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Prediction of body fat in male athletes from ultrasound and anthropometric measurements versus DXA

Short title : Prediction of body fat

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Original article

Abstract

Background: To compare the accuracy of body fat percentage (BF%) measured by an ultrasound portable device and anthropometric measurements with a Dual Energy X-ray Absorptiometry (DXA) as the reference technique in male athletes.

Methods: A total of 100 athletes: 16 boxers, 4 rowers, 5 gymnasts, 6 base ball players, 19 judo players, 10 taekwondo players, 7 basket-ball players, 21 wrestlers, 6 cyclists on track and 6 karate expert aged from 18 to 30 years participated. All athletes were selected from the French National Institute of Sports and Physical Education . Ultrasound measurements were made with a sonographic US BOX at the mid-thigh level. We developed a multi -linear model of body fat estimation from ultrasound and anthropometric dimensions (height, weight, waist circumference) using the DXA reference method. A cross-validation study was then performed with this linear regression on 62 males athletes proportionally stratified across the sports.

Results: The best accuracy of BF was obtained using a multi-linear model from ultrasonic and anthropometric measurements with a concordance correlation $\rho_c = 0.941$. This model was then used to estimate BF on the 62 males athletes. The concordance correlation $\rho_c = 0.931$ and SEE =1.60. The 95% limits of agreement for individual BF% were [-4.1;3.6%] with symmetrically distributed deviations.

Conclusions: Comparing to DXA, ultrasonic and anthropometric measurements are both accurate techniques to estimates BF%. Our results suggest that this regression model is practical to apply to different sports.

Key-words: Body fat mass, ultrasound, anthropometry, DXA, male athletes.

Introduction

In sport disciplines with weight categories assessment of body composition will help to optimize competitive performance and therefore is of considerable interest [1,2]. Excess BF may negatively affect performance [3]. The weight loss is difficult to regulate for many athletes because it often results in poorer performances [4]. Therefore the knowledge of body composition in relation to total body fat (BF) is required. Body composition is usually evaluated by measuring fat mass and fat free mass then using these values to compute the body fat percentage (%BF) [5]. The body composition giving body size and configuration is described by anthropometric measures such as body weight, body mass index (BMI), circumferences, skinfold thicknesses [6,7]. Dual energy X-ray absorptiometry (DXA) which measures three components (fat mass, lean mass and bone mass) in the full body is considered as a reference technique for measuring body composition due to its high precision and accuracy compared with other body composition assessments [8]. Indeed, DXA provide precise and reliable measurement of body composition and has low radiation emission. Other indirect prediction methods such as bioelectrical impedance analysis and air displacement plethysmography are commonly used to assess body composition. However, BF% estimates from these techniques versus DXA presents a skew of the mean values higher than 2% and a large standard error of estimate [9,10].

Pritchard [11] indicated that total body fat mass values obtained by DXA are very well correlated with the 4-C reference model described by Wang [12]. Ultrasound technique can also be used to estimates the body fat mass with a high accuracy. [13-15]. In a previous study [16], we have developed a new model to predict fat mass in 93 athletes from a

combination of anthropometric dimensions and ultrasound measurements at the abdomen and mid-thigh with higher correlation to the BF% DXA .

In this study, we aimed to determine the whole body fat with high accuracy in young male athletes by using different anthropometric and ultrasonic equations. Here, we use a A-mode ultrasound to measure the subcutaneous adipose tissue thickness of the thigh and umbilical level and anthropometric variables as the main predictors according to the reference method DXA. A cross-validation study between ultrasound technique with anthropometry dimensions and DXA was then performed using the multiple regression linear model.

