COMPARISON OF DIFFERENT METHODS OF BODY FAT MEASUREMENT IN NON-OBESE YOUNG ADULTS

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The aim of the study was to compare the results of body fat (in% and kg) measurements, obtained from 15 young non-obese adults (4 males, 11 females) with the use of different methods: Underwater Weighing (UWW) and Air-Displacement Plethysmography (BOD POD); Dual X-ray Absorbtiometry (DXA); Bioelectrical Impedance Analysis (BIA), 4 Skinfolds measurements and BMI related formula, and to assess their correlation with UWW as a reference. The most accurate and best correlated with the reference were BOD POD and DXA. BIA gave results similar to and correlated well with UWW. Results of anthropometric methods correlated less with UWW, but mean values were not significantly different from the reference.

INTRODUCTION

The assessment of the body composition is an important measure of the nutritional status in man, because body fat (BF) is directly related to obesity and diet-related diseases, whereas low levels of fat-free mass (FFM) may be more critical to the health of infants and children, elderly, malnourished persons, maturating women, and those with muscle-wasting diseases.

Truly direct measurements of BF are possible only by cadaver analysis. Therefore, alternative procedures have been employed, all with their own limitations depending on assumptions and theoretical model [Ellis, 2000], cost, ease of operation, technical skills and subject's cooperation [Lukaski, 1987]. The method regarded as a reference one [Ellis, 2001] is underwater weighing (UWW) [Hansen *et al.,* 1993; McCrory *et al.,* 1995]. After correction for residual lung volume, it gives results of body density (BD), which are used to estimate% or total BF from the equation of Siri [Mukherje & Roche, 1984]. A similar densitometry approach is used by air-displacement plethysmography (BOD POD) system. The volumes of the two chambers, with a subject sitting in one of them, while the other serves as a reference, vary slightly and the difference in air pressure is used for the body volume calculation, with corrections for isothermal properties of the air in the lungs and near skin's surface [McCrory *et al.,* 1995]. Dual-energy X-ray absorptiometry (DXA) uses X-rays of two distinct energy levels that are differently attenuated by bone mineral, fat and fat-free soft tissue [Lunt *et al.,* 1997]. Bioelectrical Impedance Analysis (BIA) offers a great potential for noninvasive assessment of body composition because it is safe, portable, easy to use and much cheaper than the previous, instrumental techniques. From the measurement of re-actance and resistance, the total body water (TBW) and FFM could be calculated [National Institute of Health, 1996] and converted into BF content using a variety of equations [Houtkooper *et al.,* 1996]. The cheapest and most common methods to assess BF are anthropometric techniques, especially skinfolds thickness measure, which provide an estimate of the subcutaneous fat depot, recalculated for the total BF or BD [Durnin & Rahoman, 1967]. For the assessment of BF in epidemiological studies, a weight-height index is the most simple and inexpensive method, and the errors in measurement due to intra- or inter-observed variation are small. The body mass index (BMI) seems to be the most appropriate, because its correlation is high with BF% and low with body height [Deurenberg *et al*., 1991].

The aim of the study was to compare the results of body fat content (in% and kg) obtained from 15 young non-obese adults (4 males, 11 females) with the use of presented, different methods: instrumental – UWW and BOD POD, DXA, BIA and anthropometric − 4 skinfolds measurements and BMI related formula, and to assess their correlation with UWW as a reference.

MATERIAL AND METHODS

The subject group consisted of 15 healthy, white, young adults (4 males and 11 females, students) in the mean age of 21.9±1.6 years, body weight of 62.7±9.6 kg, and BMI of 21.3±1.9 kg/m² (Table 1). All subjects completed anthropometry, UWW, BIA, BOD POD and DXA measurements at the Human Nutrition Department, Wageningen University. Subject were studied in the morning (from 8:00 to 12:00) after light, standard breakfast. All subjects participated in all mea-

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TABLE 1. Characteristic of subjects group (total n=15, male n=4, female n=11).

Parameters	Mean	SD	Minimum	Maximum
Age (y) total	21.9	1.6	20	24
Age (y) of males	22.3	1.5	20	23
Age (y) of females	21.8	1.7	20	24
Body weight (kg) total	62.2	9.6	50.8	81.2
Body weight (kg) of males	73.4	10.7	57.6	81.2
Body weight (kg) of females	58.1	5.3	50.8	65.7
Height (cm) total	170.6	8.6	156.1	185.7
Height (cm) of males	180.1	6.3	171.5	185.7
Height (cm) of females	167.1	6.5	156.1	174.4
BMI (kg/m²) total	21.3	1.9	17.1	24.6
BMI (kg/m²) of males	22.5	2.1	19.6	24.1
BMI (kg/m²) of females	20.8	1.9	17.1	24.6

surements during one week, and each subject was measured by all methods within one day with swim suits, without any shoes or socks.

