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Correlations between selected fatness indices and total body fat estimated by means of the impedance method

Małgorzata Socha

ABSTRACT The aim of the present work was the evaluation of measures of total body fat and distribution of adipose tissue, including the new conicity index, and their correlation with total body fat (in kg and %) estimated by means of the impedance method. Moreover, attention was paid to the bilateral differentiation of fat distribution. The basis for the analyses and comparisons was a group of 186 females of various age. Using cluster analysis and factor analysis for fatness measures, it was shown that the measures under study form two distinctly separate groups referring to different aspects of fatness: total body fat, and adipose tissue distribution.

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Introduction

The adipose tissue, considered until quite recently a store of body fat, is extremely active in metabolism and constitutes a kind of tissue of endocrinous secretion. It is one of the most plastic tissues in the human system. Its genetically determined amount depends also on many environmental factors, both intra and extrasomatic ones. One of the obscure aspects of adipose tissue biology is its excessive development leading to considerable deviations from desirable body mass in a constantly growing number of representatives of the contemporary human population. The growing problem of obesity, diversity of its types and health problems it related to have induced a search for proper evaluation measures of both total body fat and distribution of adipose tissue. Especially the evaluation of fat distribution is of significant practical meaning, because it enables the determination of health impedance in various pathologic entities. This concerns above all visceral fat, which if present in large amounts in the abdominal cavity increases a risk of metabolic complications and determines the type and pace of development of disease [JONES 1996; SZOSTAK 1996; CHRZANOWSKA 1997; ANDRZEJEWSKA *et al.*, 1997]. Satisfactory criteria of fatness evaluation have not been determined so far. It is therefore important to select such measures, which could comprehensively inform us on the amount and distribution of adipose tissue within a system. Most authors engaged in problems of overweight and obesity use in their investigations almost exclusively the BMI index, the value of which is strictly connected with fat amount, and the WHR

Institute of Human Biology
University School of Physical Education
Al. Paderewskiego 35, 51-612 Wrocław

index which takes into account its distribution in the body. Other indices have been used only in a few studies. Although easy and convenient in application, they are somewhat forgotten. ZIÓŁKOWSKA [1997] gives interesting data on the dynamics of changes of Škerlj's corpulence index, in BERGMAN & ROGUCKA'S [1998] paper intercorrelations for a larger number of measures and fat distribution are presented, MICHAŁOWSKA [1991] analyses the changes of Rohrer's index values in patients with selected diseases. Worthy of mentioning are also the works of MUELLER *et al.* [1996*a*, *b*] and of BOSE & MASCIE-TAYLOR [1998] popularizing the new, very interesting conicity index, which informs us on the central distribution of adipose tissue.

There is also a separate, interesting issue of bilateral differentiation of fat distribution. Suggestions concerning asymmetry in respect to distribution of body-tissue components, including adipose tissue, are given in papers by GRAVES *et al.* [1989] and by BERGMAN [1997 unpublished].

The purpose of the present study is to carry out the evaluation of some both frequently and rarely used measures of general fatness and fat distribution, taking into consideration also the new conicity index, in females of various age, paying attention to the bilateral differentiation of fat distribution.

Materials and methods

The basis for the analyses and comparisons consisted of a group of female students from the University School of Physical Education in Wrocław – Department of Physiotherapy, aged 19 to 23.5 (n = 78), a group of female participants of the "University of Third Age" in Wrocław*, aged 57 to 88 (n = 76), and a small group of female patients suffering from disorders of the lower back, from the "Przerzeczyn" health resort in Przerzeczyn Zdrój, aged 59 to 69 (n = 32) [TRAWNICZEK 1998].

For elaboration the following variables were used: stature (cm), body mass (kg), waist circumference, hip circumference, chest circumference measured at rest, four limb circumferences (arm, forearm, thigh, calf), and thickness of six skinfolds (over triceps, subscapular, rib, hips, abdominal, popliteal). The circumferences and skinfolds were measured on both sides of the body. The values of skinfolds were logarithmically transformed according to the formula by EDWARDS *et al.* [1955].

