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Anthropometric Indices as Predictive Screening Tools for Obesity in Adults; The Need to Define Sex-Specific Cut-Off Points for Anthropometric Indices

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Abstract: Due to the lack of full agreement as to the best indicators for obesity diagnosis and type, the aim of this study was to assess the comparative classification capabilities with the use of BIA results and selected anthropometric indices in individuals aged 20–60 years. This was a cross-sectional observational study among 368 Caucasian subjects aged 20–60 years. Body size and four skinfolds measurement were taken. To assess individual body composition, the bioelectrical impedance (BIA) method was applied. The results of fat mass (FM, kg) and fat-free mass (FFM, kg) were taken to calculate FM/FFM, fat mass index (FMI), and fat free mass index (FFMI). Receiver-operating characteristic (ROC) curve analysis was employed to compare the predictive power of different anthropometric indices in differentiating the classification of obesity in adults. The results of this study demonstrated and confirmed the need to change the approach to commonly used indicators such as BMI (body mass index) or WHtR (waist-to-height ratio), which should lead to the establishment of new criteria for the diagnosis of obesity that will also be sex-specific, in the adult population. The measurement of body fat content should become a generally accepted indicator for effective diagnosis, as well as for screening, of obesity.

Keywords: body composition; body size; fat mass; fat free mass; somatic indexes; obesity; adults

1. Introduction

Obesity is a global health problem and most prevalent in developed countries. According to Eurostat data, the prevalence of overweight in the European region was 52.7% in the adult population in 2019. The prevalence of overweight seems to grow in eastern European countries; in the Czech Republic and Hungary it is 60%, in Slovakia 59% of adults. In Poland, 58% of the adult population is overweight based on their BMI (body mass index) [1]. According to data of the Organisation for Economic Cooperation and Development (OECD), 18.5% of the adult Polish population was obese in 2019, which surpasses the European average of 16% [2]. Evaluation of body fat content and its distribution in different body regions is of great importance in predicting various health risk factors [3].

Certain anthropometric measurements considered surrogates for obesity have long been used in medical settings for obesity-associated health risk evaluation [4]. Anthropometric measures are simple, cheap, non-invasive, and portable tools for assessing human body size or composition [5,6]. The core components of anthropometric measurements are height; weight; body circumference of waist, hip, and limbs; and skinfold thickness. They are used in different situations to compute established and known indices as BMI, which has been commonly used to assess body weight [7]; but it does not reflect actual body composition, or the accumulation and distribution of fat mass. The definition and diagnosis of obesity based on "obesity/overfat" and classification based on BMI is increasingly being questioned [8], due to its low predictive sensitivity [9] and the lack of consideration of gender, age, and race, which determine the amount of body fat [10]. Therefore, fat distribution indices, including waist-height ratio (WHtR) and waist-hip ratio (WHR), are proposed to diagnose the risk of obesity or metabolic disorders. In addition, there are new indices based on the existing ones, such as the body shape index (ABSI) [11], body adiposity index (BAI) [12], body roundness index (BRI) [13], abdominal volume index (AVI) [12], and the relative fat mass (RFM) [14].

On the one hand, body fat mass/percentage is an essential measure of body composition and is strongly associated with obesity and metabolic syndrome. It can be derived from body density obtained manually through equations, or instrumentally using devices for body composition measurements [15]. On the other hand, the results of studies in various population groups indicate that the negative impact on health and survival is associated not only with excessive adipose tissue, but above all with lower lean mass/muscle mass, which is not assessed using the above mentioned indicators [8].

Increased adipose tissue may also be accompanied by muscle loss (leading to sarcopenia), which is diagnosed as sarcopenic obesity [16]. Both sarcopenia and sarcopenic obesity are risk factors for higher mortality [17] and cannot be quantified using the above-mentioned measures/indicators, which focus solely on adipose tissue. Therefore, a better approach is to measure body composition, which identifies the two main components: fat and free mass/muscle mass, and the relationships between them. Simple and non-invasive methods of assessing muscle mass include measuring the arm circumference together with tricep skinfold thickness as the mid-upper arm circumference (MUAC), arm muscle area (AMA), or muscle-arm circumference (MAC) [18].

One of the technologies commonly used to assess body composition, also in clinical trials, is bioelectric impedance analysis (BIA). It allows determining the fat mass (FM) and fat free (lean) mass (FFM) [19]. It is recommended to relate the obtained values to themselves (FM/FFM) [20] or to body height [21]. Both fat and lean mass (kg) should be normalized by height squared (m^2), as the fat mass index (FMI) and fat free mass index (FFMI) [8,21]. Then, these results are used to assess the risk of obesity, sarcopenia, or sarcopenic obesity. Moreover, additional research is necessary in populations where the varieties of anthropometric measures, especially those newly proposed, have not been expansively analyzed and studied. Due to the lack of full agreement as to the best indicators of obesity diagnosis and type, the aim of this study was to assess their comparative classification capabilities, with the use of BIA results and selected anthropometric indices in individuals aged 20–60 years.

