Differences in the frequency of overweight and obesity measured by means of body adiposity index (BAI) or body fat percentage (BF%) in 18-year-old students from southeastern Poland

Różnice w częstości rozpoznawania nadwagi i otyłości przy zastosowaniu wskaźnika otłuszczenia ciała (BAI) oraz odsetka tkanki tłuszczowej (BF%) u 18-letnich uczniów z południowo-wschodniej Polski

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Wstęp. Zawartość tkanki tłuszczowej jest podstawą dla rozpoznawania otyłości i jest uważana za czynnik ryzyka zdrowotnego. Wiele wskaźników antropometrycznych znalazło dotąd zastosowanie w określaniu stopnia otłuszczenia ciała. Jednym z najczęściej używanych w codziennej praktyce jest wskaźnik masy ciała (BMI), jednakże nie pozwala on na dokładne określenie zawartości i rozmieszczenia tkanki tłuszczowej. Deurenberg i wsp. zaproponowali wzory dla oceny odsetka tkanki tłuszczowej (BF%) ustalanego w oparciu o BMI. Natomiast Bergman i wsp. zdefiniowali wskaźnik otłuszczenia ciała (BAI), który określa odsetek tkanki tłuszczowej w oparciu o wzrost i obwód bioder.

Cel pracy. Ustalenie różnic w częstości występowania nadwagi i otyłości określanych w oparciu o odsetek tkanki tłuszczowej w zależności od zastosowanego wskaźnika w grupie 18-latków.

Materiał. Badana grupa obejmowała 631 uczniów (377 K i 254 M) z południowo-wschodniej Polski.

Wyniki. Częstość rozpoznawania otyłości oceniana za pomocą BAI i BF% w całej badanej grupie wynosiła odpowiednio 12% (K-0,7; M-28,7) and 2,2% (K-1,6; M-3,1). Nadwaga rozpoznana za pomocą BAI stanowiła 21,2% (K-3,6; M-44,5) i 2,2% (K-2,4; M-2,0) za pomocą BF% w całej grupie. Prawidłowe otłuszczenie ciała charakteryzowało 66,7% (K-93,6; M-26,8) uczniów (w ocenie za pomocą BAI) i 95,6% (K-96; M-93,7) (na podstawie BF%).

Wniosek. Częstość otyłości i nadwagi w badanej grupie uczniów oceniana za pomocą BAI była istotnie wyższa niż w ocenie z zastosowaniem BF%, a różnice te były stwierdzane głównie w grupie chłopców.

Słowa kluczowe: *otyłość, nadwaga, wskaźnik otłuszczenia ciała (BAI), odsetek tkanki tłuszczowej (BF%)*

Introduction. The assessment of body fat is fundamental in the diagnosis of obesity and used as an indicator of health risk. Several anthropometric indices are applicable in determining body fat content. The most popular – body mass index (BMI) – fails in determining the amount and distribution of body fat. Deurenberg et al. proposed formulas for an assessment of body fat percentage (BF%) calculated from BMI. However Bergman et al. defined the body adiposity index (BAI) which estimates the percentage of adipose tissue from a given height and hip circumference.

Aim. To determine the differences in the frequency of overweight and obesity diagnosed with an assessment of the percentage of body fat depending on the used index in a group 18-year-olds.

Material. The material covered 631 students (377 females and 254 males) from southeastern Poland.

Results. The prevalence of obesity in the whole group assessed by means of BAI and BF% was 12% (F-0.7; M-28.7) and 2.2% (F-1.6; M-3.1) respectively. Overweight was diagnosed by means of BAI in 21.2% (F-3.6; M-44.5) of all the students and in 2.2% (F-2.4; M-2.0) by means of BF%. Normal fat content characterized 66.7% (F-93.6; M-26.8) of the students (on the basis of the BAI evaluation) and 95.6% (F-96; M-93.7) (on the basis of the BF% evaluation).

Conclusion. The percentage of overweight and obesity in the tested group determined with BAI was significantly higher than the one determined with BF% and these differences were observed mainly in the male group.

