, and Metabolic Diseases at Independent Public Clinical Hospital No. 4 in Lublin, Poland. The study involved 702 patients with overweight or obesity, with an average age of 44.1 ± 13.8 years, including 557 women (79%). A retrospective analysis of data from medical records was conducted, with a particular focus on anthropometric data, such as age, gender, BMI, waist circumference (WC), waist to height ratio (WHtR), results of body composition analysis using the bioimpedance method (percent body fat (PBF), visceral fat rating (VFR)], and indirect indicators of insulin resistance: Quantitative Insulin Sensitivity Check Index (QUICKI), Homeostatic Model Assessment of Insulin Resistance (HOMA-IR), and triglyceride to high-density lipoprotein ratio (TG/HDL ratio). This article is a part of the LUCAS series, with the main question being asked: is the visceral fat rating better than body mass index in predicting insulin resistance in patients with overweight and obesity?

Body composition measurement

Body weight was measured with an accuracy of 0.1 kg, along with body composition, using direct electrical bioimpedance. A Tanita Corporation Body Composition Analyzer DC-430MA device was used for this purpose. The device uses 4 integrated electrodes within the platform. This method is based on the introduction of low-level alternating current into the body at 2 frequencies: 6.25 kHz and 50 kHz. As a result of this measurement, the following data can be obtained: body weight in kg ± 0.1 kg, BMI, PBF (with an accuracy of ± 0.1%), and VFR.

Indices

One of the indicators used to assess abdominal obesity is waist circumference (WC). To measure it correctly, it is recommended that a measuring tape be placed at the midpoint between the hip bone and the lower margin of the last rib. The measurement should be taken with the patient standing, after soft expiration, with both feet touching the ground and arms hanging freely. The measuring tape should be positioned perpendicular to the body's long axis, horizontally to the floor, with appropriate tension, but without exerting pressure on the abdominal wall [7].

In the study, commonly used indices were utilized, such as HOMA-IR, QUICKI, and the TG/HDL ratio. HOMA-IR is a widely used index for detecting and assessing central insulin resistance dynamics, calculated by multiplying fasting blood glucose levels (mmol/L) by fasting insulin levels (μU/mL), and then dividing the result by 22.5 [8, 9]. QUICKI is calculated using the following formula: QUICKI = $1/[\log(I) + \log(G_0)]$, where I_0 represents fasting insulin (μU/mL) and G_0 is fasting glucose (mg/dL) [9]. The triglyceride to HDL cholesterol ratio is a commonly used indicator for assessing cardiovascular risk and inflammatory status in the body. Calculating this ratio requires determining the lipid profile of the patient and calculating the TG/HDL ratio.

Table 1. Baseline Characteristics of the Patients

Variable	Female	Male	P-value
Age [years]	43.71 ± 13.63	45.52 ± 14.29	0.160647
Body weight [kg]	99.33 ± 17.75	119.38 ± 22.78	0.000000
BMI [kg/m^2]	36.66 ± 5.95	37.68 ± 6.58	0.000000
Waist circumference [cm]	109.51 ± 12.85	124.25 ± 15.22	0.000000
Visceral fat rating	10.71 ± 3.41	19.1 ± 5.27	0.000012
Percent body fat [%]	42.5 ± 5.58	36.3 ± 18.81	0.077400
Systolic blood pressure [mmHg]	132.39 ± 16.33	138.64 ± 14.41	0.002340
Diastolic blood pressure [mmHg]	86.68 ± 10.46	87.7 ± 9.34	0.434855
HOMA-IR index	3.46 ± 2.24	4.69 ± 2.82	0.000002
QUICKI index	0.33 ± 0.03	0.31 ± 0.03	0.000002
TG/HDL ratio	2.69 ± 1.65	4.54 ± 5.93	0.000000

BMI — body mass index; HOMA-IR — Homeostatic Model Assessment of Insulin Resistance; QUICKI — Quantitative Insulin Sensitivity Check Index; TG/HDL — triglyceride to high-density lipoprotein ratio

Ethics approval

This study did not require approval from the Ethics Committee because it was based solely on anonymized and non-identifiable data routinely gathered at our department.

Statistical analysis

Statistical analysis was performed using Statistica software, applying receiver operating characteristic (ROC) curve analysis to assess the diagnostic performance of different anthropometric and body composition indicators (BMI, WC, PBF, VFR) in predicting insulin resistance. For this purpose, 3 insulin resistance indices were used: HOMA-IR, QUICKI, and the TG/HDL ratio.

