Prediction of percent total body fat in adult men using ultrasonic and anthropometric measurements versus DXA

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Abstract

BACKGROUND: The aim of this study was to verify the accuracy of a portable ultrasound device associated to anthropometric measurements using a reference method, dual-energy x-ray absorptiometry (DXA) for estimate body fat (BF) and body fat percentage (BF%) in adult male.

METHODS: A total of 63 subjects (18-60 years) participated for this analysis. Patients were voluntarily selected through a high variability in body mass index (BMI) and total BF. A cross-validation between ultrasound and anthropometric predictors of BF% was performed on 35 males in this study.The present study was to conduct and validate generalized prediction equation for total BF% using the combination of ultrasonic and anthropometric measurements versus DXA in a sample of French men with a large variability of BF%. We verified the accuracy of our ultrasonic measurements by performing an umbilical MRI at the same subcutaneous fat thickness. We developed a multiple regression model of BF and BF% estimate from ultrasound and anthropometric dimensions using the DXA reference method.

RESULTS: BF% estimates was strongly correlated with BF% DXA on 63 males (R^2 =0.86, SEE=2.8%). A cross-validation study performed on 35 males showed again a high correlation (R^2=0.86, SEE=2.9%) between BF% DXA and BF% estimate. The 95% limit of agreement with individual differences are [-5.1%; +5.7%].

CONCLUSIONS: Ultrasonic and anthropometric measurements are both accurate techniques to estimate BF%. Our results suggest that this ultrasound technique should be easy to use in epidemiologic studies.

KEY-WORDS : Body composition, Absorptiometry, Ultrasonography, Anthropometry

Introduction

The increase in obesity resulting from modern lifestyles and diets is a public health problem. Excess body fat is a risk factor for developing chronic diseases and premature death [1-3]. Worldwide obesity has nearly doubled over the past 30 years. In France there are 11.3% of obese adults, representing 3.5 million individuals [4]. Obesity is associated with cardio metabolic risk [5].

Epidemiologic studies commonly use the body mass index (BMI) calculated from weight and height (Weight (kg)/Height^2(m)) as an indicator of overweight and obesity [6]. Although BMI correlates well with fat mass percentage (BF%) [7], it gives only a fair estimate of BF% at individual level [8]. Moreover, it does not inform us about the distribution of the total body fat mass [9,10]. Most of the BF% equations using anthropometric variable have been validated against DXA measurements in different studies [11,12].

For this reason, the use of accurate and reliable methods of measuring body composition offers protection of health through good diagnostic criteria and intervention control.

Many measurement techniques and equations have been established for body composition evaluation ; among them are reference, laboratory, and field methods [13,14].

Dual-energy X-ray absportiometry (DXA) is a reference method commonly used for measuring body composition in cross-sectional and longitudinal studies [15]. However, this technique is irradiant, expensive and not easily accessible in routine.

Ultrasonic technique is an accurate and reliable method for measuring subcutaneous adipose tissue [16,17]. However this highly innovative technique allows to measure thicknesses of subcutaneous adipose tissue but cannot be used to determine the total body fat mass.

The present study was to conduct and validate generalized prediction equation for total BF% using the combination of ultrasonic and anthropometric measurements versus DXA in a sample of French men with a large variability of BF%. Anthropometric measurements, such as BMI and waist circumference (WC), remain the most commonly used measures of adiposity in epidemiologic studies [7].

Our objective was to determine an accurate estimate of BF (kg) and BF% from the anthropometric criteria: BMI and waist circumference (WC) and from ultrasound measurement of fat thickness at the umbilical level [18]. A cross-validation study was carried out on the basis of the previous model. Data accuracy was analyzed from DXA reference measurements.

Methods

Study participant

This study was carried out in a university hospital under a French medical agreement. All patients signed a written consent form in accordance with the Declaration of Helsinki as revised in 2013. The majority (95%) of the subjects were Caucasians. Inclusion criteria include only patients who gave written consent after receiving a letter of information on the measurement. Enrolled patients were healthy and have high variability in BMI and total body fat mass. Criteria for exclusion apply to patients with hydration disorders, heart failure, kidney failure, pregnancy, use of diuretics, corticoids or antidepressants. Cancer patients taking medication and patients refusal to sign informed consent are also excluded. For each subject examined, total body fat was measured simultaneously by DXA and by ultrasound technique on the same day.

