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Original research

Association of body composition indexes with cardio-metabolic risk factors

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ABSTRACT

Objective: This study aimed to evaluate the ability of Body Mass Index (BMI), waist circumference (WC), waist-to-height ratio (WHtR) and Visceral Adipose Index (VAI) to assess biochemical and blood pressure parameters.
Methods: The retrospective cross-sectional study included 2333 people (1276 women and 1057 men) in age between 40 and 60 years who took part in local health promotion program. The data including anthropometrical parameters, blood biochemical parameters and blood pressure were used to compute the indexes and analyze their relationship with cardio-metabolic risk factors. Data were analyzed using Receiver Operating Curves and Pearson's correlation coefficient.
Results: Significant correlations have been found between all indexes and analyzed risk factors except LDL-C. The highest values of correlation coefficient were observed between WC and risk factors excluding total cholesterol. Values of area under the curve (AUC) indicated weak (AUC < 0,7) ability of indexes to predict deviations from the norm of biochemical and blood pressure parameters. Significant ability was presented by WC in predicting HDL-C, triglycerides (TG) and uric acid (SUA); BMI and WHtR in predicting HDL-C, TG, SUA and fasting plasma glucose (FPG); VAI in predicting SUA and FPG.
Conclusions: The results suggest that BMI, WC, WHtR and VAI may be useful in clinical assessment of cardio-metabolic risk factors. Yet, there is no evidence supporting replacement of WC as a recommended central obesity index.

1. Introduction

Overweight and obesity are commonly related to cardio-metabolic risk factors such as elevated blood glucose level, dyslipidemia and high blood pressure (Kannel et al., 1961; Gill et al., 2003; Whitlock et al., 2009; Jensen et al., 2013; Yumuk et al., 2015; Bischoff et al., 2017). The more exact parameter defining this risk is the visceral fat level (Mathieu et al., 2009; Guglielmi and Sbraccia, 2018; Tong et al., 2007; Després and Lemieux, 2006; Carr et al., 2004). Body fat measurements methods like magnetic resonance (MRI), computed tomography (CT), Dual-energy X-ray Absorptiometry (DXA), bioelectrical impedance, despite having high accuracy, are not used in clinical practice due to high financial and time requirements (Andreoli et al., 2016). For this reason, the surrogate indexes of body fat amount were created basing on the anthropometrical data of the patient. According to clinical recommendations, apart from Body Mass Index (BMI), to stratify the patient risk the central obesity index should be used – the waist circumference (WC). However, the recent studies proposed new and potentially more specific indexes that can be used in clinical practice. They include additional data: the height of the patient in case of waist-to-height ratio (WHtR); the lipid parameters in Visceral Adipose Index (VAI) (Amato et al., 2010; Ashwell et al., 2012). Yet, whether those indexes achieve better efficiency in population aged 40–60 years remains still unclear.

The aim of this study was an assessment of the effectiveness of surrogate obesity indicators in the estimation of cardio-metabolic risk factors. The relationships between BMI, WC, WHtR, VAI, and lipid profile, fasting glucose level, uric acid level and blood pressure in the population aged 40–60 years were studied.

2. Materials and methods

The retrospective cross-sectional study included data of 2333 people (1276 women and 1057 men) in age between 40 and 60 years from Bialski County (Lubelskie voivodeship) located in eastern Poland. The study enrolled women and men of low socioeconomic status, low awareness of the impact of risk factors on cardiovascular and metabolic morbidity and mortality and low awareness about the need to control

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their health. The data collection was conducted between 2014 and 2016 as a part of prevention and health promotion program entitled "Together for the heart". Funding of the program came from Norwegian Financial Mechanism 2009–2014 – PL-13 and the state budget. All participants signed a consent to take part in the project.

The size of somatic features was assessed based on measurements of body height (BH) and body mass (BM). BH and BM were measured with accuracy to 0.1 cm and 0.1 kg respectively using a SECA column scale with height meter. Besides, the subjects have measured the waist circumference (WC) with a SECA circumference measuring tape with an accuracy of 0.1 cm.