Key words: *adiposity, overweight, body adiposity index (BAI), body fat percentage (BF%)*

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Introduction

Obesity is a chronic multifactorial disease, defined as an excess of body fat. Overweight and obesity are a growing epidemic in the world adult population and also an increasingly frequent health problem in children and adolescents [1-5]. The content of body fat is fundamental in the diagnosis of obesity and overweight and used as an indicator of health risk. A type of body fat which is closely connected with an increased risk of metabolic and cardiovascular disorders is considered the visceral adipose tissue [1-5]. Excessive fat content is a risk factor of many chronic diseases including type 2 diabetes mellitus, cardiovascular diseases, hypertension, stroke, dyslipidemia, liver and gallbladder diseases, sleep apnea and respiratory problems, osteoarthrosis, abnormal menses, infertility and cancer [2, 3, 5].

An assessment of a body composition is an important procedure in the investigation of nutritional status. An accurate quantification of visceral fat compartment can be obtained by magnetic resonance imaging or computed tomography, dual-energy X-ray absorbtiometry (DXA), bioelectrical impedance analysis (BIA), but their economic costs and complexity make them too expensive in daily clinical practice or epidemiological studies [5-7]. Because of this limitation, it is suggested to use anthropometric measures in the estimation of body fat content [5-10].

Actually, several anthropometric indexes are applicable in the assessment of body adiposity [1, 5, 7-10]. For a long time, the one of the most frequently used, both in epidemiologic studies and in clinical practice, was BMI (Quetelet, 1869). Although BMI has been proved to closely correlate with body fat irrespective of age and gender, it does not identify gender and ethnic differences in body adiposity and fails to measure fat distribution [5, 7-10].

In 1991 Deurenberg and et al. [10] proposed formulas for an assessment of body fat percentage (BF%) calculated by means of BMI. They concluded that BMI is the most appropriate for an assessment of body fat percentage, because of its high correlation with body fat and low with body height. They found that proposed formulas gave a valid estimation of body fat in males and females at all ages and that their prediction error is comparable with an error of other ways used in the assessment of body adiposity [10].

In 2011 Bergman et al. [11] defined a new, alternative parameter – the body adiposity index (BAI) – which can be calculated only from a hip circumference and height. In the authors' opinion [11], it directly estimates a percentage of adipose tissue, is more available than BMI (it does not request a weight account) and may become a new international standard for determining body adiposity.

Aim

To determine the differences in the frequency of overweight and obesity diagnosed with the use of a percentage of body fat, depending on the implementation of a newly proposed index BAI or an old BF%, in the group of 18-year-olds from southeastern Poland.

Material and Methods

The tested group comprised 631 subjects, 18-year-old students (377 females and 254 males) from three randomly selected secondary schools from southeastern Poland (e.g. Lublin, Stalowa Wola and Opatów). The tests were performed in September 2007. Basic anthropometric parameters such as body mass, height and hip circumference of every student were tested using standard medical scales and measuring tape. On the basis of these measurements BMI, BAI and BF% were calculated.

BMI was determined by means of the following formula: weight in kg / [height in m]^2

BAI was determined by means of the following formula [11]:

$$BAI = \frac{\text{hip circumference (in cm)}}{\text{height (in m)} \times \sqrt{\text{height (in m)}}} - 18$$

The percentage of body fat (BF%) was calculated from Deurenberg and et al. [10] formula for adults. Deurenberg's population of adults included individuals from the age of 16 years.

$BF\% = 1.2 \times BMI + 0.23 \times age - 10.8 \times sex - 5.4$

Male =1; female 0

In order to identify overweight the authors determined the values of BMI, BAI and BF% between the 85-95th centile and to identify obesity the values of BMI, BAI and BF% were >95 centile adequately to gender and age. According to McCarthy et al. [12], the percentage of body fat was calculated upon tabulated body fat centile values with relation to an exact age. In order to determine the adopted values of BMI centile scales, Polish growth references for school-aged children and adolescents according to Kułaga et al. [13] were used (tab. I).

Table I. BMI ranges {Kułaga et al. [13]} and percentage of body fat {according to McCarthy et al. [12]} [BAI; BF%] used in determination of obesity, overweight and normal fat content in the group of 18-year-old students

Category of body fat content (centile)	Gender	BAI and BF% (percentage of body fat) ranges	BMI kg/m^2 ranges
Obesity >95 c	girls	>34.8	>26.6
	boys	>23.6	>28.2
Overweight >85c - <95c	girls	30.8-34.8	23.9-26.6
	boys	20.1-23.6	25.3-28.2
Normal fatness >5c - 85c <	girls	>14.7-30.8	17.3-23.9
	boys	>9.6-20.1	18.0-25.3

The frequency of the occurrence of particular body adiposity categories and the percentage values of adipose tissue among 18-year-olds was independently assessed by means of BMI and BAI (group 1) and BF% (group 2) separately for females and males. The percentage of adipose tissue in every student was assessed by means of the second index (group 1 – BF% and group 2 – BAI) in the determined body adiposity categories, then they were compared. Finally, the percentage of the adipose tissue in the students in particular body adiposity categories determined by BAI was compared with the percentage of adipose tissue in particular body adiposity categories determined by BF% separately for females and males.