Materials and methods

Study participants

This study was conducted at the National Institute of Sports and Physical Education (INSEP), Paris, France. We studied 100 males of national level recruited at INSEP with 16 boxer, 4 rowers, 5 gymnasts, 6 base ball players, 19 judokas, 10 taekwondo players, 7 basket-ball players, 21 wrestlers, 6 cyclists on track and 6 karate experts aged from 18 to 30 years. We only included well-trained athletes and all weight categories from super-light to heavy were represented. After being informed about the purpose of this study, all athletes signed a written consent form in accordance with the Declaration of Helsinki as revised in 2008. The study protocol was approved by the regional ethics committee for healthy volunteers. For each athlete examined, ultrasonic and anthropometric measurements as well as BF DXA (kg) were simultaneously recorded on the same day.

A Cross-validation between the ultrasound technique with anthropometry and DXA was performed on 62 males of national level recruited at INSEP with 10 boxer, 2 rower, 3 gymnast, 4 base ball players, 11 judokas, 6 taekwondo players, 5 basket-ball players, 14

wrestlers, 3 cyclists on track and 4 karate expert aged from 18 to 30 years proportionally stratified across the sports.

Anthropometric measurements

Anthropometric variables were recorded by the same operator using standard techniques [17]. Body weight was measured to the nearest 0.1 kg using a calibrated scale (HD-372, Tanita Neuilly sur-Seine, SA , France and height to the nearest 0.5 cm using a stadiometer (Holtain, Crosswell, UK). Body Mass Index (BMI) in kg/m^2 was calculated as weight (kg)/height² (m). Waist circumference (WC) in cm was measured at umbilical level. BMI and WC are often associated with metabolism risk factors [7]. Sun et al. [18] also indicated that the validity of simple anthropometric measures such as BMI and waist circumference is comparable to DXA measurements of BF% as assessed by their correlation with obesity - related risk factors for cardiovascular disease.

Ultrasound device

Ultrasound measurements were taken using a sonographic US BOX in A-mode (Lecoeur Electronique, Chuelles, France) [19]. The ultrasonic technique can be used to measure the thickness of fat between the skin and the muscle. A transducer probe emits through the skin, an ultrasonic wave, part of which is reflected in the fat-muscle interface. MRI was used to determine the repartition of the subcutaneous adipose tissue on a single side transverse slice at the umbilical level and at mid-thigh. We selected two anatomical areas: the intra-abdominal area and the mid-thigh area (Figure 1) which gives the better correlation ship with the body fat mass DXA. Subcutaneous fat was located in a horizontal plane with an approximately 45° vertebral axis at the umbilical level, in the middle of the knee, and at the top of the thigh interiorly. Mid-thigh subcutaneous fat thickness is the mean fat thickness of right and left side Abdominal and mid-thigh subcutaneous fat was measured using a 5.0-

MHz linear array probe. A probe diameter of 0.75 in (1.90 cm) is the most suitable in terms of positioning, location, orientation, contact, and pressure. We obtained highly reliable, repeated measurements of fat thickness with 2 examiners with an intra-class correlation above 0.97.

Figure 1: Measurement points at umbilical level (right and left back) and at mid-thigh level using a 5.0 MHz linear array probe.



Dual energy X-ray absorptiometry

Total body fat (BF, kg) was measured using a whole-body DXA (Hologic QDR 4500, Waltham Massachusetts, USA). The DXA method uses an X-ray tube with a filter to 40 kV and high-energy (100 kV). The DXA machine was calibrated daily to a lumbar spine phantom for bone density and to a tissue bar for Fat-free-mass. Scan time for a total body measurement is approximately 7 minutes. DXA machine produces highly accurate BF and BF% values according to the 4-C model [11]. The body weight of each athlete can also be calculated.

