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ORIGINAL ARTICLE

THE USE OF PORTABLE ABDOMINAL BIOIMPEDANCE ANALYZER YSCOPE IN THE ASSESSMENT OF ABDOMINAL OBESITY

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ABSTRACT

Background. Obesity, especially abdominal obesity, is strongly correlated with metabolic and other health risks. Diagnosis and assessment of obesity is important in clinical and routine preventive practice. From the point of view of risk, it is necessary to distinguish not only the area of fat tissue accumulation, but also its type.

Objective. The aim of the study was to use a new portable abdominal bioimpedance analyzer, which is intended for the area of abdominal adipose tissue, as part of the evaluation of the body structure of a selected group of volunteers with a focus on the differentiation of subcutaneous and visceral adipose tissue and to assess its usefulness in practice.

Material and methods. Body composition was analyzed using a portable abdominal bioimpedance analyzer Yscope (PA-BIA) in combination with a bioimpedance device InBody 970 (high-frequency bioelectrical impedance/HF-BIA). Eighty-three volunteers at the age of 24.92±7.24 years with representation of both sexes participated in the study.

Results. Abdominal fat did not differ significantly between the sexes, women reached an average value of 2.01±1.14 kg, men 2.22±1.60 kg ($p>0.05$). Gender differentiation was manifested in the case of visceral fat ($p<0.01$) and visceral fat area ($p<0.01$), the values of which were lower in women than in men. In the case of subcutaneous fat, we found the opposite trend of values in relation to gender, where lower values were achieved by men, but there were no significant differences ($p>0.05$). Visceral fat was most correlated with abdominal fat ($r=0.86$) and waist circumference ($r=0.85$), subcutaneous fat had the strongest positive correlations with abdominal fat ($r=0.93$) and with body fat mass ($r=0.93$).

Conclusions. PA-BIA in combination with HF-BIA makes it possible to determine the representation of subcutaneous and visceral fat in the abdominal area, which the conventional MFS-BIA method does not allow. When evaluating body composition, significant gender differentiation is confirmed, which is an important factor affecting different health risks related to gender and the representation of different types of fat tissue localized and accumulated in different parts of the body.

Keywords: *fat, abdominal, visceral, subcutaneous, bioimpedance, Yscope, InBody*

INTRODUCTION

Adipose tissue has been considered an energy reservoir for decades, but nowadays it is considered a complex organ that, although it still fulfills the function of an energy source, is also metabolically active and interacts with systemic and local inflammation [23]. The health risk is represented by adipose tissue dysfunction in the form of adipocyte hypertrophy, low level of free fatty acid intake, reduced triglyceride synthesis, impaired adipogenesis, resistance to the inhibitory effect of insulin on lipolysis, adipose tissue fibrosis, secretion of pro-inflammatory cytokines and others [19, 27, 28, 46]. There is no doubt that not only total adiposity, but also abdominal adiposity is strongly associated with metabolic disorders and cardiovascular risk factors [7, 8, 33, 40].

Abdominal obesity is a condition in which fat accumulates excessively in the abdominal area. It is associated with diseases such as dyslipidemia, diabetes mellitus, atherosclerosis, and hypertension [1, 21, 33, 38]. Abdominal fat can be divided into subcutaneous and visceral fat according to its location. Abdominal visceral adipose tissue represents the largest proportion of visceral fat in the body. It consists of fat deposits in the retroperitoneal, omental and mesenteric spaces [23]. We can currently estimate the prevalence of visceral adiposity at a total of more than 20%. Excessive visceral adiposity is observed not only in the obese, but also in those with

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overweight or even normal body weight [8]. Visceral fat is considered a key factor in the pathogenesis of insulin resistance, chronic inflammation [11, 48] and type 2 diabetes [4]. Excessive visceral adipose tissue produces inflammatory mediators, producing three times more interleukin-6 compared to subcutaneous fat [29]. Increased IL-6 levels contribute to an increase in C-reactive protein, another inflammatory marker [10]. Excessive accumulation of visceral adipose tissue induces low-grade systemic inflammation [2, 5, 47]. The health risks of subcutaneous fat are still unclear and controversial. Compared to visceral adipose tissue, subcutaneous tissue is less cellular, has a smaller proportion of large adipocytes, is less vascular, and contains a smaller number of inflammatory and immune cells [15]. Several studies have suggested a protective effect of subcutaneous tissue on glucose metabolism [12, 14]. However, several studies suggest a positive relationship between the amount of subcutaneous fat and metabolic and atherogenic risks [9, 22]. Even excessive accumulation of subcutaneous adipose tissue can cause insulin resistance, so any adiposity, whether subcutaneous or visceral, should be considered and evaluated [34].