The study group was used for developing an anthropometric equation for predicting BF(kg) and BF%. A sample of 63 men aged from 18-60 years old were recruited from hospital consultations or hospitalization units. A cross-validation study between anthropometric and ultrasound measurements was performed on a second independent sample of 35 males from the predictive equation established on the validation group of 63 men.

Anthropometry

Anthropometric measurements were collected by the same operator according to the standard techniques used [19]. Height and weight were recorded on patients in standing position without shoes. Weight was measured with an accuracy of 100g using an electronic scale, (HD-372,Tanita Neuilly sur-seine), height with an accuracy of 2 mm using a Stadiometer (Holtain, Croswell, UK), and BMI was calculated as weight(kg)/height^2(m). Waist Circumference (WC) in cm was recorded at umbilical level with an accuracy of 3 mm.

Ultrasonic technique

Ultrasound measurements (UT) were performed with a sonographic US BOX in A-mode from Lecoeur Electronic Co (Chuelles, France). The UT enables to measure the thickness of fat (in mm) between the skin and the muscle. A transducer probe emits, through the skin, an ultrasonic wave that is partially reflected at the fat-muscle interface. The subcutaneous fat thickness (SAT) is calculated based on a linear relationship involving the speed and the duration of the wave propagation.

Using the MRI technique, we selected the abdominal area (Figure 1) passing through the umbilicus which is often associated with metabolic risk factor [20,21]. The study participants were placed on the platform of a 1.5 T scanner (General Electric 6X Horizon, Milwaukee, WI, USA).

The subcutaneous fat thickness (SAT) measured from the ultrasound technique (UTumb) is located in a horizontal plane with approximately 45° axis vertebral at umbilical level (Figure 2). We verified the accuracy of our ultrasonic measurements by performing an umbilical MRI at the same subcutaneous fat thickness. We obtained a high reproducibility of fat thickness measurements with 3 examiners working with the same 10 subjects using ultrasound technique versus MRI as showed in Figure 1. The intra-class correlation was above 0.98.

Figure 1: Fat thickness (UTumb) at umbilical level measured by magnetic resonance imaging

Ultrasound measurements were recorded on subjects in the standing position. A specific anatomical landmark was used to pinpoint the measurement site. Moreover, the skin thickness was not included in the subcutaneous fat thickness measurement. Abdominal subcutaneous fat was measured using a 2.25-MHz linear array probe. Gel is placed on the head of the transducer before the measurement. Measurements at umbilical site can be achieved using a probe diameter of 0.75 inches which is the most suitable in terms of positioning, location, orientation, contact and pressure.

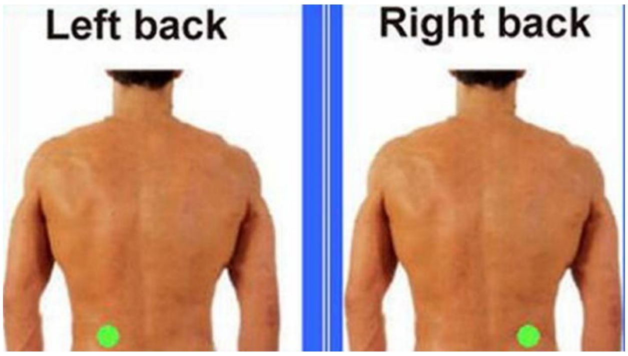


Figure 2: Measurement points at umbilical level (right and left back) using a 2.25 MHz linear array probe.

Dual energy X-ray absorptiometry

BF(kg) measurements were recorded using a Hologic QDR-4500W (version 11.25; Hologic Bedford, Mass. USA) for the total sample. The DXA technique that scans the whole body with a 2-energy X-ray beam is a reference method for measuring fat mass, lean mass and mineral content [22]. Photons absorption can be expressed as a ratio of attenuation at the lower energy relative to attenuation at the higher energy level. DXA can be used with humans of all ages because it has low irradiation (1mrem).