Statistical analysis

Means and standard deviations were calculated for each variable of interest. We developed a series of multi-linear regressions to predict BF of the DXA measured fat mass as a

dependent variable in relation to the anthropometric and ultrasonic measures as predictor variables. The relationships between BF% DXA and BF% estimate according to the techniques used (anthropometry and ultrasound) were examined using paired t-tests. The accuracy of BF prediction was evaluating from the concordance correlation using the formula $\rho_c = \rho C_b$ with $C_b = ([(v+1/v)+u^2]/2)^{1/2}$; $v=SD_1 / SD_2$; $u = (\mu_1 - \mu_2) / \sqrt{SD_1 SD_2}$ were ρ_c is the Pearson correlation. We used the variance inflation factors $VIF= 1/(1-R^2)$ to test the co-linearity. Agreement between BF% estimate and BF% DXA of the 62 males athletes was examined by calculating the 95% limits of agreement as described by Bland and Altman [20]. For all analyses, P value smaller than 0.05 were considered significant. All statistical analyses were carried out with the Statistical software (Stat soft, Tulsa, OK, USA).

Results

Anthropometric and ultrasonic prediction equations for body fat mass

The descriptive statistics is given in Table 1. All variables showed a great variability and range.

Variables	Mean (n=100) ± SD	Range	CV%
Body mass (kg)	75.1 ± 14.8	41 - 137	
Height (cm)	177.8 ± 9.6	155 - 206	
BMI (kg/m ²)	23.6 ± 3.1	16.6 - 35.7	
Waist (cm)	80.3 ± 8.5	66 - 121	
Umbilical thickness of fat(mm)	11.3 ± 5.6	2.2 - 42	
Mid-thigh thickness of fat (mm)	7.1 ± 2.5	2.0 - 14.5	
BF DXA (kg)	7.0 ± 4.3	3.3 - 31.7	61.4
BF % DXA	9.0 ± 3.4	4.7 - 23.2	37.7

Table 1 : Characteristics of the male athletes (CV=100 Mean/SD)

The proposed anthropometric and/or ultrasonic equations to predict BF are shown in Table 2. For all equations from 1 to 7, the variance inflation factors (VIF) is less than 10 and the tolerance is greater than 0.1. So, we consider that we have no problem of co-linearity between the variables.

The simplest model including BMI explained only 46% of the variation of BF. Adding BMI² and waist circumference in the model significantly increased the R² from 46 to 89 % and decreased SEE from 3.18 to 1.47. Moreover addition of ultrasonic measurement as mid-thigh area significantly increased the R² from 0.46 to 0.89 (p<0.01). The concordance correlation calculated with the equation 6 is $\rho_c = 0.941$. We observed that the thickness of fat at umbilical level does not make a significant contribution in the equation 5.

Moreover the introduction of the specific sport variable does not provide additional precision in body fat estimate (equation 7).

	intercept	BMI kg/m ²	BMI ²	Waist (cm)	UT 1 (Cm)	UT 2 (cm)	Spec. Sport	R ²	SEE	VIF
Anthropometry										
Equation 1	-15.3	0.946						0.46	3.18	1.9
Equation 2	63.7	-5.56	0.132					0.73	2.28	3.7
Equation 3	32.64	-4.29	0.093	0.288				0.80	1.97	5.0
Ultrasound										
Equation 4	-2.32				0.633			0.63	2.64	2.7
Ultrasound and anthropometry										
Equation 5	47.32	-5.09	0.111	0.156	0.638	- 0.017		0.89	1.48	9.1
Equation 6	46.19	-4.99	0.109	0.154	0.627			0.89	1.47	9.1
Equation 7	46.12	-4.95	0.108	0.151	0.627		-0.03	0.89	1.48	9.1

Table 2 : Anthropometric and ultrasonic prediction equations for body fat mass in the 100 male athletes (UT1 is mid-thigh thickness of fat; UT2 is umbilical thickness of fat).

The multiple linear regression equation to produce BF estimate with anthropometry and ultrasonic measurement is:

$$\text{BF (kg) estimate} = -4.99 \text{ BMI} + 0.109 \text{ BMI}^2 + 0.154 \text{ Waist} + 0.627 \text{ UT mid-thigh} + 46.19$$

with a concordance correlation $\rho_c = 0.941$. Pearson correlation $R^2 = 0.89$ and $SEE = 1.47$.

Predict $BF\% = 100 BF(kg) \text{ estimated} / \text{Body mass (kg)}$.