The evaluation of fatness was performed on the basis of more or less often used indices calculated from the above-mentioned variables:

1. Body Mass Index (BMI)
2. Rohrer's Index
3. Pignet-Verwaeck's Index =
$$= \frac{\text{body mass} + \text{chest circumfer.}}{B-v} \times 100$$
4. Marty's Index =
$$= \frac{\text{chest circumfer.}}{B-v} \times 100$$
5. Waist circumference Index =
$$= \frac{\text{waist circumfer.}}{B-v} \times 100$$
6. Hips through buttocks Index =
$$= \frac{\text{hip circumfer.}}{B-v} \times 100$$

* The study of the participants of the "University of Third Age" was financially supported by the KBN (Scientific Research Committee), grant No. 6P2040015

7. Index of trunk circumferences =

$$= \frac{\text{chest circumfer.}}{\text{hips circumfer.}} \times 100$$

8. Škerlj's (corpulence) Index =

$$= \frac{\text{tigh circumfer.}}{B - v} \times 100$$

9. Conicity Index =

$$= \text{waist circumfer. (m)} / 0.109 \times \sqrt{\text{body mass (kg)/body height (m)}}$$

10. Waist-Hip-Ratio (WHR) =

$$= \frac{\text{waist circumfer.}}{\text{hips circumfer.}} \times 100$$

11. Waist-Thigh-Ratio (WTR) =

$$= \frac{\text{waist circumfer.}}{\text{thigh circumfer.}} \times 100$$

12. Trunk-Extremities-Ratio (TER) =

$$= \frac{\text{log subscapular skf.} + \text{log abdominal skf.}}{\text{log arm skf.} + \text{log popliteal skf.}} \times 100$$

13. Abdomen-Subscapularis-Ratio (ASCR) =

$$= \frac{\text{log abdominal skf.}}{\text{log popliteal skf.}} \times 100$$

For the determination of the intensity of changes in the analysed fatness measures, as well as for the bilateral differentiation of fat distribution the method of comparative profiles was used. This method proposed by Szaferowa for the field of botany [JENTYS-SZAFEROWA 1951] found its application in studies on asymmetry [BERGMAN *et al.* 1962]. Modified for purposes of interpopulational comparisons [BERGMAN *et al.* 1975], it allows to describe in a simple and effective way one or a number of variables in the background of the basic object accepted as a point of reference. Values of indices of fatness and fat distribution, computed for young female students of the University School of Physical Education were taken as a reference point in the present work.. Szaferowa's ratio for the analysed fatness measures was calculated according to the formula $B/P \times 100$ (where: B – a value of fatness and distribution measures in the compared group, P – a value of fatness and distribution in the reference group), and presented as a comparative profile. The asymmetry indices as Szaferowa's ratio for four limb circumferences and six skinfolds were calculated according to the formula $P/L \times 100$ (where P – measure value on the right side, L – measure value on the left side of the body).

The electric parameters of impedance serving for estimation of the total body fat, expressed in kilograms and percentages of body mass, were measured by means of an impedance analyzer of RJL – Akern type, model 101/S (tetrapolar version) [BERGMAN & JANUSZ, 1992; BERGMAN, 1996].

Statistical analyses and graphs were made with the use of the statistical software package "Statistica". Apart from basic methods of statistical description, basic statistical tests (Student's and Wilcoxon's) and Spearman's rank correlation coefficients also the tree clustering (Ward's) method and factor analysis were applied.