2. Materials and Methods

2.1. Study Design and Participants Participants

A total of 400 people from the local community living in Warsaw (the capital and the largest city of central Poland) and the surrounding area (including small towns and villages) volunteered for a cross-sectional observational study in the period from January 2018 to August 2021. The following inclusion criteria were used: age 18–60 years, BMI < 50 kg/m^2, informed consent on all study procedures, proper preparation for BIA, and no contraindications for the BIA measurement. Finally, 368 Caucasians aged 20–60 years were enrolled. Due to contraindications to BIA and improper preparation for the examination 32 subjects were not finally included (also due to low dehydration status). All participants gave informed consent prior to participating in the study. The study was conducted according to the Declaration of Helsinki and was approved by the Ethics Committee of the Faculty of

Human Nutrition and Consumer Science, Warsaw University of Life Sciences, Warszawa, Poland (Resolution No. 04p/2017).

2.2. Data Collection and Procedures

A self-designed questionnaire was administered to consenting study participants for sociodemographic data such as age, sex, education, place of living, occupation, as well as self-assessment of physical activity (categories: 1—as low, 2—as moderate, 3—as vigorous), economic, professional and health status (categories: 1—as poor, 2—as fair, 3—as good, 4—as very good).

2.2.1. Anthropometric Measurements and Indices

Body height (H), and body weight (BW), waist (WC), hip (HC), mid-upper arm circumference (MUAC), and skinfolds were measured using professional equipment and standardized procedures [22,23]. Height was measured with a portable stadiometer with the head in the horizontal Frankfurt plane and recorded with a precision of 0.1 cm (SECA 220, Hamburg, Germany). Weight was measured using an electronic digital scale to the nearest 0.1 kg (SECA 799, Hamburg, Germany). Waist circumference (WC) was measured with a stretch-resistant tape that provides constant 100 g tension (SECA 201, Hamburg, Germany), at the midway point between the iliac crest and the costal margin (lower rib) on the anterior axillary line in a resting expiratory position [23,24]. Hip circumference was measured around the widest part of the buttocks, with the tape parallel to the floor [23].

On the non-dominant side of the body mid-upper arm circumference (MUAC) and skinfolds were measured. MUAC was taken at the mid-point between the bony protrusion on the shoulder (acromion) and the point of the elbow (olecranon process), with the elbow to be flexed 90 degrees with palm facing upwards using a flexible tape, read to the nearest 0.1 cm [25].

Participants' biceps, triceps, subscapular, and suprailiac skinfolds were measured using skinfold calipers (Harpenden Skinfold Caliper F0120, Baty International, Burgess Hill, UK) [26].

All measurements were performed under strictly standardized conditions (room temperature 22 °C, air humidity 45%) by well-trained researchers, using the same device, in order to avoid inter-observer and inter-device variability. Measurements were taken twice, and if a difference existed between the first two measures of <5% for skinfolds and <1% for all other measures, a third measure was taken, and the averages were calculated. The intra-tester technical errors of measurement (TEM) for skinfolds was 3.4% and for all other measures was 0.5%.

Based on anthropometric measures several anthropometric indices, most commonly found in screening studies were calculated:

1. used for obesity diagnosis:
   - ABSI = WC (in m)/[BMI (in $kg/m^2)^{2/3} \times$ H (in m)$^{1/2}$]; $m^{11/6}\ kg^{-2/3}$
   - AVI = [2 $\times$ WC (in cm)^2 + 0.7 $\times$ (WC (in cm) $-$ HC (in cm)^2]/1000; cm^2
   - BAI = [HC (in cm)/H (in m)$^{1.5}$] $-$ 18; %
   - BMI = BW (in kg)/H (in m)^2; kg/m^2
   - BRI = 364.2 $-$ 365.5 [1 $- \pi^{-2}$ WC (in m)^2 $\times$ Height (in m)$^{-2}]^{1/2}$; no units
   - RFM = 64 $-$ [20 $\times$ (H (in m)/WC (in m)] + 12 $\times$ sex (0 for men, 1 for women); no units
   - WHR = WC (in cm)/HC (in cm); no units
   - WHtR = WC (in cm)/H (in cm); no units.
2. used as a marker of muscle mass [27,28]:
   - Muscle Arm Circumference, MAC = (MUAC (in cm) $- \pi \times$ triceps skinfolds (in cm)); cm
   - Arm Muscle Area, AMA = [MUAC (in cm) $-$ ($\pi \times$ triceps skinfolds (in cm)^2)/4 π]; cm
   - MUAC/H = MUAC (in cm)/H (in cm); no units.

2.2.2. BIA Measurements

To assess individual body composition, a portable, a single-frequency (50 kHz), eight-point Tanita Analyzer (Tanita BC-418 MA, Tanita Co., Tokyo, Japan) was used, following the procedures for BIA measurement (refraining from vigorous physical activity at least 12 h prior, intake of no caffeine and alcohol for 24 h prior to testing, fast or 4 h after a meal, and empty the bladder 30 min prior to testing). Due to the fact that dehydration is a recognized factor affecting BIA measurements, hydration status was tested in a urine sample using a gravity test (with a urometer) and the color for each person. BIA was performed under standardized conditions, according to the manufacturer's protocol. The results of fat mass (FM, kg) and fat-free mass (FFM, kg) were taken to calculate FM/FFM, fat mass index (FMI), and fat free mass index (FFMI):

- FMI = FM (in kg)/H (in m)^2, kg/m^2;
- FFMI = FFM (in kg)/H (in m)^2, kg/m^2.

2.2.3. Diagnostic Criteria of Obesity or Sarcopenia Based on FM and FFM

According to Gonzalez [17,29], results of FMI $\geq$ 8.3 for men and 11.8 for women were classified as high fat mass, and FFMI $\leq$ 17.4 for men and 15.0 for women as lower fat free mass. Based on this classification, four types were determined: sarcopenic obesity (lower FFM and high FM), obesity (high FM), normal weight, and sarcopenia (lower FFM).

