Ultradian comparison of different techniques for assessing body components in athletes – skinfold measurements, circumferences, near infrared interactance, and bioimpedance analysis

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Abstract

Objectives: Four techniques are compared for estimating body composition in young athletes analysing diurnal changes.

Subjects and methods: In 24 young healthy athletes, body components (body fat percentage, %FM; percent lean body mass, %LBM, and total body water percentage, %TBW) were measured thrice from 7:25 a.m. to 7:22 p.m, using three-site skinfold measurements (SKF), circumference measurement (CIR), near infrared interactance (NIR), and bioimpedance analysis (BIA).

Results: SKF, CIR, NIR and BIA methods were compared with each other. There were significant differences in the %FM values among the four methods with the SKF method providing the lowest %FM and the CIR method the highest values ($p<0.001$, Friedman test). Ultradian changes in %FM were significant when measurements were performed with SKF ($p<0.028$) or with BIA ($p<0.002$). Ultradian changes in %FM from morning to evening showed significant decreases using SKF ($p<0.05$) and significant increases using BIA ($p<0,01$). No ultradian changes in %FM were observed by use of the CIR and NIR methods ($p>0.05$).

Conclusions: For young athletes, the application of NIR for the determination of %FM is less affected by daily changes in hydration level than the other methods. NIR and SKF techniques provide the most comparative measures. For the detection of changes in fluid balance, BIA might be the most appropriate one.

INTRODUCTION

The skinfold measurement technique, circumference technique, near infrared interactance, and bioelectrical impedance analysis are non-invasive, safe, and inexpensive methods for determining body composition, especially in the field of kinanthropometry. The SKF, NIR, and BIA allow to estimate the body components lean body mass (LBM) and fat mass (FM). In addition, the BIA and NIR can be used to predict total body water (TBW).

Skinfold measurements (SKF):

Skinfold measurements are performed by use of so-called skinfold calipers. Skinfold thickness derives from two skinfolds and the subcutaneous fat between them. In the course of time a lot of skinfolds were recommended by different authors, but in kinanthropometry the methodology of Parizkova (1977) is established and well accepted. Her skinfold measurement sites differ markedly from those given in the handbook of anthropology of Martin and Knußmann (1988). In 1973, Forsyth and Sinning noted deviations in the determination of the % FM of athletes, if equations for non-athlete populations were applied to athletes. In German athletes, the equations are frequently used which were developed in Eastern Germany, because they are representative for Germans and are based on huge population groups. Johnsen (1983) introduced equations for children, which are based on twelve skinfold sites, whereas Tittel and Wutscherk (1972) recommended for sports anthropological investigations a modified Parizkova (1977) technique which is originally based on ten sites. Parizkova and Buzkova (1971) developed a simpler equation for men which is based on three sites - triceps, subscapular and suprailiac - and is suited for field investigations in kinanthropometry. As they did not introduce a similar equation for females, an adequate regression of Sloan et al. (1962) is used for women which computes the body density. Based on this value, the % FM can be determined by means of the formula of Siri (1956).

Circumference technique (CIR)

The anthropometry was completed additionally by use of one sex-independent equation of Weltman and Katch (1978), which allows prediction of body fat percentage by means of body weight and thigh circumference. So it is a further method which is independent from skinfolds.

Near infrared interactance (NIR):

Approximately 1970, the U.S. Department of Agriculture discovered a new and simple non-destructive method for providing measurements of organic constituents. This method involved the use of near-IR light (Conway et al. 1984). In 1988, a commercial instrument was introduced that uses the interactance measurement technique. This FUTREX-5000 Body Composition Analyser performs optical measurements at two wavelengths and has the ability of entering certain physical characteristics of the person being measured. The optical measurements are made at approximately 940 nm and 950 nm, because these two wavelengths have been shown to provide best results. The more advanced version of the FUTREX-5000, the FUTREX-6100 Body Composition Analyser, was introduced in 1996. The physical parameters used are height, weight, sex, and age of the person.

Bioelectrical impedance analysis (BIA):

Although the principles of BIA have been known for more than 45 years, this method is used for estimation of body compartments since 1970. The technique is based on the different conductive and dielectric properties of various human tissues at one frequency or at different frequencies of an injected electrical current. Due to its high water content and electrolytes, the fat free mass is a good conductor of the injected current, whereas fat mass is a bad conductor. Hoffer et al. (1969) demonstrated that a technique with four surface electrodes could be used for estimating body water. The first commercially available bioimpedance devices for analysis of body composition were introduced in the 1980s by RJL, Inc. (Detroit, MI). Until 1991, bioimpedance measurements were performed at one frequency (50 kHz). Thomasset and co-workers (Ducrot et al. 1970, Jenin et al. 1975) have shown that the use of bioimpedance measures at different frequencies enables to separate extracellular fluid from total body water. As a consequence, during the last ten years, bioimpedance analysers have been developed that work at different frequencies.

The purpose of this study was the parallel determination of body components by use of these different methods in the course of one day, in order to assess differences in diurnal variation.