The regression coefficients of the $BF(kg)$ estimated by anthropometric and ultrasonic measurements versus $BF \text{ DXA (kg)}$ are all significant with $p\text{-level} < 0.01$ (Table 3).

Variables	Regression coefficients B	Standard error of B	t (157)	P-level
Intercept	46.19	6.86	6.7	<0.01
BMI (kg/m^2)	-4.99	0.47	-10.6	<0.01
BMI ² (kg/m^2)	0.109	0.01	10.6	<0.01
Waist (cm)	0.154	0.04	3.9	<0.01
Umbilical thickness at mid-thigh (cm)	0.627	0.07	8.8	<0.01

Table 3: Regression summary for dependant variable $BF(kg) \text{ DXA}$ (N=100)

When comparing the remaining athletes, $BF\%$ determined by the equation 6 showed using the Paired t-test a non significant difference compared with DXA .

Mean bias for $BF\% = -0.004 \pm 1.8$ ($P = 0.98$).

Cross-validation study

The characteristic of the 62 males athletes is given in Table 4.

Variables	Mean (n=62) \pm SD	Range	CV%
Body mass (kg)	75.3 \pm 16.5	47 - 130	
Height (cm)	177.1 \pm 11.4	155 - 216	
BMI (kg/m^2)	23.8 \pm 3.0	18.2 - 34.0	
Mid-thigh thickness of fat (mm)	7.7 \pm 3.0	2.5 - 18.0	
$BF \text{ DXA (kg)}$	7.3 \pm 4.5	3.0 - 29.7	61.6
$BF \% \text{ DXA}$	9.4 \pm 3.3	4.8 - 24.8	35.1

Table 4 : Characteristics of the 62 male athletes

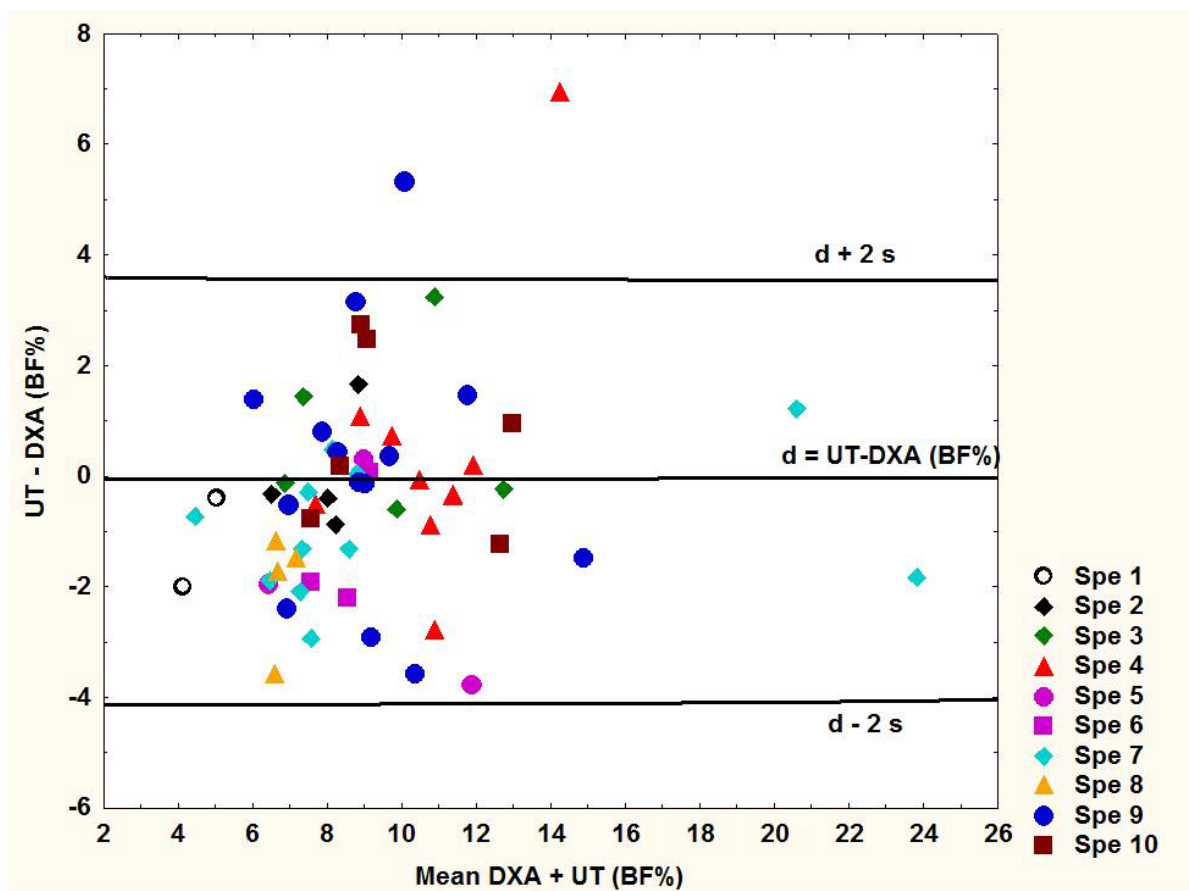
BF and BF% estimate from the equation 6 gives us the relation:

