Coll. Antropol. **33** (2009) 2: 391–396
Original scientific paper

Estimating DXA Total Body Fat Percentage by Lipometer Subcutaneous Adipose Tissue Thicknesses

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A B S T R A C T

DXA is an accepted reference method to estimate body composition. However several difficulties in the applicability exist. The equipment is rather expensive, not portable, impractical for measurement of big study populations and it provides a minimal amount of ionizing radiation exposure. The optical device Lipometer (EU Pat.No. 0516251) provides non-invasive, quick, precise and safe measurements of subcutaneous adipose tissue (SAT) layer thicknesses at any site of the human body. Compared to DXA there are some advantages in the Lipometer approach, because this device is portable, quick, not expensive and no radiation is involved. To use these advantages in the field of total body fat% (TBF%) assessment, an acceptable estimation of DXA TBF% by Lipometer SAT thicknesses is necessary, which was the aim of this study. Height, weight, waist and hip circumferences, DXA TBF% and Lipometer SAT thicknesses at fifteen defined body sites were measured in 28 healthy men (age: 33.9 ± 16.6 years) and 52 healthy women (age: 40.1 ± 10.7 years). To estimate Lipometer TBF% stepwise multiple regression analysis was applied, using DXA TBF% as dependent variable. Using the fifteen Lipometer SAT thicknesses together with age, height, weight and BMI as independent variables provided the best estimations of Lipometer TBF% for both genders with strong correlations to DXA TBF% (R=0.985 for males and R=0.953 for females). The limits of agreement were –2.48% to +2.48% for males and –4.28% to +4.28% for females. For both genders we received a bias of 0.00%. The results of this paper extend the abilities of the Lipometer by a precise estimation of TBF% using DXA as »golden standard«.

Key words: *body composition, subcutaneous fat distribution, subcutaneous adipose tissue topography (SAT-Top), total body fat, DXA, lipometer*

Introduction

Interest in the field of body composition is growing because the study of changes in various compartments of fat helps to elucidate the dynamics of related health outcomes. There are different methods for assessing body composition: densitometry, 2H dilution, total body K, dual-energy x-ray absorptiometry (DXA), anthropometry, bioelectrical impedance analysis (BIA) and Near Infrared Interactance (NII). Some of these methods are expensive, technically awkward and impractical for use in a field study. Skinfold caliper measurements have been recommended for the assessment of subcutaneous adipose tissue thickness and fat mass (FM). However, the accuracy of this field method in terms of measurements of FM depends on an appropriate prediction equation. Exposure to high doses of radiation (computed tomography) should be avoided[1].

DXA offers precise data and is an accepted reference method to estimate body composition as »golden standard« although several difficulties in the applicability exist. The equipment is rather expensive, not portable and impractical for measurement of big study populations. Furthermore, DXA provides a minimal amount of ioniz-

Received for publication September 5, 2008

ing radiation exposure that is equivalent to 1% of the radiation exposure from a chest X ray; the risks versus benefits of body composition assessment must be considered. DXA is not recommended for the use with pregnant women, and a pregnancy test is necessary before DXA measurements are made in women of childbearing age.

NII can provide a rapid, safe and non-invasive technique for nutritional assessment and body composition measurement. The optical properties of tissue components, several kinds of lipid and tissue layers were measured in the near infrared range. The changes of corresponding signals according to the changes of subcutaneous adipose tissue layer thickness were measured by animal experiments, and the changes were compared with those of the actual thickness in tissue biopsies[2].

The optical device Lipometer (EU Pat.No. 0516251) provides non-invasive, quick, precise and safe measurements of subcutaneous adipose tissue (SAT) layer thicknesses at any site of the human body. Its technical characteristics and validation results using computed tomography as a reference method have been presented before[3–5]. Previous results confirmed the importance of describing the Lipometer SAT distribution in the field of obesity and metabolic disorders of adults[6–10].