Abdominal obesity can be determined based on anthropometric data such as waist circumference, the ratio of waist circumference to hip circumference or using the ratio of waist circumference to height. However, these variables do not differentiate between subcutaneous and visceral fat, and are characterized by a high degree of imprecision [41]. Therefore, it is necessary to determine abdominal fat using technologies that are most suitable for this diagnosis. Among all methods, computed tomography (CT) is considered the gold standard [24]. In addition to this technique, magnetic resonance imaging (MRI) and dual-energy X-ray absorptiometry (DXA) are also used. However, they are very expensive, not readily available, and expose the patient to the risk of radiation exposure [17, 32]. In contrast, bioelectrical impedance (BIA) is non-invasive, inexpensive and without the risk of exposure to radiation [35, 50]. The principle of the method consists in the passage of an electric current through parts of the body that create resistance and cause a delay in conduction through the membranes, which causes reactance [30]. BIA uses the difference in electrical conductivity according to the biological characteristics of the tissue [18]. BIA is able to determine the representation of fat and fat-free mass, as well as body water. Among other things, the multi-frequency segmental BIA method (MFS-BIA) is also capable of segmental body composition analysis using electrodes that are in contact with the limbs [26]. Currently, non-invasive MFS-BIA is mainly used to estimate visceral adipose tissue [20, 36]. For visceral fat, this technique has been shown to have a significant correlation with values determined by CT, MRI or DXA [37]. This correlation is moderate, therefore creating an opportunity for improvement of the BIA technique. Scharfetter et al. [42] developed a technique to quantify abdominal subcutaneous fat with electrical impedance in the waist region. Ryo et al. [39] introduced the determination of VFA using local BIA. In 2020, a portable abdominal impedance analyzer (Yscope R; InBody Corporation, Seoul, South Korea) was developed for these purposes, which works on the principle of transverse abdominal impedance and waist circumference measurements. It can quantify the amount and area of subcutaneous and visceral fat. Yoon et al. [50] showed that the use of the MFS-BIA technique in combination with a portable abdominal BIA device improved the correlation with CT measurements.

The aim of the study was to carry out anthropometric measurements using the InBody 970 bioimpedance device (high-frequency bioelectrical impedance/HF-BIA) together with the Yscope (portable abdominal bioimpedance analyzer/PA-BIA) device, which is specified for the area of abdominal fat tissue, and to assess its relevance and usefulness in common practice.

MATERIALS AND METHODS

Study design

The study was conducted from October to December 2023. The total number of subjects settled at eighty-three, of which 55 were women and 28 were men. The participants were informed about the measurement procedure and possible risks in the case of an electrical device implanted in the body on the heart or in the case of pregnancy. Before the measurement, participants were asked to exclude and refrain from drinking large amounts of water, not to consume alcohol 24 hours before testing, to avoid food with a high sugar, salt or fat content for 12 hours before testing, to refrain from intense physical activity for at least 12 hours beforehand. In addition to informed written consent, all participants also signed consent to the processing of personal data. The study was conducted with the approval of the Ethics Committee of the Specialized Hospital of St. Zoerardus Zobor in Nitra, Slovakia (protocol no. 20230512/2) according to the guidelines of the Declaration of Helsinki.