$$\text{BF DXA estimate} = 7.2 \pm 4.8 \text{ kg} \quad \text{and} \quad \text{BF \% DXA} = 9.1 \pm 3.6$$

The concordance correlation $\rho_c = 0.931$. Pearson correlation $R^2 = 0.87$ and $\text{SEE} = 1.60$.

Individual BF% differences between BF% estimate and BF% DXA from the equation 6 are illustrated by the figure 2. The Bland and Altman plot (Figure 2) demonstrated small limits of agreement, ranging from $[-4.1; 3.6]\text{BF\%}$. This plot showed a high level of accuracy for the BF% with a symmetric dispersion around the mean difference ($\text{BF\%} = -0.26 \pm 1.97$; $P = 0.29$). Figure 2 also indicates that no bias was present ($P = 0.18$).

Figure 2: Residual comparisons plotting differences between BF% DXA and BF% UT and AP (equation 6) Spe 1: rower ; Spe 2: baseball; Spe 3: basket-ball; Spe 4: boxer Spe 5: cyclists; Spe 6: gymnast; Spe 7: judo; Spe 8: karate; Spe 9: wrestlers; Spe 10: taekwondo.



Discussion

Body composition analysis is currently used in clinics and in sports medicine. Reference methods such as DXA can provide accurate results. However this method is costly and largely inaccessible to coaches in routine. For this reason, we developed anthropometric and/or ultrasonic prediction equations to estimate body fat mass percent fat mass using a sample of 100 males of national level ranging widely in BMI (16.6-35.7 kg/m²) and BF DXA (3.3-31.7 kg).

BMI and waist circumference are simple anthropometric measures with an inter operator accuracy lower than 1%. The use of BMI is largely inaccurate method for estimating BF% in weight-class male athletes with a R²=0.46 and SEE=3.18. The anthropometric equation 3 with BMI, BMI² and waist which is the most practical equation showed valid results with high predictive ability (R²=0.80, SEE=1.97). Moreover, the addition of anthropometric measurements with ultrasonic measurement at mid-thigh (equation 6) gives us a better prediction of body fat mass versus DXA ($\rho_c = 0.942$, P<0.05 and SEE=1.52).

A cross-validation was performed on 62 males athletes proportionally stratified across the specific sports. The predicted value of BF% estimate from the equation 6 was accuracy with a concordance correlation of $\rho = 0.931$ (P<0.05) and the SEE =1.6 is ideal according to the Lohman classification [21] . This author indicated that the SEE must be less than 3% for a new method to be accepted as accurate.