Analysis and discussion

It was shown using Ward's method that both in young and in elderly females there occur two distinct groups of measures estimating different aspects of fatness (Figs. 1, 2). A large and extensive cluster is formed by measures of total fatness, while the other cluster consists of measures informing on fat distribution. BERGMAN & ROGUCKA [1998], who

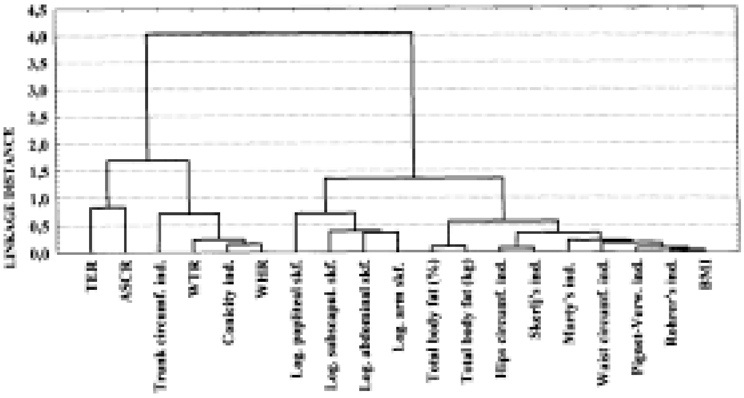

Fig. 1. Tree diagram for 19 measures of total body fat and distribution of fatty tissue in females (*n* = 78) aged 19-23.5 years. (Linkage rules according Ward's method; distance measure = 1-*r*)

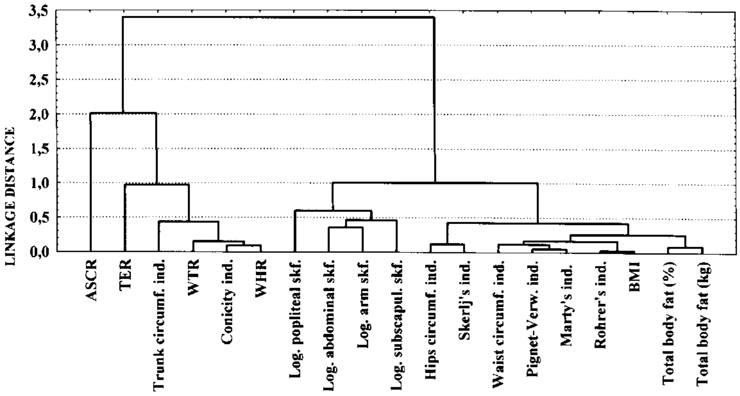

Fig. 2. Tree diagram for 19 measures of total body fat and distribution of fatty tissue in females (*n* = 76) aged 57-88 years. (Linkage rules according Ward's method; distance measure = 1-*r*)

investigated correlation coefficients of selected fatness measures obtained a similar picture. The division of the applied indices into two different groups is of great practical importance, as the evaluation of fatness' degree advancement and its distribution frequently depends on the choice of method, as well as on the result of disease treatment [ZAHORSKA-MARKIEWICZ 1996]. According to the latter mentioned author, certainpharmacological remedies used in the treatment of obesity cause a decrease in the amount of fat in strictly defined body areas, e.g. within the abdominal cavity. This can be observed by means of the method of magnetic nuclear resonance, but also, as it seems, with the use of a well-defined fatness index. A detailed analysis of the dendrograms obtained shows that in both groups of measures there occurs a distinct differentiation. The following indices are located in a separate subcluster of the cluster of total fatness measures: BMI, Rohrer's index, Pignet-Verwaeck's index, waist circumference index, Marty's index, Škerlj's index, and the hip circumference index. These are strongly correlated with total body fat in kg and % of body mass estimated by the impedance method (r = 0.53–0.76 in young females, and r = 0.70–0.92 in elderly females). A separate group is formed by skinfolds. Their values indicate the amount of subcutaneous fat, and the correlation coefficients with total body fat are somewhat lower (r = 0.38–0.57 in young females; r = 0.46–0.72 in elderly ones). As evident, higher correlation of the analysed measures of general fatness with total body fat occurs in elderly females (higher values of correlation coefficients) than in young females. This is a picture of the well-known tendency to adipose tissue increment with age. MOUGHAN [1993] and NAWARYCZ [1996], who thereby indicated the comparability in using these methods, showed the relation between skinfold thickness and amount of fat estimated by means of the impedance method. In the "distributive" cluster in young females, apart from the classic measures of fat distribution (WHR, WTR), the new conicity index and the index of trunk circumferences, in a separate subcluster there are localized distribution measures based on proportions of skinfold thickness (TER, ASCR). This division disappears in elderly females because TER index and ASCR index join the remaining measures of fat distribution. Perhaps also in this case this is caused by the overall increment of body fat at that age. The analysis of correlation coefficients has shown that two distribution measures (WHR and conicity index) correlate statistically significantly with total body fat in kg and %, but the correlation coefficients are distinctly lower in comparison with overall measures (r = 0.31–0.46 in young females; r = 0.39 – 0.46 in elderly females). These indices, though distributive by nature, contribute also a certain amount of information on a system's total fatness. On the other hand, WTR and the index of trunk circumferences do not correlate at all with total body fat in kilograms and percentages (correlation close to zero). The indices informing on fat distribution show a similar tendency. The TER index does not correlate significantly with total body fat in either of the groups of females, the ASCR index correlates significantly, but negatively, only in elderly females (r = −0.46, and r = −0.45). Similar results were obtained by BERGMAN & ROGUCKA [1998], who found significantly negative correlations between measures of total body fat and the ratio of the upper and lower part of the trunk (ASCR) (r = from −0.37 to r = −0.23).