Standard measurements of systolic (systolic blood pressure – SPB) and diastolic blood pressure (diastolic blood pressure – DBP) were performed using the oscillometric method with OMRON i-Q142 electronic sphygmomanometer. The interpretation of the obtained results was conducted following the current recommendations of the Polish Society of Hypertension (PTNT) (Tykarski et al., 2015).

After instructing the subjects, blood samples were drawn 12 h after the last meal into Sarstedt system vacuum tubes (Germany). Using the automatic biochemical analyzer Hitachi COBAS c501 (Japan) from venous blood serum determined: total cholesterol (TC), low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), triglyceride (TG), fasting plasma glucose (FPG) and serum uric acid (SUA). Concentrations of TC, LDL-C, HDL-C, TG, FPG, and SUA were determined by an enzymatic-colorimetric method using standard reagents. Determination of TC and LDL-C, HDL-C concentrations was possible in the range 0,1–20,7 mmol/dl and 0,08-3,12 mmol/dl respectively, TG in range of 0,1–10 mmol/dl, while FPG and SUA respectively in the range of 0,11–41,6 mmol/dl and 12–1487 μmol/dl Blood collection and analysis were done in the laboratory of Provincial Specialist Hospital in Biała Podlaska.

Based on the anthropometrical and biochemical measurements the BMI, WHtR and VAI indexes were calculated:

- BMI = body weight/height^2 (kg/m^2);
- WHtR = WC/height;
- VAI was calculated separately women and men using the formulas:
  - o VAI = [WC/39.68 + (1.88 × BMI)] × (TG/1.03) × (1.31/HDL) for men;
  - o VAI = [WC/36.58 + (1.89 × BMI)] × (TG/0.81) × (1.52/HDL) for women.

Differences between sex groups regarding mean values of BH, BM, WC, concentrations of TC, HDL-C, LDL-C, TG, FPG, SUA, systolic and diastolic blood pressure and calculated surrogate indexes (VAI, WHtR, BMI) were assessed using student T-test. Pearson's correlation coefficient was determined between the particular indexes and the biochemical and blood pressure data. The Receiver Operative Characteristic (ROC) analysis in form of the area under the curve (AUC) was performed to evaluate the specificity and sensitivity of indexes in predicting the deviations from the biochemical and blood pressure parameters. The significance of statistical tests was assumed at $p \leq 0.05$ or higher.

3. Results

Characteristic of 2333 people (1276 women and 1057 men) is presented in Table 1. Women were older than men (52,4 ± 5,7 vs. 51,1 ± 5,8) and had anthropometric parameters, blood results except HDL-C (1,58 ± 0,45 mmol/dl vs. 1,38 ± 0,48 mmol/dl) and SBP (144,4 ± 18,7 mmHg vs. 147,3 ± 17,8 mmHg) with DBP (88,3 ± 11,3 mmHg vs. 90,8 ± 10,8 mmHg) lower in comparison to men. Surrogate indexes of body fat (VAI, WHtR, BMI, WC) were lower in women than in men. Sex differences were significant for all variables except TC, LDL-C and VAI, WHtR and BMI.

Analysis of the relationships between surrogate body fat indexes and lipid parameters (Table 2) showed significant ($p \leq 0{,}05$) correlations between TC and VAI, inverse correlation between TC and BMI, WC, as well as, lack of relationship between TC and WHtR. Inverse significant ($p \leq 0{,}001$) correlations were observed between HDL-C and surrogate indexes except VAI which was calculated using this parameter. Also, LDL-C did not have a significant relationship with any of the surrogate index. Concentration of TG, glucose and uric acid was highly significantly ($p \leq 0{,}001$) correlated with VAI, BMI, WHtR and WC except the relationship between TG and VAI calculated with use of TG. The values of systolic and diastolic blood pressure were weakly ($p \leq 0{,}05$) correlated with VAI and strongly ($p \leq 0{,}001$) positively correlated with BMI, WHtR and WC.