The 95% limits of agreement as described by Bland and Altman are relatively small [-3.8;+3.5%] with a mean difference of -0.26%. (P=0.29). We observed that our model of regression gives us a high BF% estimate whatever the sports discipline practiced.

Heyward & Wagner [22] recommended that the correlation coefficient for body fat predictions equations should exceed 0.8 and the limits of agreement should be within 5% when compared to the reference method.

Anthropometric measurements as skinfold thicknesses have currently been used for predicting body density and %BF. Novack et al. [23] developed novel mathematical models to predict BF% in 31 male professional soccer players using skinfold thickness measurements versus DXA as a reference method with a $R^2=0.86$ and $SEE=1.6$. Oliver et al. [24] have developed multiple regression equations using standard anthropometric measurements as skinfold thicknesses and abdominal circumference to estimate %fat in 157 collegiate football players because equations developed to predict BF% have been shown to be population specific and might not be accurate for football athletes. Silva et al. [25] indicated that the skinfold equations developed by Jackson and Pollock did not accurately track body composition changes in elite male judo athletes. Shakeryan et al. [26] compared the BF% through skinfold thickness using Lohman's method and BIA using hydrostatic as a standard method. Their results showed that Lohman's skinfold-thickness method is not valid because there is a significant difference between averages of Lohman's three-point method in wrestlers.

Several studies have compared anthropometric equations with bioelectrical impedance analysis (BIA) in the estimation of body fat. Martin Moreno et al. [27] observed that anthropometric equations provided different body fat estimates than those derived from skin-fold measurements and BIA. Aristizabal et al. [28] compared anthropometric methods with BIA in estimating percent body fat. They observed that the anthropometric methods showed higher values. Porta et al. [29] observed that in males, the level of agreement between the anthropometric method and the four BIA devices was poor to moderate. Stewart et al. [30] established a prediction of fat and fat free mass in male athletes using DXA as reference method. The equation of Ball et al. [31] using seven skin-folds showed the highest

level of agreement. However, BIA and anthropometric techniques are not interchangeable in ultra-endurance athletes.

Wagner et al. [32] evaluated the validity and reliability of the BodyMetrix™ BX2000 A- mode ultrasound for estimating percent body fat (%BF) in 45 athletes by comparing it to skinfolds and the BOD POD. Linear regression using the BF% estimate from ultrasound to predict %BF from BOD POD resulted in $R^2=0.849$, $SEE=2.6BF\%$. As observed by the authors and despite a very homogeneous BMI (24.1 ± 2.4), the validity of the this method is questionable, particularly for female athletes. Bielemann et al. [33] developed equations to estimate body fat based on anthropometric measurements of subcutaneous fat thickness and muscle thickness measured by A-mode ultrasound (BodyMetrix) in Brazilian adults. Lower and upper 95% limits of agreement were $[-6.5\%-6.7\%]$. Leahy et al. [15] found UT to accurately predict BF% in 83 sedentary young men with an $SEE=1.9\%$ and 95% limits of agreement of $[-3.6;+3.8\%]$. Ultrasound has been also used to predict the body density of sumo wrestlers [34] and the body fat mass of prepubertal Japanese children [35]. Utter and Hagger [36] showed that the ultrasound estimates of fat-free mass was significantly correlated with the estimate from hydrostatic weighing ($r=0.97$). Ripka et al. [37] showed that ultrasound applied in a specific regression for BF% prediction in 71 adolescents has a strong correlation ($r=0.848$) with DXA.

Conclusions

The multiple regression linear model established in the present study from simple anthropometric measurements (height, weight and waist circumference) accurately predicts BF% according to the reference DXA method. The use of the ultrasonic technique giving a non invasive measurement of the thickness at mid-thigh makes a significant improvement of the prediction of the BF% with a concordance correlation of $\rho_c=0.931$ and $SEE=1.60$.

Our results suggest that our anthropometric and ultrasonic model should be easy use in different sports with weight categories. It should be validated on different samples of athletes.

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