Body weight (wt) was measured to the nearest 0.01 kg and height (ht) to 0.5 cm using scale Sartorius 3826-MP 8-1 (Sartorius GmbH, Gottingen, Germany).

Body volume and density measurement by UWW were done in a stainless steel water tank using a standard method [Akers & Buskirk, 1969]. Functional residual capacity lung volume was estimated by the helium dilution technique [Brown *et al.,* 1998].

A Lunar DXA scanner- Lunar DPXL bone densitometer (Oldelft Benelux B.V., Delft, The Netherlands) with Lunar DPXL software version 1.35 (Lunar Corporation, Madison, WI, USA) was used, which has a declared precision of < 1%.

BOD POD body composition tracking system with software version 2.1 (Life Measurement Inc, Concord, CA, USA) was used for measurement of %body fat,%body lean and density. Declared precision was < 70mL (< 0.5%) with a declared error of < 2%.

BIA was used to estimate total body fat using single-frequency, four electrodes model Xitron 4000 (Xitron Technologies, San Diego, USA). Total body fat was calculated from formulas for FFM, developed by Gray *et al.* [1989]:

Females: FFM = 0.00108 * Ht² – 0.02090 * R + 0.23199 * Wt – 0.06777 * Age + 14.59753

Males: FFM = 0.00132 * Ht² – 0.04394 * R + 0.30520 * Wt – 0.16760 * Age + 22.66827

The anthropometric equation of Durnin & Womersley [1974] was used to predict BD with log transformation of the sum of four skinfold thickness ($\sum$ST): triceps, biceps, subscapula and iliac crest, measured with the use of AccuMeasure Body Fat Caliper (Dorset, UK).

Females: (20-29 y): BD = 1.1599 – 0.0717 * log $\sum$ST

Males: (20-29 y): BD = 0.0632 – 1.1631 * log $\sum$FT

Body fat, as for UWW method, was then calculated from body density using Siri equation:

% body fat = ((4.95/body density) – 4.50) * 100%

Body fat was also calculated from BMI data with Deurenberg *et al.* [1991] formula:

% body fat = 1.20 * BMI – 0.23 * age – 10.8 * sex + 5.4

The influence of measurement methods on body fat (in relative and absolute values) was checked using one way analysis of variance ANOVA and Multiple Range Test (LSD) for significance of the differences between means. All data

TABLE 2. Means, standard deviations (SD) and the range of % and total body fat content in non-obese young adult (n = 15) measured by different methods: UWW-underwater weighing, BOD POD-air displacement plethysmography, DXA-dual X-ray absorptiometry, BIA--bioelectrical impedance analysis, SKINFOLDS-estimation of body density from four skinfolds thicknesses, BMI-body mass index.