Compared to DXA there are some advantages in the Lipometer approach, because this device is portable, quick, not expensive and no radiation is involved. To use these advantages in the field of total body fat % (TBF%) assessment, an acceptable estimation of DXA TBF% by Lipometer SAT thicknesses is necessary, which was the aim of this study.

TABLE 1
ANTHROPOMETRY, BODY COMPOSITION AND 15 SAT LAYERS OF THE SUBJECTS (X ± SD)

	Males (N=28)	Females (N=52)
Age (yrs)	33.9 ± 16.6	40.1 ± 10.7
Height (cm)	182.1 ± 7.1	167.0 ± 5.7
Body mass (kg)	82.3 ± 16.0	77.7 ± 16.0
BMI (kg/m^2)	24.8 ± 4.6	27.9 ± 5.8
Waist circumference (cm)	85.4 ± 13.5	85.6 ± 14.4
Hip circumference (cm)	93.0 ± 9.6	105.6 ± 12.7
Waist / hip ratio	0.92 ± 0.06	0.81 ± 0.06
DXA TBF%	15.4 ± 7.4	34.5 ± 7.2
Lipometer TBF%	15.4 ± 7.3	34.5 ± 6.9
Lipometer SAT layer thicknesses (mm)		
Neck	4.6 ± 4.3	9.8 ± 5.9
Triceps	4.7 ± 2.8	15.3 ± 5.9
Biceps	2.1 ± 1.7	10.0 ± 4.7
Upper back	3.4 ± 2.8	10.1 ± 5.7
Front chest	4.8 ± 4.1	11.3 ± 6.9
Lateral chest	4.5 ± 4.1	14.4 ± 9.5
Upper abdomen	7.0 ± 6.4	13.7 ± 6.7
Lower abdomen	6.2 ± 5.0	11.3 ± 6.5
Lower back	6.1 ± 3.4	12.3 ± 5.4
Hip	6.0 ± 4.6	13.6 ± 6.5
Front thigh	2.6 ± 1.6	8.4 ± 3.0
Lateral thigh	2.3 ± 1.3	8.7 ± 2.8
Rear thigh	1.9 ± 1.2	6.1 ± 3.0
Inner thigh	4.2 ± 3.0	10.3 ± 3.3
Calf	1.4 ± 0.9	3.8 ± 1.9

Subjects and Methods

Healthy subjects

The participants were consented to the study after full explanation of the protocol by a physician. The procedures were in accordance with the Declaration of Helsinki and the local ethics committee recommendations. Height was measured using a stadiometer (SECA®-220, Hamburg, Germany), and body weight was determined by a Soehnle® scale (Soehnle® 7700, Murrhardt, Germany). The body mass index (BMI kg/m^2) was calculated. Waist and hip circumferences were determined with the use of an insertion tape (CMS Ltd, London, United Kingdom); hip circumference was measured at the point of maximum circumference over the buttocks. The waist measurement was taken from the midpoint between the iliac crest and the lower ribs measured at the sides. As a criterion method, the TBF% was determined using DXA (Lunar DPX-IQ scanner, Lunar Corporation, USA). Height, weight, waist and hip circumferences, DXA TBF% and Lipometer SAT thicknesses at fifteen defined body sites were measured in 28 healthy men (age: 33.9 ± 16.6 years) and 52 healthy women (age: 40.1 ± 10.7 years). For anthropometry, body composition and SAT layer thicknesses see Table 1.

Measurement of subcutaneous adipose tissue topography (SAT-Top)

To determine the thickness of a SAT layer (in mm), the sensor head of the Lipometer is held perpendicular to the measured body site. Light-emitting diodes illuminate this SAT layer and a photodiode measures the corresponding back-scattered light intensities. These light signals are converted into a SAT layer thickness[3,11].