A FM to FFM ratio <0.4 was classified as metabolic health, with 0.4–0.8 as obese, and with >0.8 as sarcopenic obesity (adopted from: [4,20]).

2.3. Statistical Analysis

A descriptive analysis of the participants' characteristics was carried out using the mean and standard deviation (SD) for numerical variables, and the absolute and relative frequencies (%) of the categorical variables. The normality of variable distribution was checked with a Kolmogorov–Smirnov test. Spearman r correlations and linear regression equations were used to evaluate the relationship between variables. Data were analyzed with STATISTICA 13.3 computer software (TIBCO Software Inc., StatSoft, Cracow, Poland).

Receiver-operating characteristic (ROC) curves ROC analysis was employed to compare the predictive power of different anthropometric indices in differentiating the classification of obesity in adults. The area under the curve (AUC) was used to summarize the predictive power of these measures for obesity or sarcopenia diagnosis. An AUC of 1 reflected a perfectly accurate test, whereas 0.5 suggested that the test had no discriminatory ability. An AUC <0.7 was considered poor, 0.7–0.8 as acceptable, 0.8–0.9 as good, and >0.9 as excellent. The optimal cut-off points of the anthropometric indices were also determined, according to the values of the indices that maximized the Youden index (sensitivity + specificity − 1). The acceptable level of sensitivity and specificity of screening tests adopted in this study was 70.0% [30]. The significance of the difference between two AUC values was assessed using the Hanley and McNeil approach [31]. MedCalc ver.20.104 software was used for ROC analysis.

For all tests, a significance level of $p < 0.05$ was assumed, indicating statistically significant differences, while between $p < 0.001$ and $p < 0.0001$ was strongly significant.

3. Results

3.1. Baseline Characteristics of the Participants

A total of the 368 adults were included, with 61% women, 70% individuals with secondary and university education. Over 70% of the study group lived in the city >100,000 inhabitants, and about 50% were working full time. The mean age of individuals was 40 $\pm$ 14 years (Table 1).

Table 1. Characteristics of the participants (Mean ± SD or %).

Variables	Total *n* = 368	Women *n* = 224	Men *n* = 144
Sociodemographic			
Age (years) *	39.77 ± 14.41	39.77 ± 14.23	39.77 ± 14.50
Education, %			
primary and vocational	12.8	9.8	17.4
secondary	31.8	30.8	33.3
university	36.7	39.3	32.6
while studying	18.7	20.1	16.7
Place of living, %			
village	8.4	9.4	6.9
city <100,000 inhab.	17.7	17.8	17.4
city >100,000 inhab.	73.9	72.8	75.7
Professional status, %			
not working	16.3	17.9	13.9
work part-time	8.4	7.6	9.7
work full time	48.9	45.5	54.2
study and work	13.3	12.9	13.9
study	13.1	16.1	8.3
Economic status, %			
low	22.0	25.0	17.4
middle	29.6	26.8	34.0
high	25.0	21.4	30.5
very high	23.4	26.8	18.1
Health status *	2.39 ± 0.85	2.30 ± 0.88	2.52 ± 0.78
Physical activity *	1.78 ± 0.78	1.76 ± 0.76	1.81 ± 0.81
Anthropometrics *			
Direct measurements			
Height, m	1.71 ± 0.10	1.65 ± 0.07	1.79 ± 0.07
Body weight, kg	79.6 ± 22.6	71.8 ± 19.6	91.77 ± 21.6
WC, cm	91.9 ± 20.5	86.0 ± 19.2	1000 ± 19.1
HC, cm	104 ± 11.7	104 ± 13.0	104 ± 9.52
MUAC, cm	30.0 ± 4.75	28.8 ± 4.92	31.8 ± 3.83
$\sum$ 4 skinfolds, mm	76.1 ± 32.6	78.4 ± 32.9	72.5 ± 31.8
FM, %	28.4 ± 10.6	31.6 ± 10.6	23.4 ± 8.67
FFM, %	71.5 ± 10.9	68.2 ± 10.8	76.6 ± 9.08
Indices			
ABSI, $m^{11/6}$ $kg^{-2/3}$	0.078 ± 0.01	0.076 ± 0.01	0.082 ± 0.01
AMA, cm	51.5 ± 17.4	44.8 ± 16.1	62.0 ± 13.8
AVI, cm^2	17.9 ± 7.85	15.8 ± 7.02	21.2 ± 7.97
BAI, %	28.8 ± 6.72	31.0 ± 7.24	25.5 ± 3.92
BMI, kg/m^2	27.3 ± 7.16	26.5 ± 7.64	28.6 ± 6.15
BRI, -	4.40 ± 2.55	4.10 ± 2.67	4.87 ± 2.30
FFMI, kg/m^2	18.9 ± 3.20	17.3 ± 2.35	21.4 ± 2.72
FM/FFM, -	0.43 ± 0.23	0.50 ± 0.25	0.32 ± 0.15
FMI, kg/m^2	8.34 ± 5.09	9.09 ± 5.59	7.16 ± 3.93
MAC, cm	25.1 ± 4.24	23.4 ± 4.00	27.7 ± 3.12
MUAC/H, -	0.18 ± 0.03	0.18 ± 0.03	0.18 ± 0.02
RFM, -	32.4 ± 8.98	35.7 ± 8.63	27.3 ± 6.88
WHR, -	0.88 ± 0.14	0.83 ± 0.12	0.97 ± 0.13
WHtR, -	0.54 ± 0.12	0.52 ± 0.12	0.57 ± 0.11