Body composition was analyzed using the InBody 970 (HF-BIA; InBody Corporation, Seoul, South Korea), which measured the impedance of five body segments at 1, 5, 50, 250, and 500 kHz and 1, 2, and 3 MHz (higher frequencies allow constant current to pass and minimize error) [13, 49], and Yscope (PA-BIA; InBody Corporation, Seoul, South Korea) with sine waves of 50 and 250 kHz. When measuring

with the InBody 970, the measured subject stood barefoot on the platform electrodes and held both hand electrodes. The Yscope measurement was performed on the right side of the abdomen after wiping the skin with a wet tissue. After each measurement, the contact surfaces were cleaned with an alcohol swab. Visceral and subcutaneous fat area was estimated using axial and transverse impedance values [50].

For the purpose of assessing body composition, most parameters, with the exception of height and age, were determined directly by bioimpedance analysis. When evaluating individual parameters and indicators and their mutual correlation, we relied on classifications of risk values. According to BMI, obesity was defined as BMI ≥30 kg·m^{-2}, underweight as BMI <18.5 kg·m^{-2}, healthy weight between 18.5 and 25 kg·m^{-2} and overweight between 25 and 30 kg·m^{-2}. Obesity was also defined in our study as waist circumference ≥88 cm and ≥102 cm for women and men, %FM ≥28% for women and ≥20% for men. According to the WHR, we defined obesity at values higher than 1.0 in men and 0.85 in women. WHR values of 0.94 in men and 0.8 in women defined the cutoff value of low health risk related to abdominal obesity. The optimal value of the visceral fat area is less than 100 cm^2.

Statistical analysis

We used Microsoft Office Excel 2016 (Los Angeles, CA, USA) in combination with XLSTAT (version 2019.3.1) for data processing. We performed statistical analysis using the computer software STATISTICA 13 (TIBCO Software, Inc., Palo Alto, CA, USA) and MedCalc software (MedCalc® Statistical Software Ltd, Ostend, Belgium, version 22.021). The normality of the variable distribution was checked by the Shapiro-Wilk test. We used the paired t-test if the data were normally distributed, if the distribution was not normal, the Wilcoxon signed rank test was used. We performed descriptive analysis using mean ± standard deviation. For the monitored parameters, we present the 95% CI (confidence interval). To evaluate the relationship between variables, we used Spearman›s correlation analysis and expressed it graphically with color scales through correlograms. The level of statistical significance was set as $p < 0.05$.

RESULTS AND DISCUSSION

The study was conducted on a sample of eighty-three young subjects with an average age of 24.92±7.24 years. The female gender was represented by 55 women aged 25.67±8.66 years, the male by 28 individuals aged 23.43±2.43 ($p>0.05$). The research group consisted of individuals with an average BMI of 24.10±3.76 kg·m^{-2}, which categorizes them as a group with a normal body weight. Waist circumference was 82.01±11.31 cm, WHR 0.84±0.07, body fat mass 18.08±7.69 kg, while it turned out that the most fat mass was located in the trunk, then in the arms and least in the legs. The proportion of fat in body weight was 25.65±8.65%. The total abdominal fat was 2.08±1.31 kg, of which visceral fat was 0.71±0.55 kg and subcutaneous fat 1.37±0.86 kg. The average value of the area of visceral adipose tissue was 73.8±52.91 cm^2, which is within the reference range, and the area of subcutaneous adipose tissue was 139.44±85.98 cm^2. The results clearly show that subcutaneous fat has a significant advantage compared to visceral fat. The individual parameters are summarized in more detail in Table 1.