Table 3 shows values of area under the curve (AUC) of surrogate body fat indexes in predicting the invalid values of biochemical parameters and blood pressure. Designated values of AUC indicated weak (AUC < 0,7) ability of indexes to predict deviations from the norm of lipid parameters, uric acid, glucose, systolic and diastolic blood pressure. Significant ability was presented by WC in predicting HDL-C, TG and SUA; BMI and WHtR in predicting HDL-C, TG, SUA and FPG; VAI in predicting SUA and FPG (Fig. 1).

4. Discussion

In clinical practice, the surrogate indexes of body fat are commonly used to quickly estimate the patient's body composition and risk of metabolic and cardiovascular diseases (Global BMI Mortality Collaboration et al., 2016; Huxley et al., 2010; Yusuf et al., 2005; Meigs et al., 2006). Indexes that assess the distribution of body fat in the organism are more accurate in determining the risk compared to indexes that evaluate total body fat. Epidemiological studies suggest that anatomical localization of body fat has a crucial influence on health, life expectancy, and risk of disease development. These parameters are most affected by visceral and abdominal subcutaneous fat (Yumuk et al., 2015; Bischoff et al., 2017; Mathieu et al., 2009). In men, visceral fat makes up to 20%, while in women 5–8% of total body fat (Freedland, 2004).

Among anthropometrical indexes, the most widespread is BMI, commonly used to asses nutritional status (World Health Organization, 2000). Despite its wide use, previous studies have shown, that the BMI is not an accurate indicator of cardiovascular risk. It is due to its characteristics: is not sex-specific, does not differentiate between fat and muscle tissue and most importantly it does not take into account the fat distribution in the body since it does not include any body circumference parameter (Yusuf et al., 2005; Melmer et al., 2013; Bergman et al., 2011; Rahman and Berenson, 2010). Several studies have found that visceral obesity determined by WC is more strongly associated with cardiovascular risk factors than BMI (Freedman et al., 2012; Snijder et al., 2012; de Lima et al., 2012). The results of this study are partly consistent with previous observations of other authors. The BMI was less correlated with cardiovascular risk factors than the WC, however, more strongly than the indicators derived from WC, i.e. VAI and WHtR. Strong correlations ($p \leq 0.001$) between BMI and biochemical parameters may result from characteristics of the study population, which included people aged 40–60. In this group, there were no people with an extensive muscular structure whose BMIs could have corrupted the correlation values.

The WC is the basic clinical indicator used to assess the amount of visceral fat (de Koning et al., 2007). The advantage of the WC is simplicity of measurement, no additional calculations necessary to obtain the final result, and taking into account the anatomical location of visceral fat (Okafor et al., 2011; farhangiyan et al., 2019). In the study, the WC index, in comparison with VAI, BMI and WHtR, was most strongly correlated with all biochemical parameters except TC. AUC values analysis, indicating the ability to detect incorrect values of

Table 1
General characteristic of the population.

Variables	Total (n = 2333)	Female (n = 1276)	Male (n = 1057)	P value
Age [years]	51,8 ± 5,7	52,4 ± 5,5	51,1 ± 5,8	< 0,001
BH [cm]	168,9 ± 8,4	163,4 ± 5,9	175,5 ± 6,0	< 0,001
BM [kg]	86,4 ± 17,0	80,4 ± 15,7	93,7 ± 15,7	< 0,001
WC [cm]	98,57 ± 13,51	95,68 ± 13,97	102,06 ± 12,05	< 0,001
TC [mmol/dl]	5,72 ± 2,49	5,70 ± 2,09	5,74 ± 2,92	0,704
LDL-C [mmol/dl]	3,60 ± 1,02	3,57 ± 0,97	3,64 ± 1,08	0,074
HDL-C [mmol/dl]	1,49 ± 0,47	1,58 ± 0,45	1,38 ± 0,48	< 0,001
TG [mmol/dl]	1,77 ± 1,28	1,58 ± 0,94	2,00 ± 1,57	< 0,001
FPG [mmol/dl]	5,89 ± 1,58	5,72 ± 1,39	6,09 ± 1,76	< 0,001
SUA [μmol/dl]	321,2 ± 88,6	288,3 ± 72,6	360,4 ± 92,8	< 0,001
SBP [mmHg]	145,7 ± 18,4	144,4 ± 18,7	147,3 ± 17,8	< 0,001
DBP [mmHg]	89,4 ± 11,2	88,3 ± 11,3	90,8 ± 10,8	< 0,001
VAI	2,30 ± 2,26	2,26 ± 2,04	2,36 ± 2,49	0,280
WHtR	0,58 ± 0,08	0,58 ± 0,09	0,59 ± 0,07	0,237
BMI [kg/m^2]	30,25 ± 5,26	30,09 ± 5,60	30,43 ± 4,81	0,123