We utilized the Youden index and tangential method to determine the optimal cutoff points for each indicator. The area under the curve (AUC) was calculated to compare the effectiveness of these indicators in identifying insulin resistance across different patient groups (separated by gender), providing a measure of overall diagnostic accuracy. A higher AUC indicates a better discriminatory ability of the test or indicator in question. The Youden index was specifically used to identify the optimal cutoff value for visceral fat rating (VFR) in diagnosing insulin resistance. The Youden index is calculated using the following formula: J = Sensitivity (S) + Specificity (T) – 1, where sensitivity represents the ability of the test to correctly identify patients with insulin resistance (true positives), and specificity represents its ability to correctly identify patients without insulin resistance (true negatives). The Youden index ranges from 0 to 1, with values closer to 1 indicating a more effective test. The point at which the Youden index is maximized is considered the optimal cutoff, as it balances sensitivity and specificity.

In our analysis, we used the Youden index to find the most appropriate cutoff for VFR, which maximized the ability of VFR to differentiate between patients with and without insulin resistance. The index allows us to pinpoint the VFR value where the test's diagnostic performance is highest.

Results

In the analyzed group, women constituted a larger proportion (557, 79.34%) compared to men (145, 20.66%). Due to significant differences in average body composition, the groups were analyzed separately. Regarding sex, age, body weight, BMI, and WC, males exhibited a higher average body weight of 119.38 kg and WC of 124.25 cm. Females displayed lower average values in body weight (99.33 kg) and WC (109.51 cm). There were no significant differences observed in age and BMI between the genders.

Focusing on VFR and PBF, the mean VFR was significantly higher in men (19.1) compared to women (10.71), with a p-value approaching zero. Women had higher average PBF (42.50%). In terms of blood pressure, men showed elevated systolic blood pressure (mean: 138.64 mmHg), whereas women had an average systolic blood pressure of 132.39 mmHg. There were no significant differences in diastolic blood pressure.

Lastly, metabolic indicators revealed more pronounced dysfunction in men, evidenced by a higher average HOMA-IR of 4.69 and a TG/HDL ratio of 4.54. Women showed a more favorable profile, with an average HOMA-IR of 3.46 and a TG/HDL ratio of 2.69. Differences in QUICKI were also significant, indicating lower insulin sensitivity in men (mean QUICKI: 0.31) than in women (mean QUICKI: 0.33), with a p-value less than 0.00001. The results are gathered in Table 1.

Table 2. Percentage of Patients with Insulin Resistance

Variable	Female	Male
HOMA-IR > 2.5	59.01%	80.95%
QUICK-I > 0.34	70.56%	88.57%
TG/HDL > 2	58.98%	81.25%

HOMA-IR — Homeostatic Model Assessment of Insulin Resistance; QUICKI — Quantitative Insulin Sensitivity Check Index; TG/HDL — triglyceride to high-density lipoprotein ratio

Additionally, there was a higher percentage of insulin resistance in the population of males regarding all 3 insulin sensitivity indices, as shown in Table 2 (the difference between sexes was statistically significant, with $p < 0.001$).

Similar ROC curves were observed for BMI, WC, and VFR when using commonly accepted cutoff points for HOMA-IR (2.5), QUICKI (0.34), and TG/HDL ratio (2). Because of important statistical differences between genders regarding most of the analyzed statistics, they were calculated separately. In both genders, the highest AUC was observed regarding BMI, and WC regarding both HOMA-IR and QUICKI. The AUC for VFR was lower than both BMI and WC, and the difference was statistically significant ($p < 0.001$). The results are gathered in Table 3.

When analyzing VFR in the population, there were no males below rating 11. Additionally, because of the large percentage of male patients with insulin resistance in the studied group, only females were analyzed. The proposed cutoff value for VFR in the studied population, based on the Youden index, was 16, with a possible secondary value of 14, which had better sensitivity and reduced specificity (Fig. 1).

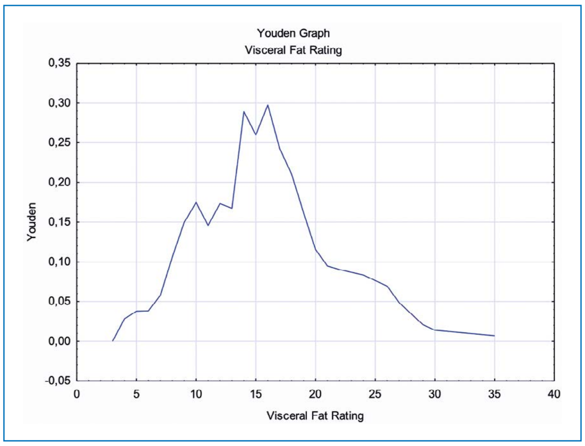

Figure 1. Youden Graph for Visceral Fat Rating (VFR) Predicting Insulin Resistance in Women

Discussion

In our study, patients with obesity underwent analysis using bioimpedance, and their results were compared with commonly used indicators in obesity diagnosis to assess the severity of IR.