For the purpose of a more detailed determination of relations between measures of fatness, assembled in separate clusters the factor analysis was used. For determination of eventual changes in the character of fatness measures, i.e. in order to find out whether they are stable or whether they are losing their importance with age, the factor analysis was also carried out in two groups of distinctly different age, but for the same sets of variables. The components were extracted by means of the method of principal components, together with orthogonal rotation VARIMAX. The number of factors was determined on the basis of Cattell's scree test and factor component Eigen values (Kaiser's criterion). Only variables for which the factor loadings were higher than 0.7 were used. On the basis of fatness measures three fairly clearly definable factors were extracted (Table 1). Factor 1 accumulates variables being measures of total body fat. With this factor highly correlated are total body fat in kg and %, BMI and Rohrer's index, but also such indices as Pignet-Verwaeck's index, Marty's index, waist index, hip index and Škerlj's index. Smaller, but also significant, loadings contribute the logarithmic values of two skinfold measures – the subscapular and popliteal skinfolds whose thickness reflect the total body fat. The popliteal skinfold gains particular importance with age. Factor 2 combines indices expressing fat distribution (WHR, WTR, conicity). On the other hand, the index of trunk circumferences (distributive according to Ward's method) correlates stronger with this factor only in elderly females. It seems that this index acts as a measure of fat distribution only in overweight and obese persons. Both methods applied confirmed the character of the new conicity index, which expresses an individual's waist circumference relative to the circumference of a hypothetical cylinder generated with that person's weight and height assuming a constant for body density. The higher the value of this index, the more central the distribution of adipose tissue. Index values below 1.0 evidence a good distribution of fat ("biconcave" type), value 1.0 indicates an increased amount of fat in the area of waist and hips ("cylindrical" type), values over 1.0 inform on excess of fat in the area of waist and hips ("biconical" type) [MUELLER *et al*. 1996*a*, *b*; BOSE & MASCIE-TAYLOR 1998], Factor 3 is defined less clearly and shows a high correlation with ASCR in female students, and also with TER in elderly females, i.e., with measures of distribution based on proportions of skinfold thickness. It could be called a factor of specific distri-

Table 1. Factor loadings after varimax rotation for measures of total body fat and distribution of fatty tissue