* Mean ± SD; ABSI, body shape index; AMA, arm muscle area; AVI, abdominal volume index; BAI, body adiposity index; BMI, body mass index; BRI, body roundness index; H, height; HC, hip circumference; FFM, fat free mass; FFMI, fat free mass index; FM, fat mass; FMI, fat mass index; MAC, muscle-arm circumference; MUAC, mid-upper arm circumference; RFM, relative fat mass; SD, standard deviation; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

Among the anthropometric measures included, the BMI mean was 26.5 kg/m^2 in women and 28.6 kg/m^2 in men. For WC, the mean was 86 cm in women and 101 cm in men, and the mean of WHtR was 0.52 and 0.57, respectively. The percentage of fat mass

(FM%) determined by BIA was 31.6% in women and 23.4% in men, and it was similar to the BAI value calculated from the formula, 31% and 25.5%, respectively.

Table 2 shows the distribution of the study group, in accordance with the adopted classification of respondents based on the BIA results. According to classification based on FMI and FFMI [17,29], a higher percentage of women were classified as subjects with normal weight (62% compared to FM/FFM classification as metabolic healthy 46%). In contrast, 63% vs. 71% of men were classified as normal or metabolically healthy. None of the participants were diagnosed with sarcopenic obesity based on FMI and FFMI, whereas 17% fell into this category according to the FM/FFM criterion.

Table 2. Distribution of study participants by FM and FFM classification.

Categories	Total n = 368	Women n = 244	Men n = 144
	FMI-FFMI		
sarcopenic obesity	0	-	-
obesity	30%	29%	33%
normal	63%	62%	63%
sarcopenia	7%	9%	4%
	FM/FFM		
metabolic healthy	56%	46%	71%
obese	34%	37%	29%
sarcopenic obesity	10%	17%	-

FFM, fat free mass; FFMI, fat free mass index; FM, fat mass; FMI, fat mass index.

3.2. Association between FM or FFM with Anthropometric Indices

Both, Spearman's correlation and linear regression analyses of FM in kg and surrogate indices on the total sample (Table 3) indicated a strong positive correlation with FMI (0.973, $p < 0.0001$), BMI (0.939, $p < 0.001$), FM/FFM (0.902, $p < 0.0001$), AVI and BRI (0.888 and 0.887, $p < 0.001$), WHtR (0.878, $p < 0.001$), and WC (0.847, $p < 0.001$), as well as with RMF (0.796, $p < 0.0001$), MUAC/H (0.757, $p < 0.0001$), and BAI (0.727, $p < 0.0001$). For FFM (in kg) positive, but a moderate correlation was found with MUAC (0.660, $p < 0.001$), WC (0.655, $p < 0.001$), AMA (0.647, $p < 0.001$) and AVI (0.642, $p < 0.001$).

Table 3. Correlation between FM or FFM and anthropometric indices.

Anthropometric Indices	FM (kg)			FFM (kg)		
	r	β	p	r	β	p
∑4 skinfolds, mm	0.685	0.685	<0.0001	0.270	0.270	<0.0001
ABSI, $m^{11/6}$ $kg^{-2/3}$	0.357	0.357	<0.0001	0.350	0.350	<0.0001
AMA, cm	0.506	0.506	<0.001	0.647	0.647	<0.001
AVI, cm^2	0.888	0.888	<0.001	0.642	0.642	<0.001
BAI, %	0.727	0.727	<0.0001	0.088	−0.088	*ns*
BMI, kg/m^2	0.939	0.939	<0.001	0.529	0.529	<0.001
BRI, -	0.887	0.887	<0.001	0.451	0.451	<0.001
FFM, %	0.869	−0.869	<0.0001	0.060	0.060	*ns*
FFMI, kg/m^2	0.543	0.543	<0.001	0.887	0.887	<0.001
FM, %	0.892	0.892	<0.0001	0.044	−0.044	*ns*
FM/FFM, -	0.902	0.902	<0.0001	0.048	−0.048	*ns*
FMI, kg/m^2	0.973	0.973	<0.0001	0.191	0.191	0.0002
MAC, cm	0.731	0.731	<0.001	0.618	0.618	<0.001
MUAC, cm	0.509	0.509	<0.001	0.660	0.660	<0.001
MUAC/H, -	0.757	0.757	<0.0001	0.342	0.342	<0.0001
RMF, -	0.796	0.796	<0.0001	0.090	−0.090	*ns*
WC, cm	0.847	0.847	<0.001	0.655	0.655	<0.001

Table 3. *Cont.*

Anthropometric Indices	FM (kg)			FFM (kg)		
	r	***β***	***p***	***r***	***β***	***p***
WHR, -	0.573	0.573	<0.001	0.590	0.590	<0.001
WHtR, -	0.878	0.878	<0.001	0.460	0.460	<0.001

r, Spearman correlation; *β*, regression coefficient; ABSI, body shape index; AMA, arm muscle area; AVI, abdominal volume index; BAI, body adiposity index; BMI, body mass index; BRI, body roundness index; H, height; HC, hip circumference; FFM, fat free mass; FFMI, fat free mass index; FM, fat mass; FMI, fat mass index; MAC, muscle-arm circumference; MUAC, mid-upper arm circumference; *ns*, not significant; RFM, relative fat mass; SD, standard deviation; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