However, we found some differences in sexual differentiation (Table 2). The average value of BMI in women was 23.28±3.37 kg·m^{-2}, which categorizes them as a group with normal body weight, but in the male group the average value of BMI was 25.69±4.01 kg·m^{-2} ($p<0.01$), which categorizes them as an overweight group. However, as it turned out subsequently in connection with the representation of fat and muscle components, the increased BMI values were caused by a higher proportion of muscular mass, which is an expected condition for the male sex. Waist circumference was 79.85±10.44 cm in the female group, 86.25±11.95 cm in the male group ($p<0.05$), in both cases these were optimal values. Women had an average value of body fat mass higher than men in the order of 19.40±6.91 kg versus 15.50±8.60 kg ($p<0.05$). However, gender differentiation was not significantly demonstrated in the representation of segmental body fat ($p>0.05$), even though women had higher values than men. In both sexes, it was shown that the most fat mass was located in the torso, followed by the arms and the least in the legs. The proportion of fat in body weight was 29.55±6.41% in women, which places women in the category with an increased and risky amount of fat. The proportion of fat in body weight was significantly lower in men than in women, namely 17.98±7.28% ($p<0.001$), which is within the optimal values. Abdominal fat did not differ significantly between the sexes, women reached an average value of 2.01±1.14 kg, men 2.22±1.60 kg ($p>0.05$). However, gender differentiation was evident in visceral fat ($p<0.01$) and visceral fat area ($p<0.01$). Visceral fat in women was 0.58±0.47 kg, in men 0.98±0.59 kg. Similarly, the area of visceral fat was lower in women (62.34±48.83 cm^2) than in men (96.30±54.24 cm^2). Visceral fat representation did not reach risk values. Abdominal fat is also made up of subcutaneous fat. In this case, we registered the opposite trend of values in relation to gender, where higher values were achieved by women, but there were no significant differences ($p>0.05$). Subcutaneous fat in women had an average value of 1.44±0.73 kg, the area of subcutaneous fat was 149.83±74.55 cm^2. Subcutaneous fat in men had an

Table 1. Basic descriptive characteristics of study group

Parameters (n=83)	Mean	SD	95% CI
Age, years	24.92	7.24	23.334 - 26.497
Basal Metabolic Rate (BMR, kcal)	1505	288	1442 - 1567
InBody Score (points)	76.65	8.46	74.804 - 78.497
Weight (kg)	70.61	15.28	67.272 - 73.947
Height (cm)	170.58	9.30	168.547 - 172.609
Body Mass Index (BMI, kg·m^{-2})	24.10	3.76	23.275 - 24.915
Waist Circumference (WC, cm)	82.01	11.31	79.539 - 84.480
Hip Circumference (HC, cm)	97.04	6.62	95.596 - 98.488
Waist-Hip Ratio (WHR)	0.84	0.07	0.827 - 0.859
Body Cell Mass (BCM, kg)	34.41	8.92	32.465 - 36.361
Soft Lean Mass (SLM, kg)	49.48	12.61	46.727 - 52.234
Lean Mass of Left Arm (%)	105.84	13.42	102.904 - 108.766
Lean Mass of Right Arm (%)	106.52	12.63	103.761 - 109.275
Lean Mass of Left Leg (%)	103.56	6.84	102.066 - 105.055
Lean Mass of Right Leg (%)	103.96	6.76	102.485 - 105.435
Lean Mass of Trunk (%)	103.87	7.45	102.243 - 105.495
Fat Free Mass (FFM, kg)	52.53	13.33	49.617 - 55.438
Skeletal Muscle Mass (SMM, kg)	29.34	8.11	27.566 - 31.108
Total Body Water (TBW, L)	38.47	9.76	36.336 - 40.597
Extracellular Water (ECW, L)	14.44	3.55	13.662 - 15.213
Intracellular Water (ICW, L)	24.03	6.22	22.670 - 25.387
TBW/FFM (%)	73.22	0.16	73.189 - 73.257
ECW/TBW	0.38	0.01	0.374 - 0.377
Body Fat Mass (BFM, kg)	18.08	7.69	16.402 - 19.762
BFM of Left Arm (%)	134.67	90.91	114.815 - 154.518
BFM of Right Arm (%)	133.83	89.85	114.213 - 153.452
BFM of Left Leg (%)	119.04	41.29	110.025 - 128.056
BFM of Right Leg (%)	119.73	41.62	110.644 - 128.819
BFM of Trunk (%)	180.44	83.90	162.123 - 198.763
Percent Body Fat (PBF, %)	25.65	8.65	23.761 - 27.538
Arm Circumference (AC, cm)	31.24	3.77	30.413 - 32.057
Arm Muscle Circumference (AMC, cm)	27.40	3.50	26.636 - 28.166
AC minus AMC (cm)	3.83	1.33	3.544 - 4.124
Abdominal Fat (AF, kg)	2.08	1.31	1.797 - 2.368
Visceral Fat of abdomen (VF, kg)	0.71	0.55	0.594 - 0.833
Subcutaneous Fat (SF, kg)	1.37	0.86	1.180 - 1.557
Visceral Fat Area (VFA, cm^2)	73.80	52.91	62.244 - 85.352
Subcutaneous Fat Area (SFA, cm^2)	139.44	85.98	120.669 - 158.218
VFA/SFA	0.57	0.43	0.473 - 0.662

SD – standard deviation; CI – confidence interval

average value of 1.24±1.08 kg, the area of subcutaneous fat was 119.05±103.37 cm^2. More detailed results based on gender differentiation are presented in Table 2.