Variables	*Female students* (*n* = 78)			Elderly females (*n* = 70)		
	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3
Total body fat (kg)	**0.857**	0.178	0.224	**0.907**	0.247	0.074
Total body fat (%)	**0.768**	0.175	0.260	**0.868**	0.222	0.111
BMI	**0.960**	0.044	0.017	**0.937**	0.247	0.045
Rohrer's index	**0.961**	0.004	–0.020	**0.920**	0.239	0.049
Pignet-Verwaeck's index	**0.926**	0.209	0.035	**0.871**	0.413	0.073
Marty's index	**0.822**	0.322	–0.001	**0.755**	0.567	0.107
Waist circumfer. index	**0.861**	0.437	0.040	**0.752**	0.613	0.081
Hips through buttocks index	**0.914**	–0.230	0.008	**0.931**	0.016	0.031
Škerlj's index	**0.927**	–0.212	0.034	**0.924**	–0.120	–0.110
Index of trunk circumfer.	0.043	0.690	–0.003	–0.003	**0.841**	0.131
Conicity	0.139	**0.856**	0.129	0.331	**0.844**	0.094
WHR	0.214	**0.940**	0.061	0.219	**0.936**	0.102
WTR	–0.126	**0.896**	0.018	0.058	**0.919**	0.227
ASCR	–0.398	–0.084	**0.784**	–0.365	–0.251	–0.660
TER	–0.315	0.190	0.140	–0.181	0.253	**0.861**
Log. arm skinfold	0.541	0.137	0.540	0.696	0.116	–0.174
Log. subscapular skinfold	**0.747**	0.268	0.192	**0.701**	0.232	0.567
Log. abdominal skinfold	0.370	0.188	**0.865**	0.668	0.050	0.068
Log. popliteal skinfold	0.572	–0.034	0.088	**0.735**	–0.138	–0.346
Eigen value	8.791	3.567	1.861	9.203	4.467	1.800
Percentage of variance	46.3	18.8	9.8	48.4	23.5	9.5

bution of subcutaneous fat. The existence of two factors referring to the distribution of adipose tissue confirms the view that distribution of this tissue, that is, its anatomical location, is an important and independent element of attempts to estimate body fat [SKŁAD & SKIBIŃSKA 1977; CHRZANOWSKA 1992]. The extracted factors account jointly for 74.9 % of variance in female students and 81.4 % of variance in elderly females.

In spite of the growing with age differentiation in respect of total body fat, the differences in its distribution are very weakly marked. This is visible in the comparative profile for the analysed measures of fatness (Fig. 3). The thick straight vertical line represents female students of physiotherapy, accepted as a stipulated point of reference. The broken lines represent the two groups of elderly females. This diagram shows distinctly the conformity of the directions of changes in the compared groups of females with regard to the reference group. With increasing with age amount of adipose tissue a distinct increase is observed in the measures of total body fat, but a lesser or only slight increase in some measures of distribution. The conformity of the courses of the broken lines representing both groups of elderly females proves that this result is not accidental. The observed relative stability of distribution-measure values means that one factor determines the amount of adipose tissue and the other one its distribution. Analyzing metabolic variables of fatness SZOSTAK [1996] states, that some of them are connected with causes of fatness, others determine the type of fat distribution and still others play an important part in the development of fatness complications. On the grounds of twin studies, it was ascertained that the fat distribution is determined to a greater degree by genetic than environmental factors and lifestyle [REBATO *et al.* 1998]. The heritability level is higher for fat distribution than for total body fat [BOUCHARD *et al.* 1997]. Investigations of obese children performed by LIGENZA & KAŁUŻYŃSKA [1993], revealed that weight-reducing treatments have no effect on the WHR values. This suggests a relatively strong genetic conditioning in the distribution of adipose tissue.

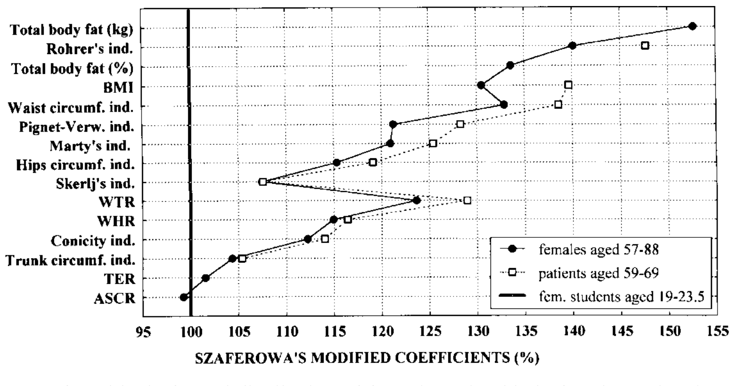

Fig. 3. Measures of total body fat and distribution of fatty tissue in elderly females and patients with lumbar region disorders at the background of female students. (Szaferowa's method of comparative profiles modified by Bergman *et al.*, 1975)