3.3. The Predictive Power of Anthropometric Indices by Sex

Tables 4 and 5 summarize the results of the ROC analysis of various anthropometric indices. Overall, in women the AUCs of AVI, BAI, BMI, BRI, %FM, %FFM, FM/FFM, RFM, WC, and WHtR indicated excellent, and AUCs of MAC, AMA, MUAC, MUAC/H, and ∑4 skinfolds indicated good predictive power in assessing obesity, according to FMI-FFMI classification; they were whereas only acceptable (range 0.7–0.8) or poor (<0.7) using FM/FFM classification. In men, AUCs of AVI, BMI, BRI, RFM, WC, and WHtR were the highest (>0.9) for both classifications. A good predictive power for obesity was shown by AUCs of WHR and ∑4 skinfolds for FMI-FFMI classification. The AUCs of WHR and ∑4 skin folds showed a good predictive power for obesity classified according to FMI-FFMI.

Due to not having enough men, the results of sarcopenia and sarcopenic obesity are shown only for women (Tables S1 and S2). Among the analyzed indices, BAI, BMI, MUAC/H had the highest AUC (>0.75), but only had acceptable predictive power for sarcopenia. The AUCs of %FM, %FFM, and MUAC indicated the highest values and had excellent predictive power for assessing sarcopenia obesity. Similarly, for most of the used indices, the AUC indicated their excellent predictive power, except ABSI and ∑4 skinfolds, which turned out to be acceptable sarcopenia obesity predictors in women.

Table 4. The area under ROC curve (AUC), optimal cut-off values, sensitivity (Sens.), specificities (Spec.) and Youden index of anthropometric indices in predicting obesity by using FMI-FFMI or FM to FFM ratio in women.

Anthropometric Indices	FFMI-FMI-Obesity								FM/FFM-Obese							
	AUC	SD	95% CI	*p*	Cut Off	Sens.	Spec.	Youden Index	AUC	SD	95% CI	*p*	Cut Off	Sens.	Spec.	Youden Index
∑4 skinfolds, mm	0.88	0.03	0.83–0.92	<0.0001	84.9	85.9	80.6	0.67	0.65	0.04	0.58–0.71	0.0001	79.5	61.4	67.4	0.29
ABSI, $m^{11/6}$ $kg^{-2/3}$	0.73	0.04	0.67–0.79	<0.0001	0.07	82.8	61.9	0.45	0.68	0.04	0.62–0.74	<0.0001	0.08	67.5	63.1	0.31
AMA, cm	0.89	0.02	0.85–0.93	<0.0001	47.0	78.1	85.6	0.64	0.61	0.04	0.54–0.67	0.0056	36.0	84.3	40.4	0.25
AVI, cm^2	0.99	0.01	0.96–0.98	<0.0001	18.4	95.3	95.6	0.90	0.72	0.04	0.65–0.77	<0.0001	12.4	85.5	65.3	0.51
BAI, %	0.96	0.02	0.93–0.98	<0.0001	31.6	93.7	89.4	0.83	0.64	0.04	0.57–0.70	0.0002	27.7	80.7	53.2	0.34
BMI, kg/m^2	0.99	0.00	0.98–1.00	<0.0001	29.7	100	99.4	0.99	0.71	0.04	0.65–0.77	<0.0001	22.2	95.2	56.7	0.52
BRI, -	0.98	0.01	0.95–0.99	<0.0001	4.70	95.3	93.1	0.88	0.95	0.001	0.64–0.77	<0.0001	2.39	90.4	58.9	0.49
FFM, %	0.99	0.01	0.97–0.99	<0.0001	61.9	96.9	95.0	0.92	0.73	0.04	0.67–0.79	<0.0001	71.3	100	73.1	0.73
FFMI, kg/m^2	-	-	-	-	-	-	-	-	0.55	0.04	0.49–0.62	0.1873	16.9	53.0	63.8	0.17
FM, %	0.99	0.01	0.97–0.99	<0.0001	37.5	98.4	95.6	0.94	0.73	0.04	0.67–0.79	<0.0001	28.3	100	73.1	0.73
FM/FFM, -	0.99	0.01	0.97–0.99	<0.0001	0.60	98.4	95.0	0.93	-	-	-	-	-	-	-	-
FMI, kg/m^2	-	-	-	-	-	-	-	-	0.74	0.04	0.68–0.80	<0.0001	6.64	98.8	70.2	0.69
MAC, cm	0.81	0.36	0.75–0.86	<0.0001	30.0	93.5	64.7	0.58	0.64	0.04	0.58–0.71	<0.0001	25.8	91.6	39.7	0.31
MUAC, cm	0.89	0.02	0.85–0.93	<0.0001	24.3	78.1	85.6	0.64	0.61	0.04	0.54–0.67	0.0056	21.3	84.3	40.4	0.25
MUAC/H, -	0.96	0.01	0.93–0.99	<0.0001	0.19	89.1	95.0	0.84	0.64	0.04	0.58–0.71	<0.0001	0.16	89.2	42.6	0.32
RFM, -	0.98	0.01	0.95–0.99	<0.0001	40.7	95.3	93.1	0.88	0.71	0.04	0.64–0.77	<0.0001	31.0	90.4	58.9	0.49
WC, cm	0.98	0.01	0.96–0.99	<0.0001	90.0	95.3	94.4	0.90	0.72	0.04	0.65–0.78	<0.0001	77.5	84.3	66.7	0.51
WHR, -	0.88	0.02	0.84–0.92	<0.0001	0.83	92.2	79.4	0.72	0.72	0.03	0.65–0.77	<0.0001	0.79	79.5	60.3	0.40
WHtR, -	0.98	0.01	0.95–0.99	<0.0001	0.57	95.3	93.1	0.88	0.71	0.04	0.64–0.77	<0.0001	0.45	90.4	58.9	0.49