Based on the correlation analysis, we further found that visceral fat was most correlated with abdominal fat (r=0.86), waist circumference (r=0.85), arm circumference (r=0.79), the proportion of fat in the trunk (r=0.71), the circumference of the arm muscle (r=0.70), the proportion of fat in the right and left leg (r=0.61/r=0.60), the proportion of fat in the right and left arm (r=0.57/r=0.56) and the same with body fat mass (r=0.56). Correlation dependences of visceral fat area

Table 2. Descriptive characteristics of the group adjusted by gender

Parameters	Female n=55		Male n=28		p-value
	Mean	SD	Mean	SD	
Age, years	25.67	8.66	23.43	2.43	ns
Basal Metabolic Rate (BMR, kcal)	1337.04	112.18	1833.79	238.69	<0.001
InBody Score (points)	73.82	5.71	82.21	10.17	<0.001
Weight (kg)	64.17	10.33	83.26	15.67	<0.001
Height (cm)	165.97	6.92	179.63	6.25	<0.001
Body Mass Index (BMI, $kg \cdot m^{-2}$)	23.28	3.37	25.69	4.01	<0.01
Waist Circumference (WC, cm)	79.85	10.44	86.25	11.95	<0.05
Hip Circumference (HC, cm)	94.80	5.26	101.45	6.89	<0.001
Waist-Hip Ratio (WHR)	0.84	0.07	0.85	0.07	ns
Body Cell Mass (BCM, kg)	29.17	3.39	44.72	7.24	<0.001
Soft Lean Mass (SLM, kg)	42.12	4.87	63.94	10.41	<0.001
Lean Mass of Left Arm (%)	102.05	10.26	113.28	15.80	<0.001
Lean Mass of Right Arm (%)	103.25	9.75	112.94	15.15	<0.001
Lean Mass of Left Leg (%)	103.17	7.10	104.33	6.36	ns
Lean Mass of Right Leg (%)	103.53	6.90	104.80	6.49	ns
Lean Mass of Trunk (%)	101.84	5.70	107.86	8.86	<0.001
Fat Free Mass (FFM, kg)	44.77	5.20	67.77	11.05	<0.001
Skeletal Muscle Mass (SMM, kg)	24.57	3.08	38.71	6.58	<0.001
Total Body Water (TBW, L)	32.78	3.78	49.63	8.09	<0.001
Extracellular Water (ECW, L)	12.41	1.44	18.41	3.07	<0.001
Intracellular Water (ICW, L)	20.37	2.36	31.22	5.05	<0.001
TBW/FFM (%)	73.21	0.14	73.25	0.19	ns
ECW/TBW	0.38	0.01	0.37	0.01	<0.001
Body Fat Mass (BFM, kg)	19.40	6.91	15.50	8.60	<0.05
BFM of Left Arm (%)	138.42	65.75	127.30	127.95	ns
BFM of Right Arm (%)	137.01	65.63	127.60	125.87	ns
BFM of Left Leg (%)	120.41	35.73	116.35	51.11	ns
BFM of Right Leg (%)	120.91	35.86	117.41	51.77	ns
BFM of Trunk (%)	177.73	68.04	185.77	109.89	ns
Percent Body Fat (PBF, %)	29.55	6.41	17.98	7.28	<0.001
Arm Circumference (AC, cm)	29.82	2.94	34.01	3.69	<0.001
Arm Muscle Circumference (AMC, cm)	25.59	2.05	30.95	3.02	<0.001
AC minus AMC (cm)	4.23	1.06	3.06	1.47	<0.001
Abdominal Fat (AF, kg)	2.01	1.14	2.22	1.60	ns
Visceral Fat of abdomen (VF, kg)	0.58	0.47	0.98	0.59	<0.01
Subcutaneous Fat (SF, kg)	1.44	0.73	1.24	1.08	ns
Visceral Fat Area (VFA, cm^2)	62.34	48.83	96.30	54.24	<0.01
Subcutaneous Fat Area (SFA, cm^2)	149.83	74.55	119.05	103.37	ns
VFA/SFA	0.37	0.20	0.96	0.50	<0.001