SAT-Top consists of a complete cycle of 15 SAT layer thickness measurements (in mm) at 15 specific body sites (neck, triceps, biceps, upper back, front chest, lateral chest, upper abdomen, lower abdomen, lower back, hip, front thigh, lateral thigh, rear thigh, inner thigh, calf) distributed evenly from neck to calf on the right side of the body[12], while the subject is in standing position. The time consumption is about two minutes for the SAT-Top determination of a person. The Lipometer is connected to a PC, which stores the data measured.

Statistics

Statistical calculations were performed by SPSS 15.0 for Windows (SPSS, Chicago, IL, USA). Means and standard deviations (± SD) were calculated. Pearsons correlation coefficients were used to determine the relationships between dependent variables. To estimate Lipometer TBF% stepwise multiple regression analysis was applied, using DXA TBF% as dependent variable. Four models with different sets of independent variables were calculated:

Model 1 used only one independent variable, the BMI, because high correlations were found between DXA TBF% and BMI (R=0.867 in men and R=0.853 in women).

In model 2 the fifteen Lipometer SAT thicknesses were presented to regression analysis.

As part of each Lipometer SAT-Top measurement cycle, gender, age, height and weight are determined and BMI is calculated. Therefore, the set of independent variables in model 3 consisted of the fifteen Lipometer SAT thicknesses, gender, age, height, weight and BMI.

In model 4 the set of model 3 was increased by waist circumference, hip circumference and waist/hip ratio.

For the best Lipometer TBF% estimations the corresponding equations were presented. To show the quality of these estimated equations, scatterplots with regression lines, 95% confidence intervals and correlation coefficients were applied. Furthermore, Bland-Altman plots[13] were used to assess the agreement between directly measured DXA TBF% and Lipomenter TBF%, deriving from stepwise regression analysis.

Results

The results of the stepwise multiple regression analysis for all 80 subjects and four different models are presented in Table 2. The corresponding equations to calculate Lipometer TBF% for model 1 and model 2 were:

(1) Lipometer TBF% = 1.496 BMI – 12.283

(2) Lipometer TBF% = 0.786 biceps + 0.473 hip + 0.403 triceps + 0.512 inner thigh + 8.097

Model 3 using the fifteen Lipometer SAT thicknesses together with gender, age, height, weight and BMI as independent variables provided the best estimation, whereby Lipometer TBF% values were predicted from the following equation:

(3) Lipometer TBF% = 0.302 hip – 10.719 gender + 0.734 BMI + 1.008 calf + 0.213 upper abdomen + 3.195

(gender=0 for females and gender=1 for males). The correlation between this estimate and DXA TBF% was R=0.976 (Figure 1). 95.2% (R^2 * 100) of the TBF% measured by DXA in these subjects were explained by this result of model 3. A bias of 0.00% showed no systematical deviation between the DXA and the Lipometer method. The limits of agreement were –5.02% to +5.02%. Exactly the same result was achieved by model 4, showing that the additional use of waist circumference, hip circumference and waist/hip ratio as independent variables could not improve the estimation.

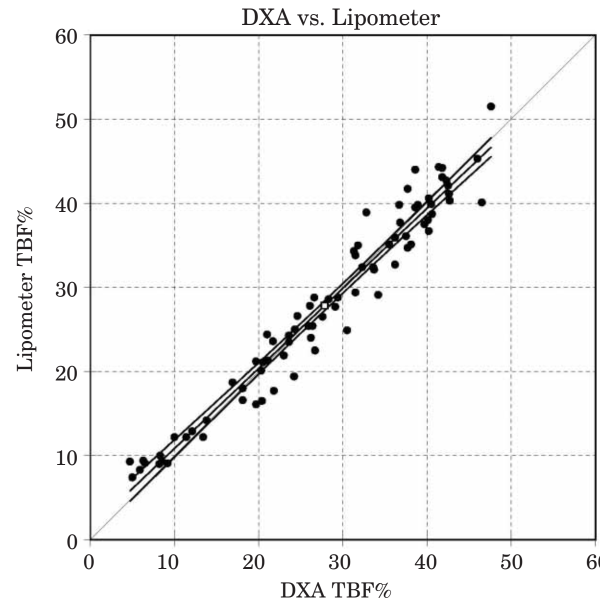

Fig. 1. Scatterplot, regression line and 95% confidence interval of 80 subjects showing DXA TBF% versus Lipometer TBF% (R=0.976) calculated by stepwise multiple regression analysis (see model 3 in Table 2).