ABSI, body shape index; AMA, arm muscle area; AVI, abdominal volume index; BAI, body adiposity index; BMI, body mass index; BRI, body roundness index; H, height; HC, hip circumference; FFM, fat free mass; FFMI, fat free mass index; FM, fat mass; FMI, fat mass index; MAC, muscle-arm circumference; MUAC, mid-upper arm circumference; RFM, relative fat mass; SD, standard deviation; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

Table 5. The area under ROC curve (AUC), optimal cut-off values, sensitivity (Sens.), specificities (Spec.), and Youden index of anthropometric indices in predicting obesity by using FMI-FFMI or FM to FFM ratio in men.

Anthropometric Indices	FFMI-FMI-Obesity								FM/FFM-Obesity							
	AUC	SD	95% CI	*p*	Cut Off	Sensit.	Spec.	Youden Index	AUC	SD	95% CI	*p*	Cut Off	Sensit.	Spec.	Youden Index
∑4 skinfolds, mm	0.82	0.034	0.75–0.88	<0.0001	66.5	79.2	68.8	0.48	0.79	0.04	0.71–0.85	<0.0001	66.5	78.6	65.7	0.44
ABSI, $m^{11/6}$ $kg^{-2/3}$	0.74	0.04	0.66–0.81	<0.0001	0.08	87.5	60.4	0.48	0.73	0.04	0.65–0.80	<0.0001	0.08	88.1	57.8	0.46
AMA, cm	0.64	0.05	0.55–0.71	0.0056	64.9	52.1	69.8	0.22	0.58	0.05	0.49–0.66	0.1365	65.0	50.0	67.6	0.18
AVI, cm^2	0.96	0.01	0.92–0.99	<0.0001	23.8	85.4	93.8	0.79	0.91	0.02	0.85–0.95	<0.0001	20.9	88.1	84.3	0.72
BAI, %	0.86	0.03	0.79–0.91	<0.0001	25.0	89.6	70.8	0.60	0.84	0.03	0.77–0.90	<0.0001	26.0	81.0	78.4	0.60
BMI, kg/m^2	0.97	0.01	0.93–0.99	<0.0001	28.9	97.9	88.5	0.87	0.92	0.02	0.86–0.96	<0.0001	28.9	93.0	81.4	0.74
BRI, -	0.96	0.02	0.91–0.98	<0.0001	5.59	85.4	93.7	0.79	0.92	0.02	0.86–0.96	<0.0001	4.80	95.2	73.5	0.69
FFM, %	0.96	0.02	0.92–0.99	<0.0001	73.6	93.6	91.7	0.85	0.98	0.02	0.94–0.99	<0.0001	71.2	95.2	99.0	0.94
FFMI, kg/m^2	-	-	-	-	-	-	-	-	0.76	0.04	0.68–0.82	<0.0001	21.1	81.0	68.6	0.49
FM, %	0.98	0.01	0.95–0.99	<0.0001	26.1	97.9	92.7	0.91	1.00	0.00	0.98–1.00	<0.0001	28.4	100	100	1.00
FM/FFM, -	0.98	0.01	0.94–0.99	<0.0001	0.35	97.9	91.7	0.90	-	-	-	-	-	-	-	-
FMI, kg/m^2	-	-	-	-	-	-	-	-	0.98	0.01	0.95–0.99	<0.0001	8.06	100	91.2	0.91
MAC, cm	0.80	0.04	0.72–0.86	<0.0001	32.6	72.9	75.0	0.48	0.74	0.05	0.66–0.81	<0.0001	32.6	66.7	69.6	0.36
MUAC, cm	0.64	0.05	0.55–0.71	0.0056	28.5	52.1	69.8	0.22	0.58	0.05	0.49–0.66	0.1365	28.6	50.0	67.6	0.18
MUAC/H, -	0.79	0.04	0.72–0.86	<0.0001	0.18	68.6	78.1	0.47	0.75	0.04	0.67–0.82	<0.0001	0.18	66.7	74.5	0.41
RFM, -	0.96	0.02	0.91–0.98	<0.0001	31.0	85.4	93.8	0.79	0.92	0.02	0.86–0.96	<0.0001	29.0	95.2	73.5	0.69
WC, cm	0.96	0.01	0.92–0.99	<0.0001	105	85.4	93.8	0.79	0.91	0.02	0.85–0.95	<0.0001	102	95.2	73.5	0.69
WHR, -	0.89	0.03	0.83–0.94	<0.0001	0.98	89.6	74.0	0.64	0.86	0.03	0.79–0.91	<0.0001	0.98	90.5	70.6	0.61
WHtR, -	0.96	0.02	0.91–0.98	<0.0001	0.60	85.4	93.8	0.79	0.92	0.02	0.86–0.96	<0.0001	0.57	95.2	73.5	0.69

ABSI, body shape index; AMA, arm muscle area; AVI, abdominal volume index; BAI, body adiposity index; BMI, body mass index; BRI, body roundness index; H, height; HC, hip circumference; FFM, fat free mass; FFMI, fat free mass index; FM, fat mass; FMI, fat mass index; MAC, muscle-arm circumference; MUAC, mid-upper arm circumference; RFM, relative fat mass; SD, standard deviation; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist-to-height ratio.