SD – standard deviation; p – significance; ns – non-significant

almost followed the trend of visceral fat dependences. VFA was most correlated with waist circumference (r=0.91), followed by abdominal fat (r=0.81), arm circumference (r=0.81), body fat percentage (r=0.76), muscle circumference arm (r=0.70), the proportion of fat in the right and left leg (r=0.64), with body fat mass (r=0.61) and the proportion of fat in the right and left arm (r=0.61/r=0.60) (Table 3).

Table 3. Correlation analysis of VF, VFA, SF and SFA in relation to anthropometric parameters

Parameters	Visceral Fat		Subcutaneous Fat		VFA		SFA	
	r	p	r	p	r	p	r	p
Fat Free Mass	0.559	***	0.046	ns	0.531	***	-0.008	ns
Skeletal Muscle Mass	0.558	***	0.041	ns	0.527	***	-0.012	ns
Body Fat Mass	0.56	***	0.928	***	0.613	***	0.936	***
BFM % of Left Arm	0.556	***	0.904	***	0.598	***	0.917	***
BFM % of Right Arm	0.568	***	0.904	***	0.608	***	0.917	***
BFM % of Left Leg	0.602	***	0.874	***	0.636	***	0.889	***
BFM % of Right Leg	0.611	***	0.873	***	0.644	***	0.888	***
BFM % of Trunk	0.707	***	0.884	***	0.761	***	0.888	***
Percentage of Body Fat	0.242	*	0.779	***	0.302	**	0.814	***
Arm Circumference	0.791	***	0.467	***	0.808	***	0.447	***
Arm Muscle Circumference	0.699	***	0.226	*	0.696	***	0.197	ns
Waist Circumference	0.845	***	0.678	***	0.914	***	0.655	***
Abdominal Fat	0.86	***	0.933	***	0.812	***	0.92	***
TBW (Total Body Water)	0.558	***	0.046	ns	0.533	***	-0.008	ns
TBW/FFM	-0.119	ns	-0.287	**	-0.102	ns	-0.281	*
Intracellular Water	0.556	***	0.041	ns	0.526	***	-0.012	ns
Extracellular Water	0.566	***	0.065	ns	0.548	***	0.009	ns
Basal Metabolic Rate	0.557	***	0.044	ns	0.531	***	-0.01	ns
Recommended Calorie Intake	0.119	ns	-0.316	**	0.058	ns	-0.376	***

r – Spearman correlation coefficient; p – significance; * – statistical significance at the level $p<0.05$; ** – statistical significance at the level $p<0.01$; *** – statistical significance at the level $p<0.001$; ns – non-significant

The correlations between subcutaneous fat tissue and subcutaneous fat area in the abdominal area are different than in the case of visceral fat tissue (Table 3). The strongest positive correlations were found between subcutaneous fat and abdominal fat (r=0.93), with body fat mass (r=0.93), the proportion of fat in the arms (r=0.90), with the proportion of fat in the trunk (r=0.88), the proportion of fat in the legs (r=0.87), the proportion of body fat (r=0.78), waist circumference (r=0.68) and arm circumference (r=0.47). With few exceptions, subcutaneous fat area replicated the correlations of subcutaneous fat amount. The strongest correlations were the area of subcutaneous fat with body fat mass (r=0.94), with abdominal fat (r=0.92), with the proportion of fat in the arms (r=0.92), with the proportion of fat in the trunk (r=0.89), with the proportion of fat in the legs (r=0.89), with the proportion of body fat (r=0.81), waist circumference (r=0.66) and arm circumference (r=0.45).