In this study, we tried to determine whether the VFR is a valuable tool in predicting IR in comparison to traditional metrics like BMI and WC. Although the Youden index for VFR at a cutoff point of 16 was below 0.3, this should not immediately discount its clinical value. The VFR provides unique insights into visceral adiposity, a key factor in metabolic dysfunction and IR, which BMI and WC might not fully capture. Visceral fat is closely linked to metabolic risk, and the fact that VFR directly measures this parameter adds value, particularly in the context of obesity, where subcutaneous and visceral fat often present different metabolic risks. The relatively low Youden index suggests some limitations to the overall sensitivity and specificity of VFR for diagnosing insulin resistance compared to other measures, but this does not negate its utility. For example, VFR may offer additional value when used in conjunction with other indicators.

Table 3. AUC between Methods Detecting Obesity in Relation to Insulin Resistance Indices

	Male			Female		
	HOMA-IR	QUICK-I	TG/HDL	HOMA-IR	QUICK-I	TG/HDL
BMI	0.819	0.808	0.611	0.663	0.663	0.596
WC	0.871	0.879	0.644	0.65	0.657	0.596
VFR	0.674	0.7	0.647	0.562	0.572	0.598
PBF	0.684	0.679	0.597	0.552	0.588	0.592
Body weight	0.796	0.858	0.573	0.631	0.63	0.594

AUC — area under curve; BMI — body mass index; HOMA-IR — Homeostatic Model Assessment of Insulin Resistance; QUICKI — Quantitative Insulin Sensitivity Check Index; PBF — percentage body fat; TG/HDL — triglyceride to high-density lipoprotein ratio; VFR — visceral fat ratio; WC — waist circumference

While BMI and WC are well-established predictors of IR with higher AUC values, they do not specifically reflect visceral fat, which plays a critical role in the pathophysiology of IR and cardiovascular disease. Moreover, in clinical practice, the combination of VFR with BMI or WC could potentially enhance diagnostic accuracy, especially in patients with obesity, where the distinction between visceral and subcutaneous fat is crucial. Given that VFR was developed to assess visceral fat, its use alongside other indicators might improve the early detection of insulin resistance in certain populations, particularly those with abdominal obesity.

Using BMI as a widely accepted indicator in obesity diagnosis has many limitations. Cutoff points for this indicator do not account for differences in fat tissue distribution between genders or ethnic origins [10]. Another reason to seek alternative diagnostic methods is the inability to differentiate between total mass and muscle mass, rendering BMI unreliable, especially among athletes. It is also crucial to use a method capable of determining the amount of fat tissue in the body; however, the quantity of fat tissue alone is not a useful indicator due to numerous limitations. Samuel Klein et al. demonstrated in their study that patients undergoing liposuction, despite reducing the percentage of body fat tissue, do not experience improvements in obesity-related metabolic disorders, nor does their risk of coronary heart disease decrease, because only the amount of subcutaneous fat tissue is reduced [11].

In one cross-sectional study involving 418,343 workers in Spain, the glucose triglyceride index (TyG Index) was utilized and compared with BMI, WHtR, and WC. Statistical analysis showed that WC plays a key role in early detection of metabolic syndrome and identification of insulin resistance [12]. However, other researchers suggest that the correlation between TyG and BMI more accurately detects insulin resistance than the previously mentioned indicator [13]. WC is also significant among individuals with normal BMI because the TG concentration and WC were found to have the greatest diagnostic value in detecting insulin resistance in participants without obesity [14]. Additionally, increased TG and WC values affect the impairment of pancreatic beta cell function [14]. WC is not an ideal indicator, however, because it does not account for height — its diagnostic utility is limited among tall and short individuals [13, 15]. Considering this, a new method has been proposed based on the ratio of waist circumference to patient height, allowing for standardization and objectivity with respect to height. One of the advantages of WHtR is better prediction of dyslipidemia, hypertension, and metabolic syndrome compared to WC or BMI [16]. Additionally, both WHtR and WC show better detection of insulin resistance than newly emerged obesity indicators such as body adiposity index (BAI) or body roundness index (BRI) [17]. Jamar et al. demonstrated in their studies that among the mentioned indices, WHtR has the highest predictive value [18].