3.4. Cut-Offs for Screening Obesity by Sex

Based on the Youden index, the optimal cut-off values of BMI for predicting obes were >29.7 kg/m^2 in women (Table 4) and 28.8 kg/m^2 (or 28.9 kg/m^2 according to FM/FFM classification) in men (Table 5), for WC 90 cm and 105 cm (102), for WHtR >0.57 and 0.60 (0.57), for WHR 0.83 and 0.98 (0.98), and for %FM >37.5 (28.3) and 26.1 (28.4), respectively. Optimal AVI cut-off values were 18.4 (12.4) for women and 23.8 (20.9) for men, BAI 31.6 and 25.0 (26.0), BRI 4.71 and 5.59 (4.80), and RFM 40.7 and 31.0 (29.0), respectively. Most indices did not show an acceptable level of specificity for the prediction of obesity classified according to FM/FFM ratio in women.

For the prediction of sarcopenic obesity in women (Table S2), the majority of indices showed good sensitivity and specificity, except ABSI and the sum of four skinfolds. Among the analyzed indices to predict sarcopenia (Table S1), none reached the assumed sensitivity and specificity, but the highest values of the Youden index were found for BMI (cut off <22.7 kg/m^2) and BAI (<24.9%).

4. Discussion

This study was designed to initially assess the predictive power of obesity indices in comparison to using FM(FMI) and/or FFM(FFMI). The results of our study confirmed that they can be implemented for obesity diagnosis and replace the questioned BMI. Considering the results of AUC, sensitivity, specificity, and Youden index (>0.9), fat mass index and percentage of fat mass could be considered the best marker for obesity screening in adults, regardless of sex. In women, the results also confirmed the need of a BIA analysis for sarcopenic obesity diagnosis. Undoubtedly, the current criteria for the diagnosis of obesity for commonly used indicators such as BMI, WC, WHtR, or WHR should be verified taking into account biological differences in body size and composition, including those determined by sex. ABSI had the lowest predictive value for obesity among the analyzed indices, regardless of sex. For the measurement of arm circumference and indicators based on its measurement, a positive moderate correlation with FFM was confirmed; but as an easy-to-use screening tool for the diagnosis of sarcopenic obesity or sarcopenia, this requires further investigation.

We found that the optimal BMI cut-offs were slightly below the obesity threshold for both sexes (BMI > 29.99 kg/m^2) and were sex-specific. This is in line with the results of Macek et al. [32], who identified the cut-off points for BMI at 27.5 kg/m^2 in women and 28.1 kg/m^2 in men for screening cardiometabolic risk in an older group of adults. It is necessary to underline that, according to standard BMI quantification, both estimated thresholds indicate overweight, not obesity. Due to the small difference between the common threshold for normal BMI values and the proposed limits for obesity, an increased risk of cardiometabolic disorders may be potentially misclassified, especially in women [32].

For indices of abdominal obesity estimation such as WC, WHtR, and WHR, the optimal cut-off values were close to the established ones (WC > 88 cm for women and >102 cm for men; WHtR $\geq$ 0.5; WHR > 0.8 for women and 0.9 for men). WHtR lower than 0.5 was previously established as the universal cut-off point for assessing abdominal obesity and cardiometabolic risk [33], but our results confirmed the need for further research, to establish sex-specific cut-off points for WHtR. Similarly, as indicated by other authors, this index is also ethnic-specific [30].

The optimal cut-off point of BRI was 4.71 in women and 5.59 (or 4.80 according to FM/FFM) in men. These values are lower than those given by Walczyk [34], according to whom values above 4.9 for women and 4.612 for men can be used as diagnostic criteria of metabolic disorders. Liu [35] indicated that the cut-off values of BRI reach values in the range 3.18 and 6.20, and even 1–16 [34], which may be due to differences in the study group, race, and diagnostic criteria. BRI is a novel index used to assess metabolic disorders, which may also be used for detecting high cardiometabolic risk [36], metabolic syndrome risk [37], or diabetes risk [35], and could be a better predictor than BMI.

AVI is used to assess general volume, and it has been highly associated with the dysfunction of glucose metabolism [38]. For Iranian men, it was determined at 16.6, and for women 17.0 [39]. Lower values of AVI, 14.25 for men and 13.03 for women, were established by Wang et al. [40] for predictive metabolic syndrome in the Chinese population. In our findings, the cut-off values for AVI were higher, but the AUC for AVI indicated excellent predictive power for obesity.

Compared with other indices, the values of AUC of ABSI showed the lowest predictive power in obesity diagnosis in our study group. ABSI was proposed by Krakauer and Krakauer, and based on WC, height, and BMI [11,41]. In previous studies, ABSI appeared to be better than traditional measures, such as BMI, as a measure of metabolic changes [3]. Currently, more and more research results have indicated the lowest AUC of ABSI for metabolic syndrome and other cardiometabolic risks [30,42,43]. As found by Ji et al. [44], ABSI can be used in predicting premature mortality risk, but is poor in predicting chronic diseases, including obesity. For Europeans, for the early diagnosis of a metabolic disorder, the proposed cut-off points: 0.076 for women and 0.080 for men [34], are similar to our findings: 0.074 and 0.081, respectively.