Statistical distribution of variables was evaluated by Shapiro-Wilk testing. Because of the non-Gaussian distribution we used the non-parametric Spearman's R correlation to check the statistical dependences between variables and U-Mann-Whitney test to check differences between the groups. Pearson's chi-squared test was used to check differences in the distribution of obesity, overweight and normal weight between the BF% and BAI measurements. Statistica 10.0.PL was used for statistical analysis and P values <0.05 were counted as significant.

Results

The results of our studies are illustrated in fig. 1, 2 and 3 and tables II-V. Obesity measured with BMI was diagnosed in about 4%, overweight in 5.2% and normal body mass in 87.9% of the whole group of students. Comparatively, with BAI implementation, obesity was found in 12% of the whole group, overweight in 21.2% and normal fat content in 66.7%. This high prevalence of excessive body adiposity determined with BAI was a result of a manifold higher frequency of obesity and overweight in the male students.

The frequency of obesity assessed with BF% amounted to 2.2% and overweight constituted 2.2% of the whole group of students. Normal adiposity was confirmed in 95.6% of all the students (fig. 1).

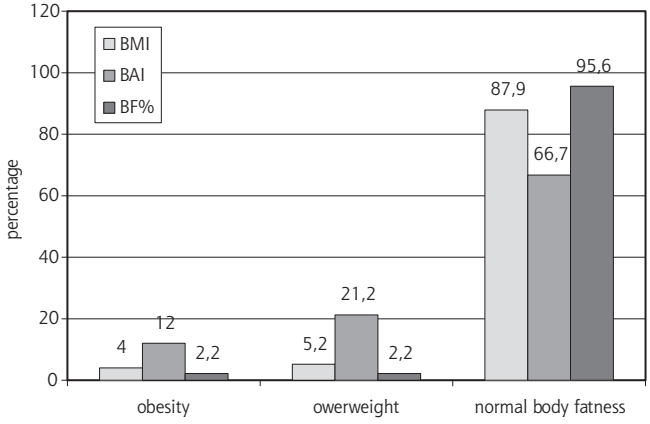

Fig. 1. Comparison of frequency of obesity, overweight and normal body adiposity in whole group of students

The frequencies of excessive and normal body fat content in female and male subgroups which depended on the used adiposity indexes are presented in table II.

In the groups who were assessed with BAI, significant differences in the prevalence of obesity and overweight between the female and male subgroups were observed (tab. II). Obesity was forty times more frequent in males than in females and overweight was about eight times more frequent in males than in females. Normal fat content characterized only about ¼ boys.

In the group assessed with BAI, the majority of females had a normal percentage of body adipose tissue. The prevalence of obesity determined with BAI was very low in females. When BF% was used, the obesity in the female group was two times more frequent than when BAI was implemented. On the other hand, the frequency of overweight was over two times lower than in the female group diagnosed with BAI. The frequency of normal body fat content did not depend on the implemented index and did not differ significantly in the tested subgroups of females. These results can suggest that BAI underestimated the percentage of body fat in females and tended to overestimate fat percentage in males.

In contrast, obesity and overweight in the male group was over seven times more frequent than when it was determined with BAI. Normal fat content was over 3 times more rare than when it was determined with BMI.

Statistical analysis with chi square test of BAI and BF% values shows significant differences in both genders ($p<0.05$; $r=0.47$ for males and $r=0.58$ for females) (tab. III, fig. 2A, fig. 3A).