SUBJECTS AND METHODS

Subjects

The study was performed on 24 healthy physical education students (16 males and 8 females), aged 22-44 years. Data collection was done in May 2002 at the Institute of Sports Sciences, Frankfurt University, Germany. All measurements were collected three times over one day in each volunteer, covering a period from 7:25 a.m. to 7:22 p.m. The subjects took meals and performed physical exercise between the measurements. Written informed consent was obtained from each volunteer. The study was performed in agreement with the declaration of Helsinki.

Methods

Body composition: FM, LBM, and TBW were determined by use of SKF, CIR, NIR, and BIA on the dominant side as follows.

- **SKF**: Subscapular, triceps, and suprailiac skinfold thicknesses were measured by use of a GPM caliper as recommended in Parizkova (1977). The GPM is a modified Holtain skinfold caliper, which is manufactured by Siber / Hegner (Zurich, Switzerland), working with a constant pressure of 10 g per mm^2 and a precision of 0.1 mm.The sum of the three skinfolds was used to estimate % FM applying the equations of Parizkova and Buzkova (1971) for men. For women, first the density was calculated after Sloan et al. (1962) and then % FM was calculated after Siri (1961).
- **CIR**: Thigh circumference was measured following the instructions of Martin / Knußmann (1988). FM (%) was calculated from thigh circumference and body weight following Weltman and Katch (1978).
- **NIR** was performed with Futrex-6100 (Vic Medic Systems GmbH, Filderstadt) using two optical densities (Ods) at the biceps in the middle between acromion and fossa cubitalis to predict FM, LBM, and TBW. The Futrex sensor was placed on the upper arm for several seconds, after logging the required individual data (sex, weight, height and age) into a mini-computer.
- **BIA**: Bioelectrical impedance analysis was administered via a tetrapolar multifrequency bioimpedance analyser (BIA 2000-M, Data Input Company, Frankfurt, Germany) operating at 800 μm and three fixed frequencies (5, 50, and 100 kHz). Impedance measurements of whole-body resistance (ohm) and reactance (ohm) were recorded. Prediction equations were used to estimate FM, LBM, and TBW from resistance, reactance, height, and weight of the subjects using Nutri 4 software (Data Input 1997).

Statistics

For statistical analyses of the data, the SPSS/PC software package for MS Windows, release 8.0 (SPSS Inc., Chicago, IL) was used. Because not all variables were normally distributed, interval data were transformed into ordinal data. Results are given as means and ranges. For each method, comparisons between means for repeated measurements were made with nonparametric Friedman's tests. The same method was applied in order to perform methods comparisons in the same volunteers. Two-tailed significance was set at the 0.05 level of probability.

RESULTS

Table 1 shows the descriptive statistics of the subjects for both sexes combined.

Diurnal variation

Table 2 gives the results of the three repeated measurements in the course of the day for each method separately. For % FM, significant daily variation is noted for SKF as well as for BIA measures. In detail, % FM, measured by SKF, decreases continuously from morning to evening by 1.1 %. In contrast, % FM, measured by BIA, decreases from morning to noon by 0.5 % and then increases until the evening by 1.2 %. The overall tendency throughout the day are rising values for both methods. However, the chronobiological changes in % FM during the investigation period are not statistically significant with respect to the CIR and NIR methods. Likewise, for the parameters % LBM and % TBW, significant daily changes are only observed, when measured by BIA, but not by NIR. Concerning the BIA method, % LBM increases from morning to noon by 0.5 % and then decreases until the evening by 1.15 %, displaying a general falling tendency. A similar tendency is observed for %TBW with a total decrease of 0.5 % during the day. The standard deviations for % FM show similar dimensions for most methods with the exception of CIR.

Methods comparison

When comparing the three values of % FM - each measured by SKF, CIR, NIR and BIA - in the course of one day (Table 2), the four methods significantly differ in their means ($p < 0.001$). The same holds true for the parameters % LBM and % TBW, each measured by NIR and BIA. For % FM, the three repeated CIR and NIR measurements on the same athlete are very consistent over one day (the 12-hour study interval), whereas the SKF and BIA values show greater variability. In synopsis, for % FM the SKF method displays lower values than the NIR, BIA and CIR methods, amounting to differences of 2.8 %, 6.7 % and 17.5 %, respectively.

DISCUSSION

In the last decades, a number of different methods was developed for estimating body composition, but only a few are suitable for practical use in field examinations due to costs, time and handling. The most common methods in sports sciences are SKF, NIR, BIA, and CIR. Time series data often reveal amazing ultradian changes of anthropometric parameters. Dittmar et al. (2002) found in healthy students that TBW, extracellular and intracellular water, LBM and extracellular mass increased from morning to midnight, whereas height decreased. These parameters have been predicted by BIA. Thus, this study considers in addition to the BIA technique further methods in order to investigate whether daily changes in measurements can also be detected by application of NIR, CIR and SKF. The knowledge on these changes might be a valuable help for the interpretation of sports-related data.