Explanations: BH – body height; BM – body mass; WC – waist circumference; TC – total cholesterol; LDL-C – LDL cholesterol; HDL-C – HDL cholesterol; TG – triglycerides; FPG-fasting plasma glucose; SUA - serum uric acid, SBP – systolic blood pressure; DBP – diastolic blood pressure; VAI – Visceral Adiposity Index; WHtR – waist-to-height ratio; BMI – Body Mass Index.

Table 2
Correlations between surrogate body fat indexes and biochemical parameters and blood pressure.

Variable	Surrogate body fat index			
	VAI	BMI	WHtR	WC
TC [mmol/l]	0,0499$^{A\#}$	−0,0470^{A}	−0,0379^{NS}	−0,0422^{A}
HDL-C [mmol/l]	X^{D}	−0,2945^{C}	−0,2778^{C}	−0,3409^{C}
LDL-C [mmol/l]	0,0152^{NS}	−0,0216^{NS}	0,0105^{NS}	0,0136^{NS}
TG [mmol/l]	X^{D}	0,1664^{C}	0,1634^{C}	0,2010^{C}
FPG [mmol/l]	0,1738^{C}	0,1968^{C}	0,1958^{C}	0,2271^{C}
SUA [μmol/dl]	0,1929^{C}	0,2971^{C}	0,2695^{C}	0,3707^{C}
SPB [mmHg]	0,0642^{A}	0,1314^{C}	0,1435^{C}	0,1540^{C}
DSB [mmHg]	0,0605^{A}	0,0974^{C}	0,0961^{C}	0,1206^{C}

Explanations: TC – total cholesterol; LDL-C – LDL cholesterol; HDL-C – HDL cholesterol; TG – triglycerides; FPG-fasting plasma glucose; SUA - serum uric acid, SBP – systolic blood pressure; DBP – diastolic blood pressure; $^{\#}$values significant on level: $^{A}p \le 0,05$, $^{B}p \le 0,01$, $^{C}p \le 0,001$, ^{D}HDL and TG are used to calculate VAI, ^{NS}value not significant.

diagnostic markers, has shown that WC has poor (AUC ≤ 0.7) but significant (p ≤ 0.05) efficacy in predicting abnormal HDL-C, TG, and uric acid levels. This can help diagnose dyslipidemia and hyperuricemia (Table 3).

Some researchers emphasize that despite high correlation values between WC and individual risk factors, WC does not translate directly into the amount of visceral fat (Hsieh and Yoshinaga, 1999). For this reason, they suggest using derived indicators such as VAI or WHtR, which also take into account the height of the examined person, thanks to which the measurement of the waist circumference is proportional to the figure. Many studies have shown that WHtR is more effective than WC in determining visceral fat and predicting the risk of type 2 diabetes, dyslipidemia, hypertension, and cardiovascular disease (Ashwell et al., 2012; Melmer et al., 2013; Bennasar-Veny et al., 2013; Zhang et al., 2019). Our study showed significant correlations between WHtR and concentrations of HDL-C, TG, glucose, uric acid and systolic and diastolic blood pressure. However, the observed correlations were at a similar or lower level compared to BMI and WC. WHtR showed the highest sensitivity and specificity in determining abnormal HDL-C concentration.