The percentages of body fat measured with BF% index in female groups with obesity and overweight

Table II. Comparison of frequency of excessive and normal body fat content in 18-year-old females and males depending on applied index

Category of body fat content	377 Girls			254 Boys		
	BMI N#	BAI N	BF% N	BMI N	BAI N	BF% N
obesity	15 [3.9%]	3 [0.7%]	6 [1.6%]	10 [3.9%]	73 [28.7%]	8 [3.1%]
overweight	18 [4.8%]	21 [5.6%]	9 [2.4%]	15 [5.9%]	113 [44.5%]	5 [2.0%]
normal	331 [87.8%]*	353 [93.6%]	362 [96.0%]	224 [88.2%]**	68 [26.8%]	238 [93.7%]***

N = number of students
*3.5% underweight females
** 2% underweight males
*** 0.7% underweight males

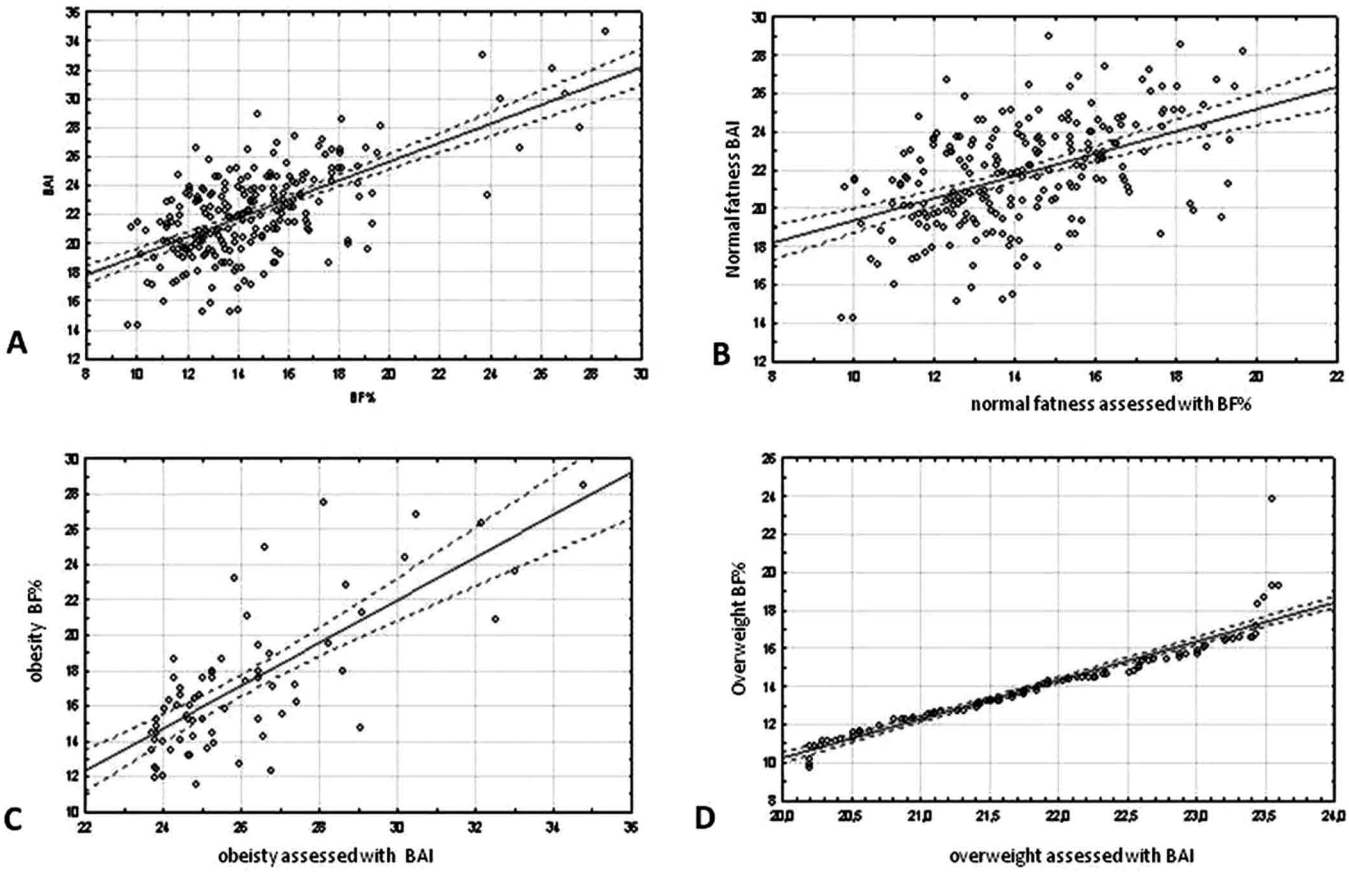

Fig. 2. Statistical results for males group: A – whole group; B – normal fat content in male group assessed with BF%; C – obesity in male group assessed with BAI; D – overweight in male group assessed with BAI