The range of DXA TBF% was very different in men (4.7–26.7%) and women (20.5–47.6%). Therefore the dataset was divided by gender. The results are presented for males in Table 3 and for females in Table 4. Again, model 3 provided the best estimations for both genders with strong correlations to DXA TBF% (R=0.985 for males (Figure 2) and R=0.953 for females (Figure 3)). Lipometer TBF% values were predicted from the following equations:

Lipometer TBF% = 0.243 BMI + 1.054 calf +
+ 0.134 age + 0.890 triceps +
+ 0.577 lateral chest – 3.431 (males)

TABLE 2
RESULTS OF THE STEPWISE MULTIPLE REGRESSION ANALYSIS FOR ALL SUBJECTS (N=80), USING DXA TBF% AS DEPENDENT VARIABLE. FOUR MODELS WITH DIFFERENT SETS OF INDEPENDENT VARIABLES WERE CALCULATED. ADDITIONALLY, THE BIAS AND THE LIMITS OF AGREEMENT ARE PRESENTED FOR EACH MODEL

Model	R	R^2	Independent variables	SEE	p	Bias	Limits of agreement
1	0.717	0.514	BMI	8.21	<0.001	0.00	–15.99% to +15.99%
2	0.949	0.901	Biceps, hip, triceps, inner thigh	3.77	<0.001	0.00	–7.21% to +7.21%
3	0.976	0.952	Hip, gender, BMI, calf, upper abdomen	2.65	<0.001	0.00	–5.02% to +5.02%
4	0.976	0.952	Hip, gender, BMI, calf, upper abdomen	2.65	<0.001	0.00	–5.02% to +5.02%

Lipometer TBF% = 0.671 BMI + 0.329 hip +
+ 0.933 calf + 0.279 front chest –
– 0.274 upper back + 0.152 triceps + 5.071 (females)

97.1% and 90.8% of the DXA TBF% were explained by these prediction equations for males and females respectively. Although R and R^2 for females were lower compared to the result of all 80 subjects (Table 2, model 3) we received much better limits of agreement, which are a more appropriate measure than the correlation coefficient for assessing agreement between two methods of clinical measurement[13]. The limits of agreement were –2.48% to +2.48% for males and –4.28% to +4.28% for females. For both genders we received a bias of 0.00%. Again, the additional use of waist circumference, hip circumference and waist/hip ratio as independent variables in model 4 could not improve the results of stepwise regression analysis.

Discussion

We found strong correlations between DXA TBF% and BMI. The reason might be that even DXA uses the BMI as a basis for the internal calculation algorithm of the TBF%.

Nevertheless, using only the BMI as independent variable for regression analysis to calculate a predictive equation for DXA TBF% (model 1) led to limits of agreement that rejected the interchangeability of the two methods (model 1 in Table 2, 3 and 4).

Better limits of agreement were achieved by offering the Lipometer SAT-Top information to the regression analysis (model 2 in Table 2, 3 and 4), providing slightly better results than that of Jürimäe et al[4]. The quality of the estimation in that previous paper[4] was evaluated as ´only partly supporting the conclusion of interchangeability between the two methods for estimating TBF%´.

Finally, the best solution was obtained by presenting both BMI and Lipometer SAT-Top to regression analysis (model 3 in Table 2, 3 and 4), showing much better limits of agreement and interchangeability between the methods compared to the previous paper[4].