The reason we seek a better, more accurate indicator is the need to differentiate between types of adipose tissue and establish norms based on gender, age, and ethnic origin. Visceral fat tissue, besides its storage function, also acts as an active endocrine organ, producing and secreting numerous adipokines and cytokines. They play a crucial role in regulating cellular responses to insulin and controlling inflammatory processes. Disturbance in the balance of these substances in favor of resistin leads to decreased insulin sensitivity and increased production of pro-inflammatory cytokines. This association affects lipoprotein lipase (LPL), responsible for lipid metabolism, leading to their excessive accumulation. This effect manifests as atherogenic dyslipidemia, characterized by elevated levels of triglycerides and low-density lipoproteins (LDL), and decreased levels of HDL, resulting from increased free fatty acid (FFA) levels [19–21].

There is increasing discussion about metabolic-associated steatotic liver disease (MASLD) (formerly known as nonalcoholic fatty liver disease, NAFLD) associated with metabolic dysfunction and insulin resistance – a state in which the release of FFAs from adipocytes increases, making them less responsive to insulin. Excess FFA is deposited as fat in the visceral area, contributing to the development of MASLD. MASLD occurs when at least 5% of hepatocytes undergo steatosis, and one of the consequences is insulin resistance [22, 23].

Several authors have suggested a positive correlation between IR and VFR in the past. Researchers suggest that regardless of gender, individuals with insulin resistance exhibit higher parameters assessing visceral fat amount compared to those without insulin resistance, indicating a positive correlation between these two indicators [21, 24]. Similar results were also obtained in a group of patients with polycystic ovary syndrome, showing a strong correlation with the presence of visceral fat tissue and the occurrence of insulin resistance in patients [25]. Zhang et al. demonstrated a positive correlation between insulin resistance and fat tissue in various body parts in their meta-analysis, with the strongest correlation observed for visceral fat tissue [26].

The examples above illustrate how much information about health status can be provided by knowledge of visceral fat tissue quantity. Therefore, finding an indicator that enables easy, widely accessible, and non-invasive measurement of visceral fat tissue is recommended. Among the indicators considered in the study, promising results were obtained using the bioimpedance method. This method has many advantages — it is inexpensive, simple to conduct, and relatively safe, though individuals with implanted pacemakers or metal implants, pregnant women, and patients with electrolyte disturbances should not undergo the examination. It does not expose the patient to additional radiation like CT and DXA scans, or the costs associated with MRI. Despite its many advantages, bioimpedance is not without flaws. In patients with electrolyte disturbances, very high BMI, or obesity, there are limitations in using this method due to the lack of measurement repeatability. Taking into account the above reasons, bioimpedance has great potential as an indicator for detecting insulin resistance; however, standardization of this method is needed to enable comparison of results obtained in different locations and greater measurement repeatability.

The male population in our study presented a higher percentage of patients with insulin resistance compared to the female group, which is why statistical differences were notable between the genders. The differences in results between the genders can be explained by several factors. Premenopausal women tend to accumulate subcutaneous fat in the buttock and thigh areas, known as gynoid obesity. In contrast, men tend to accumulate visceral fat in the abdominal region, known as android obesity [27]. Abdominal visceral fat is strongly associated with insulin resistance, unlike subcutaneous fat [27]. Another reason is that men are diagnosed later and are less willing to undergo obesity treatment compared to women [28]. These 2 factors result in a more advanced stage of the disease among men, leading to higher mortality and a lower percentage of successfully treated patients [28].

Despite these observations, men were excluded from further analysis primarily due to the significant imbalance in sample sizes. Men made up only 21% of the cohort. This distinction limits the statistical power and reliability of conclusions drawn for the male subgroup. Furthermore, the pronounced differences in visceral fat accumulation between men and women meant that analyzing the groups together would risk confusing the results, given that visceral fat has a clear impact on insulin resistance.

Conclusions

In conclusion, our findings revealed that VFR may serve as a valuable additional biomarker in assessing insulin resistance in female patients with obesity. However, further research in this area is recommended, focusing on a larger patient group with particular emphasis on the male gender.

Limitations

We conducted a retrospective study that was susceptible to selection bias. Additionally, limitations include a relatively small sample size, comprised entirely of white patients from Poland, predominantly from the Lublin Region. Body composition analysis using bioimpedance was performed using a two-electrode analyzer, and relied on the VFR index, which currently lacks full medical validation. The insulin resistance indices are estimations because the metabolic clamp method was not employed.

Article information

Authors' contributions

Conceptualization, J.G.; validation, D.P., A.Sz.-P.; formal analysis, J.W.; investigation, J.G., K.W., K.G.; writing — original draft preparation, K.W., K.G.; writing — review and editing, J.G., K.W., K.G.; visualization, J.W.; supervision, B.M.-M. All authors reviewed and edited the manuscript and approved for the submission.

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Conflict of interest

The authors declare no conflict of interest.

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