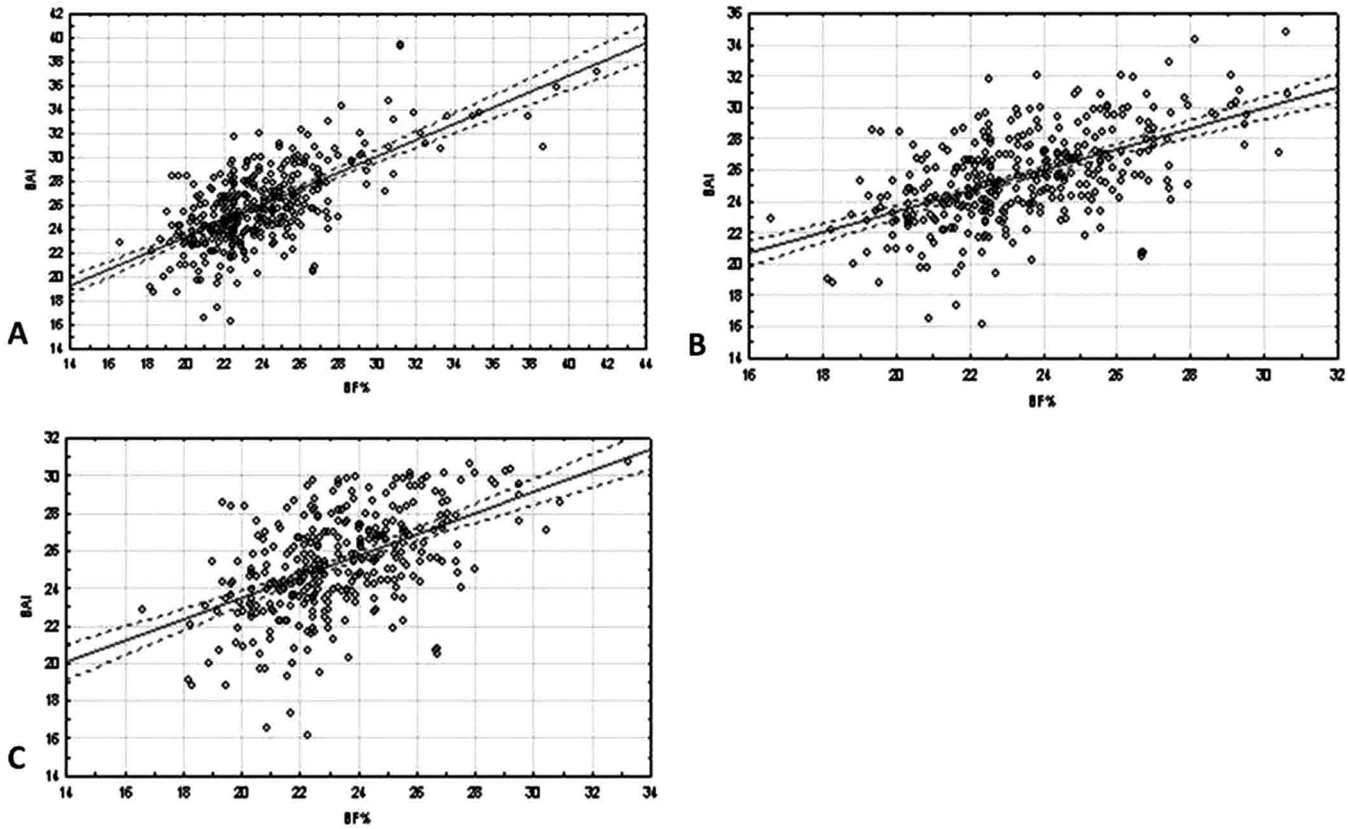

Fig. 3. Statistical results for female group: A – whole group; B – normal fat content in female group assessed with BF%; C – normal fat content in female group assessed with BAI

were subtly higher in group 2, but without statistical significance. In turn, we have found statistically significant differences between the BAI and BF% values in females with normal fat content from group 2 ($p<0.05$, $r=0.53$) and group 1 ($p<0.05$, $r=0.51$) and for the whole female group ($p<0.05$, $r=0.58$) (tab. III, fig. 3B,C). In conclusion, BAI and BF% have a comparable value in assessment of body fat percentage in obese and overweight female students.