Scan time for a total body fat measurement is about 7 min. The patient should be placed in the supine position at the center of the scan field. Hologic software produces very accurate BF and BF% estimates about 1% [23]. The subject's weight calculated by the DXA was close to the weight measured by the scale with an accuracy of less than 1%.

Statistical Analysis

Statistical analysis was carried out with the statistical software program Statistica (version 6). For all analyses that follow, the α level used for statistical significance was $p<0.05$. Mean and SD of the different samples are specified in the results. We used a stepwise multiple linear regression analysis to determine predictive models for BF and BF% from anthropometric and ultrasound measurements at umbilical level (UTumb).

Predict BF% = 100 BF(kg) estimated / weight (kg). The accuracy of body fatness prediction from the multiple linear regression analysis was evaluated using the coefficient of determination R^2 and the standard error of estimate (SEE). Residuals analysis was examined and compared between BF% estimate from UT and anthropometric model versus BF% DXA. The comparison between BF% DXA and BF% estimated was examined using paired t-test.

Agreement between BF% estimate and BF% DXA of the 35 males was obtained by calculating the 95% limits of agreement as described by Bland & Altman [24]. They proposed an alternative analysis, based on the quantification of the agreement between two quantitative measurements by studying the mean difference and constructing limits of agreement. Bias was calculated as the mean difference between methods.

Results

Mean and SD of the study subjects are presented in Table 1. All variables showed a great variability and range.

Variables	Mean ± SD	Range
Weight (kg)	77.9 ± 17.6	44.2- 131
Height (cm)	175.4 ± 7.1	160.0 -190
BMI (kg/m²)	25.3 ± 5.6	17.1 - 42.6
WC (cm)	93.8 ± 17.3	68.0 -145.0
UTumb (mm)	53.7 ± 14.7	22.0 - 92.5
BF DXA (kg)	16.3 ± 9.9	5.0 - 50.0
BF% DXA	19.72 ± 7.5	8.5 - 39.2

Table 1 : Descriptive characteristics (N=63) BMI = Weight/Height (kg/m²)

A progressive multiple regression method was performed between the three variables selected: BMI, WC and UTumb. We have specified for each equation the values of the R^2 and the SEE (Table 2).

	intercept	BMI	WC	UTumb	BFest (kg)		BF%est	
		kg/m²	(cm)	(cm)	R²	SEE	R²	SEE
Anthropometry and ultrasound measures								
Equation 1	-26.7	1.70			0.90	3.1	0.74	3.8
Equation 2	-31.4	0.96	0.25		0.94	2.4	0.81	3.3
Equation 3	-31.7	0.71	0.26	0.11	0.97	1.7	0.86	2.8

Table 2 : Multiple regression coefficients for BF and BF% estimate with R^2 and SEE.

The simplest model including BMI explained 74% of the variation of BF%. Adding BMI and waist circumference in the model significantly increased the R^2 from 74 to 81% and decreased SEE from 3.8 to 3.3. Moreover addition of ultrasonic measurement at umbilical level significantly increased the R^2 from 0.74 to 0.86 ($p<0.05$).

The multiple linear regression to produce BF% (kg) estimated with anthropometric and ultrasound dimensions is (Table 2):

BF(kg) estimate = 0.708 BMI + 0.259 WC + 0.108 UTumb - 31.7 (equation 3).

with BF% estimate = BF(kg)estimate / Weight (kg) ; $R^2 = 0.86$ and SEE = 2.8 %.

Mean and SD of BF(kg) and BF% estimate is reported in Table 3. We observed no significant difference between BF% DXA and BF % estimate (p =0.91).

BF and BF% estimate from the equation 3	Mean ± SD	Range
BF estimate (kg)	16.3 ± 9.6	2.4 - 45.8
BF% estimate	19.7 ± 7.5	5.3 - 35.9

Table 3: Mean and SD of BF and BF% estimate from the equation 3

A cross-validation study was performed on 35 males. BF and BF % were again estimated from the equation 3. Means and SD of the variables are shown in Table 4.