A new indicator taking into account the anatomical location of adipose tissue and the height of the examined person is Visceral Adiposity Index (VAI). It was introduced based on clinical data and MRI tests performed on 1498 people (Amato et al., 2010). It is determined separately for women and men, and in addition to anthropometric data, it also includes biochemical measurement values: HDL-C and TG concentrations. In our study, the VAI index significantly correlated with the concentration of TC, glucose, uric acid, and blood pressure values. Therefore, VAI may be considered as an indicator helpful in screening for dyslipidemia, hyperuricemia, hyperglycemia and hypertension and associated cardiovascular risk factors. However, the correlations obtained with all biochemical parameters, as well as, SPB and DSB except TC level were weaker compared to other anthropometric indicators. The analysis of the areas under the ROC curve shows that in the study

Table 3
Areas under the curve in predicting deviations from the norm by body fat surrogate indexes.

Variable	WC		WHtR		BMI		VAI	
	AUC	95% CI	AUC	95% CI	AUC	95% CI	AUC	95% CI
TC	0,453	0429–0,478	0467	0,443–0492	0,459	0434–0,483	0536	0,511-0,56
LDL –C	0,515	0488–0,542	0517	0,49-0,544	0,51	0,483–0537	0,572	0544-0,6
HDL-C	0,634	0608–0,661	0651	0,625–0677	0,646	0,62-0,672	0,881$^{\#}$	0,865–0896
TG	0,628	0603–0,652	0607	0,582–0631	0,602	0578–0,627	0,959$^{\#}$	0,952–0966
SUA	0,677	0647–0,707	0617	0,586–0649	0,669	0,64-0,698	0647	0,614-0,68
FPG	0,556	0533-0,58	0,605	0582–0,628	0605	0,582–0627	0,627	0604–0,649
DBP	0,552	0528–0,577	0541	0,516–0565	0,538	0513–0,562	0519	0,495–0543
SBP	0,555	0528–0,583	0551	0,524–0577	0,548	0522–0,575	0525	0,498–0551

Explanations: TC – total cholesterol; LDL-C – LDL cholesterol; HDL-C – HDL cholesterol; TG – triglycerides; SUA - serum uric acid; FPG-fasting plasma glucose; DBP – diastolic blood pressure; SBP – systolic blood pressure; WC – WHtR – BMI – VAI – AUC – area under the curve; CI – confidence interval; $^{\#}$HDL and TG are used to calculate VAI.