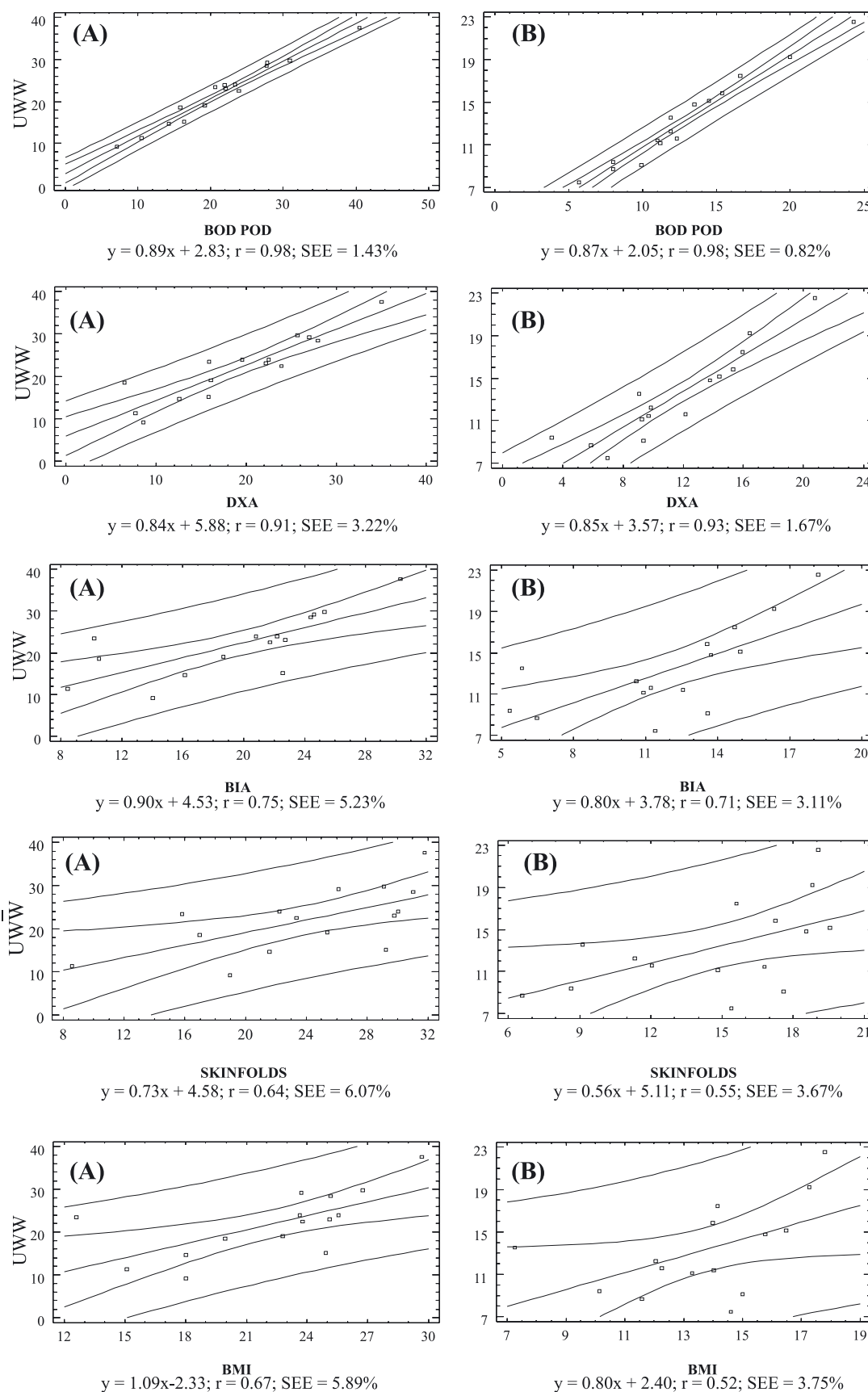| Method	% of body fat (g/100 g)				Total body fat (kg)			
	Mean	SD	Min	Max	Mean	SD	Min	Max
UWW	21.99	7.6	9.17	37.60	13.30	4.2	7.45	22.56
BOD POD	21.47	8.4	7.10	40.50	12.95	4.8	5.70	24.30
DXA	19.14	8.3	6.50	35.00	11.48	4.6	3.28	20.76
BIA	19.51	6.4	8.45	30.31	11.96	3.8	5.34	18.18
SKINFOLDS	24.00	6.7	8.59	31.77	14.74	4.2	6.59	19.54
BMI	22.21	4.7	12.60	29.67	13.71	2.8	7.26	17.80

FIGURE 1. Simple linear regression between results of %body fat in g/100g (A) and total body fat in kg (B) measured in non-obese young adult (n=15) by UWW and different methods: UWW-underwater weighing, BOD POD-air displacement plethysmography, DXA-dual X-ray absorptiometry, BIA-bioelectrical impedance analysis, SKINFOLDS-estimation of body density from four skinfolds thicknesses, BMI--body mass index. BF = a * BF by UWW + b;   r – correlation coefficient; SEE – standard error of estimate

were checked for normal distribution, and for errors of variances using standard procedure in the program. The comparison of each method with UWW as the reference was made using Simple Linear Regression analysis giving as a result values of correlation coefficient – r, and standard error of estimate – SEE.

All statistic calculations were made with Stat Graphics v 2.1 Plus for Windows.

RESULTS AND DISCUSSION

The results of mean body fat content in the studied group of young, non-obese adults measured by different methods are shown in Table 2. ANOVA shows no significant differences (p>0.05) between % and total content of BF obtained by different methods. The mean BF content measured by UWW were 21.99±7.6 for % and 13.30±4.2 for kg. The values obtained with the use of instrumental methods (BOD POD, DXA, BIA) were slightly lower, whereas data from anthropometric measurements (skinfolds and BMI) slightly higher than the UWW ones. The closest mean values to the reference gave BOD POD and BMI, whereas the biggest difference, but still in 10% range, were obtained from DXA and skinfolds measurements.

Data from correlation of different methods of BF measurements with reference (UWW) are presented in Figure 1. All regression results were statistically significant (p≤0.05). Simple linear regression shows no significant differences between total BF measured by UWW and BOD POD, with the highest r=0.98 and the smallest SEE=1.43% for %BF and =0.82 kg for total BF. Compatibility is estimated on 96.72% and 96.55%, respectively. Similarly, very high correlation of BOD POD and UWW results was found by McCrory *et al.* [1995] and Vescovi *et al.* [2001] in heterogenous group of adults: the regresion of BOD POD vs UWW was not differ from line of indentity. It indicates excellent reliability for both densytometric methods, although in the second study BOD POD was less valid for lean individuals. This method has several advantages over UWW: it is quick, relatively simple to operate and may be used in special populations such as the obese, elderly, and disabled. Furthermore, the BOD POD has been shown to predict fat mass and FFM more accurately than DXA and BIA [Sardinha *et al.,* 1998], which was also seen in the presented results.