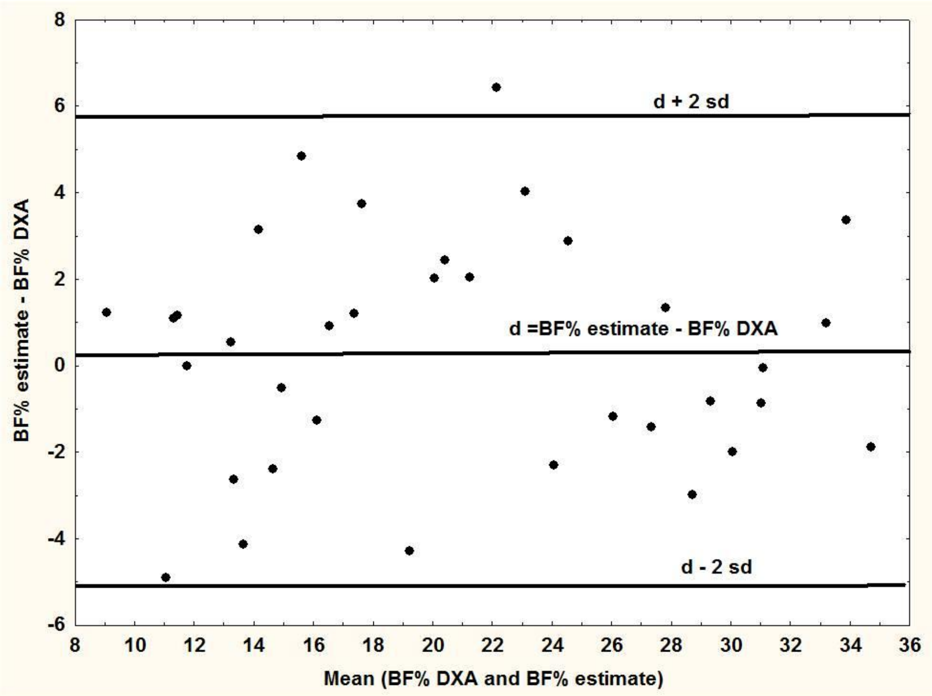
Variables	Mean ± SD	Range
Weight (kg)	80.3 ± 19.0	53.5 - 131
Height (cm)	175.2 ± 6.7	160.0 -190
BMI (kg/m²)	26.2 ± 5.9	17.9 - 42.3
WC (cm)	96.3 ± 19.0	71.0 -140.0
UTumb(mm)	56.4 ± 15.8	18.0 - 88.9
BF DXA (kg)	17.7 ± 10.3	5.6 - 42.9
BF estimate (kg)	17.9 ± 10.4	4.3 - 44.1
BF % DXA	20.7 ± 7.7	8.5 - 35.7
BF % estimate	21.0 ± 7.7	8.6 - 35.6

Table 4: Descriptive characteristics of the cross-validation group (n=35)

Mean difference ± SD between BF% DXA and BF% estimate of 0.3 ± 2.7 was not significant (p=0.54). We found again a high correlation ($R^2 = 0.86$, SEE=2.9%) between BF% DXA and BF% estimate from equation 3.

Figure 3 is a Bland and Altman plot giving the agreement between measured BF% by DXA and predicted %BF by the ultrasonic measurements. In this chart, each data point represents the difference between the two methods. The 95% limit of agreement with individual differences are [-5.1 %; +5.7%]. Moreover no bias was observed with the ultrasound technique (r = 0.01; p = 0.96).

Figure 3. Bland and Altman plot giving the agreement between measured BF% by DXA and predicted BF% by the ultrasonic measurements



Discussion

The value of this study is that the combination of anthropometric measurements with subcutaneous fat thicknesses measured by ultrasound improves the prediction of BF% versus BF% DXA. Pritchard et al. [25], reported that total body fat mass values obtained by DXA are very well correlated with the 4-C reference model described by Wang et al., [26]. DXA is one of the most accurate methods to directly measure BF% but it requires x-ray exposure.
In this study we have established an adult sample with a great variability of BMI and BF%. We introduced anthropometric measures as WC and BMI associated with ultrasound measurements to estimate total body fat. BMI has a significant contribution for the body fat prediction with anthropometric model and also with ultrasound technique. In our model,

anthropometric predictors as weight, height and WC are very easy to measure with an inter operator accuracy lower than 1%.