In contrast, the male students from group 2 were characterized with higher BAI index than in group 1 (tab. IV). The mean values of BAI in obese and overweight boys from group 2 were included in the obesity range, and students with normal fat content had a level of BAI corresponding with overweight (over 20.1%). In turn, BF% mean values in male group 1 were underestimated, and account in all fat content categories below 20.1%, fit into the interval for male normal body adiposity (tab. IV). These results suggest that adiposity and overweight calculated in boys with the BAI application included students with normal body adiposity if we implemented BF% . These data indicate that BAI overestimates the fat mass percentage and therefore the frequency of obesity and overweight in males.

In table V we compared mean values of BAI and BF% in female and male students with obesity, overweight and normal fat content. The statistically significant differences were observed only in groups with normal fat mass. In the female group BAI was statistically significantly lower than BF% ($p<0.001$), and in the male group BAI was statistically significantly higher than BF% ($p<0.001$) (fig. 2A, 3A), which can suggest that BAI underestimated the percentage of body fat in females and tended to overestimate fat percentage in male students.

The statistically significant differences between BAI and BF% values were observed in the whole male group ($p<0.05$, $r=0.47$) and the one with obesity ($p<0.05$, $r= 0.63$) and a very strong correlation in overweight ($p<0.05$, $r=0,9$) assessed with BAI (tab. IV, fig. 2). Important correlation was also found in the male group with normal fat content assessed by BF% ($p<0.5$, $r=0,47$) (tab. IV, fig. 2B). While assessing monotonic relationships between the assessed parameters (BAI and BF%) in the group of males with overweight diagnosed with BAI (group 1 – body fat content assessed with BAI), a significantly positive Spearman's correlation rank was observed ($r=0.99$ for $p<0.05$) between the BAI values and the corresponding BF% values. It indicates that among the male population with overweight from group 1 the value of BF% was increasing in proportion to BAI (tab. IV).

Discussion

There has been a persistent search for the perfect anthropometric index which would allow a simultaneous evaluation of adipose tissue mass, its localisation and the risk of its frequent occurrence connected with metabolic disorders [5, 7-11, 14-17]. Body mass index

Table III. Comparison of BAI and BF% results in female groups with excessive and normal body fat content

Category of body fat content	BAI % X±SD				BF% X±SD			
	Group 1*	Group 2**	p-value	R Spearman	Group 1	Group 2	p-value	R Spearman
Obesity >34.8	35.9±1.2	34.1±2,2	0,804	0,15	36.8±5.6	37.9±2.5	0,208	0,6
Overweight 30.8-34.8	32.3±1.2	33.6±3.7	0,097	0,36	29.7±4.5	31.9±1.0	0,715	-0,14
Normal 14.7-30.8	25.4±2.7	25.6±2.9	p<0,0000	0,59	23.4±2.5	23.4±2.4	p<0,0000	0,59

*Group 1 – body fat content assessed with BAI
**Group 2 – body fat content assessed with BF%

Table IV. Comparison of BAI and BF% results in male groups with excessive and normal body fat content

Category of body fat content	BAI% X±SD				BF% X±SD			
	Group 1	Group 2	p-value	R Sperman	Group 1	Group 2	p-value	R Spearman
Obesity >23.6	25.9±2.4	29.8±3.7	p<0,000	0,635	17.1±3.9	25.6±1.8	0,49	0,285
Overweight 20.1-23.6	21.8±1.1	28.4±2.7	p<0,000	0,999	14.0±2.3	21.9±1.1	0,188	-0,7
Normal 9.6-20.1	18.3±1.5	21.8±2.7	0,194	0,16	12.9±2.2	14.1±2.4	p<0,000	0,47

*Group 1 – body fat content assessed with BAI
**Group 2 – body fat content assessed with BF%

Table V. Comparison of mean body fat percentage assessed with BAI and BF% in female and male groups

Category of body fat content	Females			Males		
	BAI% X±SD	BF% X±SD	p-value	BAI% X±SD	BF% X±SD	p-value
obesity	35.9±1.2	37.9±2.5	p=0.24	25.9±2.4	25.8±1.8	p=0.38
overweight	32.3±1.2	32.1±1.0	p=0.59	21.8±1.0	21.9±1.1	p=0.26
normal	20.5±2.1	23.4±2.4	p<0.001	18.4±1.5	14.1±2.4	p<0.001