Correlation analysis also showed that while visceral fat and visceral fat area had moderately strong positive dependence with fat-free mass (r=0.56/r=0.53), skeletal muscle mass (r=0.56/r=0.53), total body water (r=0.56/r=0.53), ICW (r=0.56/r=0.53), ECW (r=0.57/r=0.55) and BMR (r=0.56/r=0.53), in the case of subcutaneous fat and subcutaneous fat area the correlations were weak, in some cases negative (FFM r=0.05/r=-0.01; SMM r=0.04/r=-0.01; TBW r=0.05/r=-0.01; ICW r=0.04/r=-0.01; ECW r=0.07/r=0.01 and BMR r=0.04/r=-0.01, respectively) (Tables 3 and 4). Subcutaneous fat and subcutaneous fat area showed weaker correlation associations also in relation to body weight (r=0.43 and r= 0.39, respectively) (Table 4). Visceral fat and visceral fat area had stronger associations (r=0.77 and r=0.78, respectively). In relation to BMI, stronger correlations were again confirmed for visceral fat and visceral fat area (r=0.80 and r=0.84, respectively) than subcutaneous fat and subcutaneous fat area (r=0.62 and r=0.62, respectively).

Two studies found that visceral adipose tissue was strongly correlated with body fat, suggesting a positive relationship of visceral fat to overall adiposity [2, 25]. In our study, its correlation with body fat mass, but not with PBF, was confirmed. Snell Bergeon et al. [43] reported that subcutaneous adipose tissue was more strongly correlated with BMI and waist circumference than visceral adipose tissue, but not with WHR. However, our results did not confirm this and showed a stronger correlation in the case of visceral fat.

Carroll et al. [6] found that African Americans and women had significantly lower values of visceral adipose tissue than whites and Hispanics. The amount of subcutaneous adipose tissue, on the other hand, was higher in African Americans. Mundi et al. [31]

Table 4. Correlogram of mutual associations between individual anthropometric parameters

	Weight	BMI	WHR	SLM	FFM	SMM	BFM	PBF	AC	AMC	WC	AF	VF	SF	VFA	SFA
Weight		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.9677	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
BMI	0.828		<0.001	<0.001	<0.001	<0.001	<0.001	<0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
WHR	0.522	0.57		<0.01	<0.01	<0.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
SLM	0.862	0.55	0.287		<0.001	<0.001	0.7193	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	0.6922	<0.001	0.9314
FFM	0.864	0.551	0.289	1		<0.001	0.7425	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	0.6771	<0.001	0.9463
SMM	0.858	0.55	0.286	0.999	0.999		0.6708	<0.001	<0.001	<0.001	<0.001	<0.05	<0.001	0.7111	<0.001	0.9148
BFM	0.397	0.637	0.614	-0.04	-0.037	-0.047		<0.001	<0.001	0.1306	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
PBF	-0.005	0.321	0.419	-0.449	-0.446	-0.455	0.881		0.5295	0.0541	<0.01	<0.001	<0.05	<0.001	<0.01	<0.001
AC	0.929	0.925	0.536	0.757	0.756	0.758	0.437	0.07		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
AMC	0.909	0.784	0.407	0.879	0.877	0.882	0.167	-0.212	0.948		<0.001	<0.001	<0.001	<0.05	<0.001	0.0741
WC	0.801	0.823	0.895	0.549	0.55	0.548	0.657	0.34	0.808	0.68		<0.001	<0.001	<0.001	<0.001	<0.001
AF	0.63	0.768	0.747	0.274	0.276	0.272	0.856	0.615	0.661	0.457	0.835		<0.001	<0.001	<0.001	<0.001
VF	0.771	0.801	0.697	0.558	0.559	0.558	0.56	0.242	0.791	0.699	0.845	0.86		<0.001	<0.001	<0.001
SF	0.431	0.622	0.64	0.044	0.046	0.041	0.928	0.779	0.467	0.226	0.678	0.933	0.637		<0.001	<0.001
VFA	0.782	0.836	0.789	0.529	0.531	0.527	0.613	0.302	0.808	0.696	0.914	0.812	0.939	0.59		<0.001
SFA	0.389	0.616	0.626	-0.01	-0.008	-0.012	0.936	0.814	0.447	0.197	0.655	0.92	0.619	0.995	0.575	