There is also a relatively poorly recognized problem of the asymmetry of distribution of adipose tissue [GRAVES *et al.* 1998; BERGMAN 1997] The factor analysis of asymmetry measures, calculated as Szaferowa's ratio coefficients for four limb circumferences and six skinfolds, against the background of the clear measures of total body fat and adipose tissue distribution, has shown that there is no single, unequivocal asymmetry factor in the case of young females. (Table 2). The measures of asymmetry were dispersed, though they contribute rather large loadings to the two neighboring factors. As a criterion of significance of factor loadings the 0.6 value was accepted. This factor could have probably been captured more easily in elderly females, for whom the right and left side measurements of limb circumferences and skinfolds were lacking, or perhaps if asymmetry measures based on bilateral differences had been used instead of ratio coefficients. It may be supposed that the phenomenon of bilateral asymmetry in respect to fat distribution, is more of local rather than general character.

Conclusions

The following conclusions were drawn as a result of the analysis:

1. Against the background of total body fat estimated by means of the impedance method, the BMI, Rohrer's and Pignet-Verwaeck's indices form a close and uniform group of general fatness measures.
2. The group of total body fat measures is joined by indices such as Marty's index, Škerlj's index, waist index, hips index and logarithmic values of skinfold measures; this has been confirmed by the cluster analysis and factor analysis.

Table 2. Factor loadings after varimax rotation for measures of asymmetry, on the background of typical measures of total body fat and distribution of fatty tissue

Variables	Female students (n = 78)				
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Total body fat (kg)	**0.919**	–0.201	0.046	–0.085	0.076
Total body fat (%)	**0.813**	–0.224	0.003	–0.132	0.147
BMI	**0.969**	0.002	0.030	0.044	–0.021
Rohrer's index	**0.944**	0.052	0.010	0.055	–0.020
Pignet-Verwaeck's index	**0.941**	–0.116	0.063	0.036	–0.050
Conicity	0.177	**–0.933**	0.012	–0.041	0.001
WHR	0.248	**–0.912**	0.037	0.032	–0.001
WTR	–0.094	**–0.926**	–0.086	0.013	0.007
Asym. in arm circumfer.	0.049	0.181	**0.619**	0.011	0.165
Asym. in forearm circumfer.	–0.066	0.103	0.412	**0.623**	0.051
Asym. thigh circumfer.	–0.111	0.065	**0.612**	0.011	–0.209
Asym. calf circumfer.	–0.070	0.007	0.095	–0.003	**–0.831**
Asym. in arm skinfold	0.032	–0.082	0.334	0.371	0.315
Asym. in subscapular skinfold	0.110	–0.017	–0.093	**0.655**	–0.412
Asym. in vertebral skinfold	0.229	–0.016	**0.646**	–0.182	–0.071
Asym. in hip skinfold	0.080	0.057	0.170	**–0.654**	–0.279
Asym. in abdominal skinfold	–0.183	0.146	**–0.600**	–0.171	0.069
Asym. in popliteal skinfold	0.030	0.042	0.196	0.099	0.454
Eigen value	4.454	2.747	1.919	1.489	1.358
Percentage of variance	24.7	15.3	10.7	8.3	7.5

3. The WTR and WHR indices, trunk circumferences index, and the recently proposed conicity index are decided measures of fat distribution.

4. The TER and ASCR indices, based on the proportions of skinfold thickness, are measures of specific distribution of subcutaneous fat.

5. It is suggested that other fatness indices should be evaluated in relation to the above mentioned groups of typically general and typically distributional measures of fatness.

6. In spite of the growing with age amount of total body fat, the differences in its distribution are less clearly marked.