(BMI) was introduced as a method to assess human nutritional status and body fat content. Easy to calculate, it is one of the most frequently used anthropometric parameters, both in epidemiologic studies and in clinical practice. The underlying assumption to use BMI to define obesity is that increased weight is associated with increased body fat mass [9, 11, 15, 17]. BMI was limited as far as adiposity measure and an identification of differences of body composition and fat distribution are concerned. A linear relationship was observed between BMI and body fat mass, but not with BMI and the percentage of body fat [11, 15, 17]. Therefore, BMI should be used as an indicator of body adipose tissue mass, but not as a tool to measure body fat percentage [15]. Therefore about 20 years ago, Deurenberg et al. [10] determined formulas for assessing body fat percentage from BMI.

BAI, introduced by Bergman et al. [11], involves height and hip circumference and may reflect male-female differences in adiposity better and more properly than BMI. The authors found that BAI shows a higher than BMI positive correlation with DXA evaluated body fat percentage and assumed an important conceptual advantage of BAI over BMI. For two years, a validation of accuracy of BAI in the determination of a percentage of body fat in several studies and various populations has been conducted [18-30]. Lopez et al. [18] concluded that BAI demonstrated similar limitations to those of BMI. They observed different results of the BAI measuring method in men and women while identifying individuals with a higher or lower percentage of fat. Freedman et al. [22] claimed that the use of BAI as an indicator of adiposity is likely to produce biased estimates of the percentage of body fat, errors which varied according to gender and the level of body fat content and that the evaluations based on BAI are not more accurate than those based on BMI, waist circumference, or hip circumference. Barreira et al. [20] investigated the gender-specific relationship between BAI and BMI and body fat in black and white adults. They also believed that both indices similarly estimated body fat content, but gender and race differences in relation to BAI, BMI and fat percentage made the interpretation difficult. Godoy-Matos et al. [21] used BAI as a means to evaluate obesity in women with familiar partial dystrophy and compared it with the BMI results. The authors concluded that the BAI measuring method was able to determine the differences in adiposity in patients with familial partial dystrophy and may become a more reliable indicator of fat mass content than the currently available measuring methods.

Adolescents and young adults are an object of special interest to many studies concerning the prevalence of excessive body fat and are characterised as the most likely to undergo preventive treatment in combating the obesity pandemic [4, 5, 12, 13, 15, 16]. They have been also chosen as the subject of the tests as this age group was the youngest one who underwent tests conducted by Bergman et al. [11].

Currently, in the representative sample of Polish children and adolescents presented in the study of Kułaga et al. [13], the prevalence of overweight and obesity in 2007-2009 in Poland was 7.1% and 2.1% respectively in 18-year-old females; where in 18-year-old males 3.9% obesity and 14.1% overweight was found [13]. Our results achieved with the use of the BMI implementation are similar to the ones reported by Kułaga et al. [13]. In the group of 18-year-old students, there were 3.9% of obese females and males. Overweight was lower and affected 4.8% females and 5.9% males.

Achieved with the use of the BAI measuring method, the prevalence of obesity and overweight was respectively 3 and 4 times higher in the whole our group than the one determined by means of BMI. We assumed that these results were related to the observed, dependent on the use of BAI, higher prevalence of obesity and overweight in males. It is difficult to compare our results with the reports available in the literature since there are only few investigations concerning similar problems in adults and there are no studies presenting the implementation of the BAI measuring method in the population of adolescents. Moreover, other authors [18-20] observed a similar overestimation of fat percentage in males and underestimation of fat percentage in females. We can agree with Lopez et al. [18] that BAI overestimated the percentage of fat in men with normal body fat and categorized them as the ones with excessive body adipose tissue. The authors suggest that in order to improve the specificity and sensitivity of BAI, the cut-off points for males and females should be changed. In Johnson et al. [19] research, the authors affirm high differences in values of mean fat tissue percentages obtained by the use of the BAI calculation in relation to the results gathered with the use of DXA. Those differences were especially visible in the group of people with less advanced adiposity. Schulze et al. [23] also certified that BAI overestimated the percentage of body fat among men. Moreover Vinknes et al. [30] showed that BAI tended to overestimate fat percentage in lean subjects and to underestimate it in those with higher contents of body fat, but accurately predicted the percentage of body fat in persons with BMI in a normal range.

Conclusion

The prevalence of overweight and obesity determined with BAI was significantly higher than with BF% and these differences were observed mainly in the group of male adolescents.

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