Additional measurements of waist circumference, hip circumference and waist/hip ratio were not able to im-

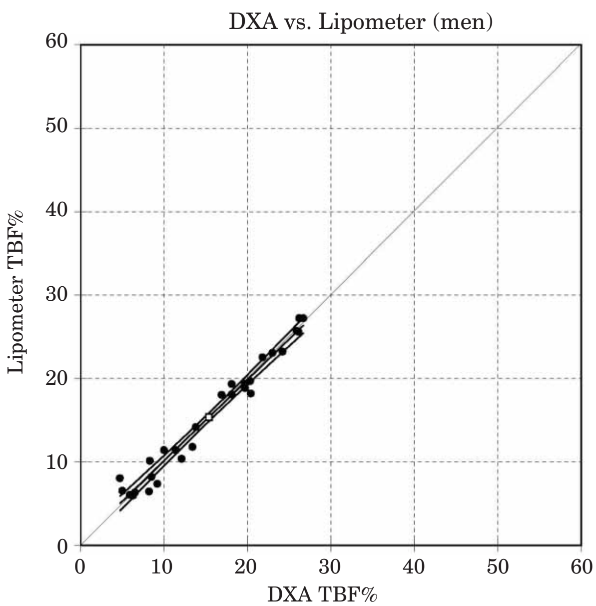

Fig. 2. Scatterplot, regression line and 95% confidence interval of 28 males showing DXA TBF% versus Lipometer TBF% (R=0.985) calculated by stepwise multiple regression analysis (see model 3 in Table 3).

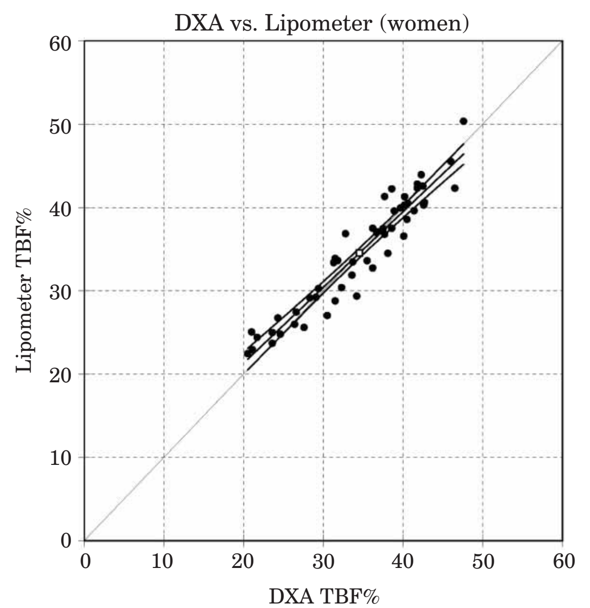

Fig. 3. Scatterplot, regression line and 95% confidence interval of 52 females showing DXA TBF% versus Lipometer TBF% (R=0.953) calculated by stepwise multiple regression analysis (see model 3 in Table 4).

TABLE 3
RESULTS OF THE STEPWISE MULTIPLE REGRESSION ANALYSIS FOR MALES (N=28), USING DXA TBF% AS DEPENDENT VARIABLE. FOUR MODELS WITH DIFFERENT SETS OF INDEPENDENT VARIABLES WERE CALCULATED. ADDITIONALLY, THE BIAS AND THE LIMITS OF AGREEMENT ARE PRESENTED FOR EACH MODEL

Model	R	R^2	Independent variables	SEE	p	Bias	Limits of agreement
1	0.867	0.752	BMI	3.75	<0.001	0.00	–7.22% to +7.22%
2	0.945	0.893	Upper back, inner thigh, triceps	2.57	<0.001	0.00	–4.74% to +4.74%
3	0.985	0.971	BMI, calf, age, triceps, lateral chest	1.40	<0.001	0.00	–2.48% to +2.48%
4	0.985	0.971	BMI, calf, age, triceps, lateral chest	1.40	<0.001	0.00	–2.48% to +2.48%