Methods comparison

A remarkable finding is the consistent significant difference between % FM measurements with the four different methods throughout the whole day, displaying the following ranking order starting with lowest values for SKF, followed by NIR, BIA and CIR. Heyward et al. (1992) reported for non-obese women no significant differences in % FM when measured by SKF, NIR, BIA, and hydrostatic weighing. For obese women, % FM was significantly underestimated by SKF, NIR and BIA, as compared to hydrostatic weighing. According to Kitano et al. (2001), % FM was higher when measured by BIA, as compared to SKF in Japanese healthy female college students. This is in line with our results. Likewise, Lanham et al. (2001) reported for Australian resident females of Chinese ancestry lower % FM values by SKF than by BIA. Houtkooper et al. (2001) found that for American heptathletes SKF equations provided more accurate estimates of % FM relative to dual energy x-ray absorptiometry than estimates from BIA equations.

The striking difference between the high values of % FM measured by CIR in comparison to the other methods can be explained by the fact that male and female sports education students have higher thigh circumferences due to their larger muscle mass, as compared to non-athletes. Usually, a larger thigh circumference indicates a higher fat mass. Furthermore, CIR is based on an equation for both sexes combined which might produce different values. The close similarity of the % FM values predicted by SKF and NIR, in relation to BIA, depends on the methodology. The SKF focus on the thickness of the subcutaneous fat layer and the NIR measurement is a composite of the subcutaneous fat and the intermuscular fat. In contrast, BIA relies on body resistance to an applied electrical current. However, the similarity of % FM values predicted by SKF and NIR only occurs in young, healthy and physically fit subjects. In more diverse populations, over a large age range and a large range of fitness, the

SKF approach may significantly differ than the NIR approach because the SKF equations were predominantly derived for fit, young adult populations.

Diurnal variation

The significant daily variation in % FM by BIA can be explained by undulations of the daily body fluid balance which is caused by the intake of fluid and food and the excretory function of the kidneys and the bowel. Chronobiological changes of the skinfolds are a function of turgor. Although the NIR targets at the same tissue layer, the alterations during the day are less pronounced. This might be due to the fact that SKF is a function of three skinfolds and NIR depends only on one subcutaneous site which is only measured in one direction. Thus, changes in fluid distribution are less pronounced in NIR measurements than in SKF ones. The NIR measurement is independent of the fluid status in the athletes. More comparative and longitudinal studies are needed to confirm the validity of NIR measurements in the longitudinal evaluation of athletes and patients. Additional research with expanded study groups is needed to further demonstrate and evaluate the utility of these body composition techniques. Diurnal variation in BIA measures are due to changes in the daily rhythmic patterns of fat, water and electrolyte metabolism. The decrease in % FM after the second measure may be explained by the ingestion of meals leading to a decrease in bioelectrical impedance, and thus, to a decrease in the calculated % FM. This is in line with observations reported by Slinde and Rossander-Hulthen (2001). The increase in % FM at the third measurement can be explained by an increase in bioimpedance due to water loss which was caused by physical exercise of the subjects in the afternoon.

In conclusion, the results of this study suggest that for young athletes the use of NIR for the determination of % FM is less affected by daily changes of water household than BIA and

SKF. For application of CIR in athletes, new sex-specific equations with respect to the sportive behaviour should be developed. The most comparative measures are obtained by application of NIR and SKF. Further studies should be directed to validate these methods against reference methods. For the detection of changes in fluid balance, which are due to physical exercise, the BIA method might be the most sensitive and appropriate one.

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Table 1. Descriptive characteristics of the athletes.

Variable	N	Mean	SD	Range
Age (years)	24	27.5	5.91	22-44
Weight (kg)	24	78.5	12.74	56.5-113.0
Height (m)	24	1.81	0.01	1.60-2.00
BMI (kg/m^2)	24	23.96	2.46	18.0-29.1

Table 2. Comparison of body composition estimates by use of four different methods in the course of one day in healthy athletes.

Variable	Method	N	First measure		Second measure		Third measure		χ^2 [2]	*P*
			Mean	SD	Mean	SD	Mean	SD		
FM (%) [1]	SKF	21	14.79	5.61	13.76	4.73	13.71	4.72	7.14	**0.028**
	CIR	22	32.31	10.80	29.06	6.57	28.51	6.14	2.27	0.321
	NIR	23	17.63	6.71	17.29	7.09	17.73	7.26	1.87	0.393
	BIA	24	21.51	6.33	21.00	6.73	22.15	6.41	12.25	**0.002**
LBM (%) [1]	NIR	23	82.37	6.72	82.71	7.09	82.27	7.26	1.87	0.393
	BIA	24	78.49	6.33	79.00	6.73	77.85	6.41	12.25	**0.002**
TBW (%) [1]	NIR	23	61.32	4.22	61.54	4.46	61.26	4.58	1.87	3.93
	BIA	24	57.46	4.61	57.83	4.92	57.00	4.71	10.33	**0.006**

Abbreviations: BIA, bioelectrical impedance analysis; df, degrees of freedom; NIR, near infrared interactance; SD, standard deviation; SKF, three-site skinfold measurement; CIR, circumference.

[1] Given as a percentage of body weight.

2 Non-parametric Friedman test, df = 2.