In our study group, the cut-off points for obesity assessment for BAI were similar to FM-BIA and ranged from 31.6–37.5% for women and 25–26.1% for men. BAI uses hip circumference and height as basic anthropometric measures and estimates body adipose tissue as a percentage [12]. BAI can be applicable in both sexes and all ethnicities, but others indicated that results can be inaccurate in subjects with adiposity at the extreme ends of body fat percentages [3,45–47]. Our fat percentage cut-off thresholds are similar with those published by Macek [32], where the cut-offs were established as 25.8% for men and 37.1% for women.

Our findings confirmed that the results of body composition analysis, including mainly fat mass and fat percentage, should be the basis for the determination of obesity risk and type. Despite the good and excellent AUC values for the majority of the tested indices, the results of the Youden index showed that both fat mass index and percentage of fat and fat free mass had the highest predictive potential for obesity. Considering the types of obesity, metabolic obesity with normal body weight is increasingly commonly diagnosed [48]. As in the case of sarcopenic obesity, it is accompanied by metabolic disorders, and diagnostics with the use of routine anthropometric measures are insufficient, and it requires body composition assessment. As found by Xiao et al. [49], FM to FFM ratio may be a good index for the evaluation of abnormal body composition, but this also requires establishing cut-off points for sexes. Non-invasive techniques consisting of a set of anthropometric measurements and indices are essential in the diagnosis of body adiposity and obesity, as well as body composition. These screening tools and indicators are fundamental to public health. Many novel body indexes, based on anthropometric measurement or based on BIA results have been studied in different population groups and have shown promise for clinical use. Undoubtedly, further studies to confirm the proposed cut-off points, using more advanced methods of body composition analysis, are warranted. As shown by Kagawa [50], in a study examining the usefulness of anthropometric parameters for obesity screening and indicators of adiposity obtained from dual energy x-ray absorptiometry (DXA), the new indicators such as BRI, BAI, or ABSI correlated poorly with DXA results and had poor screening abilities. Hence, further research is needed in this field.

The present study has some limitations and strengths that should be mentioned. First, our participants were of Caucasian ethnicity and mainly lived in a large city and around central Poland; therefore, the use of our results may be limited to this population. The classification of obesity based on the established cut-off points needs to be checked on large populations. Further studies with larger samples should be conducted, also for including the confounding effects from potential covariates such as age or physical activity. Due to the size of our study group and the distribution of sex and age categories, we did not undertake an age-specific analysis. Undoubtedly, this indicates the need for further research in sex- and age-specific groups. Second, for more accurate estimates of body components, modern technologies such as dual-energy X-ray absorptiometry (DXA) or air displacement plethysmography (ADP) should be used. The BIA method is non-invasive and low-cost, and the results are commonly used as a screening tool, but have also met with criticism among scientists [48]. However, on the other hand, BMI is also widely used, although it does not reflect body fat distribution. Due to the increasing risk of weight gain and central obesity caused by estrogen deficiency in postmenopausal women, future studies to establish cut-off values for known and new indicators for assessing the risk of obesity and related metabolic disorders, should also take into account menstrual status in women [35]. The main strength of this study is the inclusion of a sex-specific analysis of ROC and the use of two obesity diagnosis criteria for further comparisons with anthropometric indices (AVI, BAI, BMI, BRI, MAC, AMA, MUAC/H, RFM, WC, WHR, WHtR, and ABSI). To our knowledge, it is the first study assessing the ability of these anthropometric indices for predicting obesity and its type based on FM(FMI) and FFM(FFMI). The highly standardized procedures of anthropometric measurements were also major strengths of this study.

5. Conclusions

In conclusion, a good or excellent predictive power for obesity was confirmed for the majority of the analyzed anthropometric indices, except ABSI. Moreover, the results of this study demonstrated and confirmed the need to change the approach to commonly used indicators such as BMI or WHtR in adults, which should lead to the establishment of new criteria for the diagnosis of obesity that will also be sex-specific, in the adult population. The measurement of fat mass should become a generally accepted indicator for the effective diagnosis, as well as for screening, of obesity.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app12126165/s1; Table S1. The area under ROC curve (AUC), optimal cut-off values, sensitivity (Sens.), specificities (Spec.) and Youden Index of anthropometric indices in sarcopenia by using FMI-FFMI or FM to FFM ratio in women; Table S2. The area under ROC curve (AUC), optimal cut-off values, sensitivity (Sens.), specificities (Spec.) and Youden Index of anthropometric indices in predicting sarcopenic obesity by using FMI-FFMI or FM to FFM ratio in women.

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Abbreviations

ABSI	body shape index
AMA	arm muscle area
AUC	the area under the curve
AVI	abdominal volume index

BAI	body adiposity index
BMI	body mass index
BRI	body roundness index
H	height
HC	hip circumference
FFM	fat free mass
FFMI	fat free mass index
FM	fat mass
FMI	fat mass index
MAC	muscle-arm circumference
MUAC	mid-upper arm circumference
RFM	relative fat mass
SD	standard deviation
WC	waist circumference
WHR	waist-to-hip ratio
WHtR	waist-to-height ratio

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