TABLE 4
RESULTS OF THE STEPWISE MULTIPLE REGRESSION ANALYSIS FOR FEMALES (N=52), USING DXA TBF% AS DEPENDENT VARIABLE. FOUR MODELS WITH DIFFERENT SETS OF INDEPENDENT VARIABLES WERE CALCULATED. ADDITIONALLY, THE BIAS AND THE LIMITS OF AGREEMENT ARE PRESENTED FOR EACH MODEL

Model	R	R^2	Independent variables	SEE	p	Bias	Limits of agreement
1	0.853	0.728	BMI	3.80	<0.001	0.00	–7.38% to +7.38%
2	0.918	0.842	Lateral chest, biceps, hip, calf	2.99	<0.001	0.00	–5.62% to +5.62%
3	0.953	0.908	BMI, hip, calf, front chest, upper back, triceps	2.33	<0.001	0.00	–4.28% to +4.28%
4	0.953	0.908	BMI, hip, calf, front chest, upper back, triceps	2.33	<0.001	0.00	–4.28% to +4.28%

prove the results of the stepwise regression analysis (model 4 in Table 2, 3 and 4).

Concerning the statistical calculation method it should be mentioned that further improvements of the results might be achieved by applying artificial neural networks instead of regression analysis, as previous results showed[3, 14].

Concluding, the results of this paper extend the abilities of the Lipometer by a precise estimation of TBF% using DXA as »golden standard«. Unfortunately, DXA can only be applied in clinics and specialized laboratories, because of high costs, the need of technical staff and radiation[15]. To perform valid assessment of body fat in schools or other public buildings, where time and quiet laboratory conditions are not available, the instrument must be portable and relatively inexpensive, procedures should be non-invasive, and training should be provided without prerequisite courses. Consequently, the present results suggest the Lipometer as an applicable tool for body fat measurement in large samples in clinical and field situations.

Acknowledgement

The Lipometer is used exclusively for research without commercial interest. Therefore there are no conflicts of interest and fundings to declare.

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PROCIJENA UKUPNOG POSTOTKA TIJELESNE MASNOĆE DXA METODE, LIPOMETROM ZA POTKOŽNO MASNO TKIVO

S A Ž E T A K

DXA je prihvaćena metoda za procjenu sastava tijela, iako s ovom metodom postoji nekoliko objektivnih poteškoća. Oprema je relativno skupa, nije prenosiva, nepraktična za proučavanje velikog uzorka i proizvodi minimalne količine ionizirajućeg zračenja. Optički uređaj lipometar (EU Pat. No. 0516251) omogućava, ne-invazivna, brza, precizna i sigurna mjerenja potkožnog masnog tkiva na bilo kojem dijelu ljudskog tijela. Uspoređujući lipometar sa DXA metodom, njegove prednosti su to što je prijenosan, brži, nije skup i nema ionizirajućeg zračenja. Za procjenu ukupnog masnog tkiva DXA metodom potreban je lipometar. Visina, težina, opseg struka i kukova, DXA metoda i lipometrijsko mjerenje bili su uključeni u mjerenja 28 zdravih muškaraca (33,9 ± 16,6 god) i 52 zdrave žene (40,1 ± 10,7 god). Da bi se procijenio lipometar TBF% metodom, procijenjen je DXA TBF% kao neovisna varijabla. Izmjerenih 15 nabora zajedno sa dobi, visinom, težinom, indeksom tjelesne mase predstavljaju najbolju procjenu lipometra TBF% za oba spola u relaciji sa DXA TBF% (R=0,985 za muškarce i R=0,953 za žene). Zadane granice su bile od -2,48 % do + 2,48 % za muškarce i od –4,28 % do 4,28 % za žene. Za oba spola pristranost je bila 0,00 %. Rezultati su pokazali kako je lipometar precizniji od TBF-a, ako se u obzir uzima DXA.