A litle worse correlation was found for DXA results but still mean values for r were higher than 0.9 and SEE lower than 3.3%, with the compability to UWW estimated at *ca*. 85%.

Hansen *et al.* [1993] for adult women (n=100) and Kohrt [1998] for adult men (n=225) and women (n=110) reported that DXA was very precise method for BF measurement and correlated highly with UWW results, but required corrections for bone mineral variation as well as for variance in water and protein of FFM [Miliken *et al.,* 1996]. Results obtained in the presented experiments were less precise, which could be due to a small subject group (only 15 persons) and a lack of additional corrections for other fraction of FFM.

Results obtained by BIA correlated less, but acceptably with UWW; means of r-coefient was *ca*. 0.7, SEE – 5.23% and 3.11 kg, and compability around 50%. Segal *et al.* [1985] also suggested that lean BM predicted from BIA correlated

sufficiently well with values measured densitometricaly, but Hautkooper *et al.* [1996] claimed that BIA calculations of an individual's BF can vary by as much as 10% of body weight due to differences in the formulas and instrumentation applied. Results of Demura *et al.* [2004] indicate that precision of BIA methods could be improoved by the use of multi-frequency analyser and segmental measurements with eight electrodes.

Skinfolds measurements and formula based on BMI showed correlations with UWW results on quite similar level with r equal to *ca*. 0.65 and 0.53, SEE of *ca*. 6% and 3.7% and compability of *ca*. 40% and 29% for percentage and total BF, respectivly. Durnin & Womersley [1974] found a strong correlation between skinfold thickness and BD measured by UWW, but Gibson [1990] underlines that accuracy of the results depends on number and sites of skinfolds and variations in the distribution of subcutaneous fat occur with sex, race and age. Probst *et al.* [2001] found a good agreement of skinfolds thickness and UWW (r=0.76) in anorexia nervosa patients, but he used 12 skinfolds measurements.

In several studies it was shown that the BMI correlates well with the amount of BF as determined by more direct measures such as densitometry [Garrow & Webster, 1985] or skinfold thickness [Womersley & Durnin, 1977]. Deurenberg *et al.* [1991] showed that internal and external cross-validation of the prediction formulas based on BMI gave valid estimates of BF in males and females at all ages. In obese subjects however, the prediction formulas slightly overestimated the%BF. For these reasons anthropometric techniques of BF measurement can be used rather to monitor population changes than for the control of individuals [Ellis, 2001].

CONCLUSIONS

For the group of 15 non-obese, young adults, the highest agreement with UWW show instrumental methods, especially BOD POD, with better correlation and closer mean value of relative and total BF content than the DXA technique. The above results indicate that these methods are most accurate with precision similar to reference method and are the best for measurement of BF content in individuals. Less accurate, but still well correlated (r>0.7) with UWW, and giving mean values different less than 10% of reference method are BIA measurements with the use of Gray formulas. These techniques could be accepted for measurement of BF and its changes in individuals as well as in population studies. The last group of anthropometric methods based on 4 skinfolds measurements with use of Durnin and Womerslay calculation and Deurenberg formula based on BMI, due to the poorest (r<0.7) correlation with UWW but similar mean value are rather acceptable for population and epidemiological studies.

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PORÓWNANIE RÓŻNYCH METOD POMIARU TKANKI TŁUSZCZOWEJ U OSÓB DOROSŁYCH

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Celem pracy było porównanie wyników różnych metod pomiaru zawartości tłuszczu w ciele (w % i wartościach bezwzględnych) w grupie 15 młodych, nie otyłych dorosłych (11 kobiet, 4 mężczyzn,), oraz oszacowanie korelacji tych pomiarów z ważeniem ciała pod wodą (UWW) jako metodą odwoławczą. Stosowano metody instrumentalne: densytometryczne- UWW, BOD POD; oraz DXA; BIA i antropometryczne, bazujące na pomiarze fałdów skórno-tłuszczowych i na BMI. Wykazano, że najbardziej dokładne i skorelowane z UWW były metody instrumentalne: BOD POD i DXA. Metody bazujące na BIA dały średnie wartości zbliżone do referencyjnych i dość dobrze skorelowane z UWW. Wyniki pomiarów fałdów skórno-tłuszczowych były gorzej skorelowane z UWW, podobnie jak pomiar ilości tłuszczu na podstawie BMI, choć wartości średnie nie różniły się istotnie od referencyjnych.