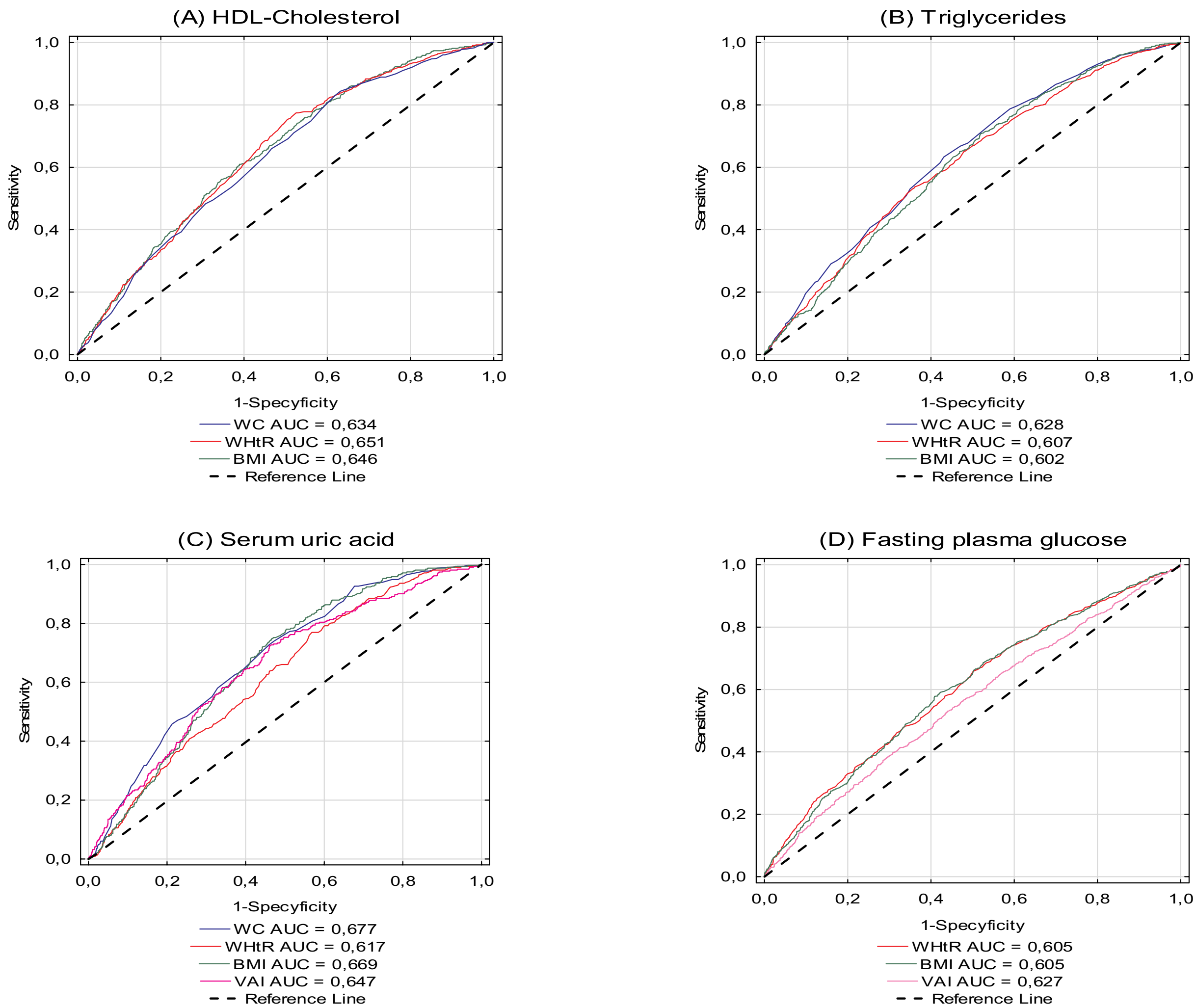

Fig. 1. Prediction for abnormal HDL-cholesterol (A); triglycerides (B); serum uric acid (C); fasting plasma glucose (D) of body fat-surrogate indexes as assessed by receiver operating characteristic curves (ROC), with Area Under the Curve analysis.

population only elevated glucose and uric acid could be predicted using the VAI index. Carried out by Amato et al. VAI analysis showed that VAI > 1.9 was significantly associated with metabolic syndrome (Amato et al., 2011). The superiority of VAI in predicting an unfavorable metabolic phenotype and cardiovascular risk in the general population has also been demonstrated (Barazzoni et al., 2019; Ferreira et al., 2019). However, further research is still needed to set limits for the diagnosis of high cardiovascular risk.

The study inherits the restrictions of a retrospective cross-sectional study. The main limitation is the lack of direct measurement of the amount of body fat which could be measured non-invasively through bioelectric impedance or skinfold test. Hence, the study lacks the crucial reference point for determining the accuracy of surrogate body-fat indexes. In the study, we did not consider an individual's eating habits and physical activity, which might affect analyzed parameters. Moreover, during data collection, the measurement of hip-circumference was omitted. Lack of this parameter prevented us from including additional indexes such as waist-to-hip ratio (WHR) or body adiposity index (BAI) to the analysis.

Our results indicate higher importance of measuring waist circumference over other examined anthropometric indicators in a population at age 40–60. In clinical practice, the simplicity of use of this indicator combined with high efficiency in the detection of metabolic and cardiovascular risk factors constitute a unique combination. Other indicators can also be useful in assessing deviations in lipid and carbohydrate metabolism and blood pressure.

Credit author statement

Marcin Czeczelewski: Conceptualization; Methodology; Formal analysis; Project administration; Visualization; Writing - Original Draft; Writing - Review & Editing

Jan Czeczelewski: Conceptualization; Methodology; Formal analysis; Investigation; Resources; Supervision

Ewa Czeczelewska: Conceptualization; Investigation; Resources; Supervision

Anna Galczak-Kondraciuk: Conceptualization; Methodology; Investigation

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