7. The attempt to extract an unambiguous factor of asymmetry of fat distribution in young females based on limb circumferences and skinfold thickness has failed.

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Streszczenie

Narastający problem otyłości, zróżnicowane jej typy i związane z nią problemy zdrowotne skłaniają do poszukiwania trafnych miar oceny zarówno otłuszczenia ogólnego jak i dystrybucji tkanki tłuszczowej. Zwłaszcza ocena sposobu rozmieszczenia tej tkanki w organizmie człowieka ma istotne znaczenie praktyczne, ponieważ pozwala na określenie stopnia zagrożenia zdrowia w różnych jednostkach chorobowych. Dotyczy to przede wszystkim tłuszczu trzewnego, którego duża ilość zgromadzona w jamie brzusznej nasila ryzyko powikłań metabolicznych i decyduje o zaawansowaniu i rodzaju choroby.

Podstawą analiz i porównań była grupa 186 kobiet w różnym wieku: studentki fizjoterapii (n = 78, wiek 19–23,5 lat), słuchaczki Uniwersytetu Trzeciego Wieku (n = 76, wiek 57 – 88), pacjentki z uzdrowiska "Przerzeczyn" w Przerzeczynie Zdroju (n = 32, wiek 56 – 69 lat).

Stosując metodę aglomeracji i analizę czynnikową w sposób jednoznaczny wykazano, że wskaźniki BMI, Rohrera, Pigneta-Verwaecka, na tle całkowitej zawartości tkanki tłuszczowej szacowanej metodą impedancji, stanowią zwartą, jednorodną grupę miar otłuszczenia ogólnego (Fig. 1, 2; Tabela 1). Do grupy tej dołączają wskaźniki rozrostu klatki piersiowej, tęgości Škerja, obwodu w pasie oraz zlogarytmowane wartości pomiarów fałdów skórno-tłuszczowych. Wskaźniki WTR, WHR, obwodów tułowia, jak i zaproponowany niedawno wskaźnik *conicity* są zdecydowanymi miarami dystrybucji tkanki tłuszczowej. Podobny charakter mają wskaźniki TER i ASCR, oparte na proporcjach grubości fałdów skórno-tłuszczowych, które określają specyficzny rozkład tkanki tłuszczowej podskórnej w organizmie. Proponuje się, aby ocena innych wskaźników otłuszczenia odbywała się w stosunku do wyodrębnionych grup miar otłuszczenia typowo ogólnych i typowo dystrybucyjnych.

Mimo narastającego z wiekiem zróżnicowania pod względem ogólnej ilości tkanki tłuszczowej znacznie słabiej zaznaczają się różnice w jej dystrybucji, co pokazuje zmodyfikowany profil porównawczy Szaferowej dla analizowanych miar otłuszczenia (Fig. 3). Widać wyraźny obraz zgodności kierunku zmian w porównywanych grupach kobiet w stosunku do grupy modelowej. W miarę przybywania tkanki tłuszczowej z wiekiem wydatnie powiększają swoje wielkości miary otłuszczenia ogólnego, a mniej lub bardzo mało niektóre miary dystrybucji. O tym, że nie jest to wynik przypadkowy świadczy zgodność w przebiegu linii łamanych dla obu grup starszych kobiet.

Analiza czynnikowa dla miar asymetrii obliczonych jako ilorazowe współczynniki Szaferowej dla czterech obwodów kończyn i sześciu fałdów skórno-tłuszczowych, na tle zdecydowanych miar otłuszczenia ogólnego i dystrybucji tkanki tłuszczowej wykazała, że u kobiet młodych nie ujawnił się jeden jednoznaczny czynnik asymetrii (Tabela 2). Miary asymetrii uległy rozproszeniu, choć wnoszą dość duże ładunki do dwóch sąsiednich czynników. Można przypuszczać, że zjawisko asymetrii bilateralnej pod względem dystrybucji tkanki tłuszczowej ma charakter bardziej lokalny a nie całościowy.