Addition of ultrasonic measurement at umbilical level (equation 3) significantly increased the BF% estimate with R^2 from 0.74 to 0.86 ($p<0.05$) and decrease the SEE from 3.8 to 2.8%. BF prediction equations with an SEE value of 3% or less are considered very good [27]. In addition, the fairly small limits of agreement [-5.1% ; 5.7%] found with the cross-validation study denote a good accuracy with a good symmetrical distribution around the difference.

The use of WC to evaluate adiposity has also been suggested by Liao et al. [28]. WC might be a better measurement to detect fragility than BMI, given its relationship with metabolic disorders. Several studies have compared anthropometric equations with DXA in the estimation of body fat. Pasco et al., [29] observed a high incidence of overweight and obese men in Australia, according to BMI and WC criteria. They indicate that the prevalence of obesity using a BMI threshold may underestimate the true extent of obesity among young and elderly men. Flegal indicated that BMI, WC, and the waist stature ratio (WSR) are possible indicators for adiposity [8]. However an estimate of body fat based on BMI, WC, or WSR for an individual may be inaccurate. Cui et al., [30] have evaluate the validity of published equations for BF% estimation in American adults using data from the National Health and Nutrition Examination Survey (1999-2004). Most equations had R^2 values between 0.5 and 0.7 which does not provide enough accuracy at individual level. Lee et al. have developed anthropometric prediction equations for BF% in adults using the National Health and Nutrition Examination Survey (NHANES) 1999-2006. BF% estimated on 5329 men from age, height, weight and WC showed a R^2 of 0.82 with a SEE=3.1%. The addition of 5 skinfold measures significantly improves the estimate of BF% with a $R^2=0.81$ and SEE=2.6%. Sun et al., (2010) [7] obtained correlations between BF% DXA and BMI of 0.74-0.79, according to the age, among 4521 adults men from the NHANES 1999-2004. These correlation values are comparable to ours.

Ultrasound technique has the advantage of being non-invasive and inexpensive. It is a specific tool for assessing adiposity in a clinical practice [12]. Different studies validated ultrasound measurements with computed tomography and MRI [31,32]. Leahy et al. [33] took ultrasound and DXA measurements in 83 men aged 18–29 years. They found that a single ultrasound measure of subcutaneous adipose tissue at the abdomen and thigh was highly correlated with BF% with $r = 0.947$ and SEE=1.9%. However BF% of 18.4 ± 6 has a lower variability than our sample of adults aged 18-60, that consequently significantly reducing the SEE. A comparable study conducted on 104 young men aged 18-26 years found that BF%

(12.0± 7.8%) measured by ultrasound underestimated BF% DXA (18.5 ± 6.2 %) with a bias of 6.5% [34]. A portable ultrasound (US) was used to estimate BF% in 71 male adolescents aged 14 ± 2 years versus DXA [35]. The authors observed an underestimation between BF% US (9.6 ± 6.6) and BF% DXA (20.0 ± 7.2) with a bias of 10.4% ($p<0.01$). Ultrasound in B-mode has been also used to predict total fat mass of 54 prepubertal Japanese children aged 6-12 years versus DXA with $R^2=0.96$ and SEE=1 % [36].

The use of anthropometric measures as ultrasound measurements to evaluate total percent body fat must take into account a sample with a great variability of total body fat.

In conclusion, our portable ultrasonic technique combined with anthropometric dimensions allowed us to obtain an accurate estimate of BF% with a high level of accuracy according to the reference DXA method with non significant bias of mean BF% difference and with limits of agreement of [-5.1%; 5.7%]. Our results suggest that this ultrasound and anthropometric technique should be easy to use in epidemiologic studies.

No conflict of interest.

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