BMI – Body Mass Index; WHR – Waist-to-Hip Ratio; SLM – Soft Lean Mass; FFM – Fat-free Mass; SMM – Skeletal Muscle Mass; BFM – Body Fat Mass; PBF – Percentage of Body Fat; AC – Arm Circumference; AMC – Arm Muscle Circumference; WC – Waist Circumference; AF – Abdominal Fat; VF – Visceral Fat; SF – Subcutaneous Fat; VFA – Visceral Fat Area; SFA – Subcutaneous Fat Area

found in the case of non-diabetic Caucasians visceral adipose tissue values of 40 cm^2 for women and 74 cm^2 for men, subcutaneous adipose tissue values were 169 cm^2 and 133 cm^2 for women and men, respectively.

As part of gender differentiation, males have a significantly larger area of visceral adipose tissue, while females tend to have slightly more subcutaneous adipose tissue, especially in the lower abdomen [9, 16, 24]. Our results confirm these findings. The largest areas of visceral adipose tissue are present in the upper abdomen, while the area of subcutaneous adipose tissue is higher in lower anatomical locations [9, 16].

Results from the Jackson Heart Study of 2477 African Americans showed that visceral and subcutaneous adipose tissue in the abdominal region were associated with adverse cardiometabolic risk factors (including diabetes), and that the strength of the effect of visceral adipose tissue was greater in women than subcutaneous adipose tissue [22]. Framingham researchers found that both types of adipose tissue, visceral and subcutaneous, were significantly associated with hypertension, dyslipidemia, impaired fasting glucose, and metabolic syndrome. However, visceral fat area had a significantly stronger association compared to subcutaneous fat [9]. The Jackson Heart Study of 2799 African Americans found a direct association between subcutaneous adipose tissue and adiponectin that persisted after controlling for BMI and WC in men, while significance was borderline in women [3]. There are differences between subcutaneous and visceral adipose tissue in the abdominal region, at the anatomical, cellular, molecular, physiological and other levels [15].

Yoon et al. [50] found that the application of PA-BIA in combination with MFS-BIA significantly improves the accuracy of abdominal visceral fat measurements. In their study, it was shown that in concordance with CT results, PA-BIA technology together with MFS-BIA was more accurate than MFS-BIA alone in determining VFA. Results did not differ either in the overall population or in subgroups adjusted for sex, age, and BMI. The use of PA-BIA allows, among other things, to determine the values of the subcutaneous fat area, which the conventional MFS-BIA method does not allow.

However, in humans, the development of obesity does not only lead to an increase in adipose tissue reserves in classical locations, such as subcutaneous and visceral adipose tissues, but also around specific organs, such as the heart (pericardial), blood vessels (perivascular) and kidneys (renal) or internal organs such as skeletal muscle (intramuscular) and liver (intrahepatic), which have all been described as sites for ectopic fat deposition [44, 45]. Excessive regional deposits of adipose tissue can alter organ function through mechanical compression or through secreted cytokines and chemokines [45] and thus pose significant health risks. Therefore, further studies and the development of more accurate but easily available diagnostic technologies determining not only visceral and subcutaneous fat tissue, but also ectopic ones are needed.

CONCLUSIONS

Obesity or excessive accumulation of fat beyond the body's physiological needs is one of the serious diseases in which, in addition to evaluating the location of fat storage, it is also very important to distinguish what type of adipose tissue it is. While subcutaneous fat is not significantly associated with serious health complications, visceral adipose tissue located around internal organs is associated with the development of several serious metabolic disorders. Many methods are currently used to determine the amount of fat in the body. Recently, a bioimpedance device designed for the assessment of abdominal obesity was developed, with the possibility of estimating not only visceral, but also subcutaneous fat. The use of such technologies in the diagnosis of obesity, especially abdominal obesity, is of great importance in practice, especially due to their non-invasiveness, affordability and relative safety. The assessment of body composition confirms significant gender differentiation, which is an important factor affecting different health risks related to gender and the representation of different types of fat tissue localized and accumulated in different parts of the body.

Conflict of interest

The authors declare no conflict of interest.

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