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ORIGINAL CONTRIBUTION

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Body composition obtained from the body mass index

An Italian study

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Abstract *Background* Since obesity and related diseases are now considered epidemic, new and more accurate formulas for epidemiological studies are of interest to the scientific community. Several equations have been proposed to estimate the body composition simply from anthropometric measurements. However, with time, the body composition of the populations studied changes in relation to their food habits and lifestyle, and, therefore, the equations must be regularly updated and corrected. *Aim of the study* The aim of the study was to develop new equations to determine the body composition among the Italian population using the body mass index and independently by variables such as age and body structure. *Methods* Bioelectrical impedance and anthropometric analysis of 764 Italian Caucasian subjects (342 females and 422 males), 11 to 80 years of age, were analysed. Females and males were analysed separately. Multiple regression analyses were performed in order to estimate the body composition of the subjects. The estimated masses were then compared with the measured masses using Bland and Altman plots. We also calculated the differences between the estimated and measured masses, reported as % of the body weight, for the 95, 85 and 75° percentile of the female and male groups. Finally we compared our formulas with the Watson equations, which are used to estimate the total body water. *Results* All body masses estimated were positively correlated to the measured values. Moreover, at any percentile analysed, our formulas resulted more precise than the Watson formula. Equations: Females: $FM = 1.9337\ BMI - 26.422$; $FFM = BW - FM$; $BCM = 0.3655\ FFM + 4.865$; $TBW = 0.5863\ FFM + 7.1732$; Males: $FM = 1.407\ BMI - 21.389$; $FFM = BW - FM$; $BCM = 0.4485\ FFM + 3.3534$; $TBW = 0.6997 + 1.4567$. *Conclusions* Although an inevitable inaccuracy must be expected in epidemiological studies, our equations are adequate to analyze the body composition state and changes occurring among the Italian population by simply considering weight and height.

Key words bioelectrical impedance – BMI – body composition – anthropometry

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Introduction

Weight problems and eating disorders have shown a dramatic increment in the Western world during the last years, and their incidence is expected to rise. Based on data collected in 2005 by the National Institute of Statistics (Istat) and published by the Ministry of Health in 2007, in Italy 34.2% of the adult population is overweight (42.5% males, 26.6% females), and 9.8% is obese (10.5 males, 9.1% females) [11].

An excess of body fat correlates with several diseases that often occur contemporaneously. These include type 2 diabetes, cardiovascular disease, atherosclerosis and high total blood cholesterol. The presence of three of these diseases is described as metabolic syndrome, which shows an increasing incidence simultaneous to the increase in fatness observed in the western population. So far, several equations have been proposed to estimate the body composition simply from anthropometric measurements [8, 12, 17]. These equations generally refer to specific populations and age groups. Since obesity and consequent diseases are now considered epidemic, new and more accurate formulas for epidemiological studies are of interest to the scientific community. Also, it must be considered that, with time, the body composition of populations changes in relation to their food habits and lifestyle. For example, in the Western population, younger generations are visibly taller than their parents, a somatic trait related to the current diet. For these reasons, equations must be regularly updated and corrected. The percentage of fat mass depends on several factors, such as age and sex. Generally, women have a higher amount of fat (between 9 and 30%), whereas males are characterized by a higher amount of muscle and a percentage of fat mass between 15 and 22%. The body mass index (BMI) is commonly used to estimate overweight, but it does not give any clear indication about the real amount of body fat. This study was purposely aimed at developing new formulas to analyze the body composition state and changes among the Italian population by simply considering weight and height and independently by variables such as age and body structure. We used Bioelectrical impedance (BIA) to determine the body composition of the subjects. BIA has been demonstrated to be accurate and to provide very similar results to other body composition measurement methods [1, 3–7, 9, 10, 13–16]. Moreover, BIA is non-invasive, well established and easy to use in a laboratory field, and, therefore, it is the most common tool used by nutritionists. Bioelectrical impedance analyses yield two physical parameters: resistance and reactance. Resistance is related to the total body water (TBW), whereas reactance is related to the body cell mass (BCM) through the difference between intra and extra cellular water. Considering that the fat free mass (FFM) has a 73% hydration, the FFM is calculated as TBW/0.73. The fat mass (FM) is therefore calculated as body weight (BW) minus FFM. In this study, we estimated the body composition of a large sample of Italian individuals simply by the BMI. We found a high correlation between the estimated and measured values, thus providing formulas suitable for epidemiological studies.

Materials and methods

Subjects

BIA and anthropometric analysis of 763 Italian Caucasian subjects (341 females and 422 males), 11 to 80 years of age, were conducted. The female and male groups were analysed separately. Analyses were performed on voluntary subjects. Subjects suffering from diseases that could affect the TBW determination were excluded from the study.

Anthropometrical and bioelectrical impedance analysis

Anthropometric and BIA measurements were performed on the same day. All data were collected by the same experienced technician. Height was measured with a fixed stadiometer to the nearest 0.1 cm, and weight was measured with a clinical scale to the nearest 0.1 kg, without shoes and heavy clothing. Subjects were asked to keep a supine position for 5 minutes, after which BIA analyses were performed. The subjects were asked to avoid food ingestion for at least four hours before the measurement and to abstain from performing significant physical activity during the day. Resistance and reactance were measured at 50 kHz with an RJL BIA instrument (model 101; RJL Systems, Inc, Detroit).The tetrapolar resistance and reactance measurements were collected between the right wrist and the right ankle with the participant in a supine position. Resistance and reactance were then analysed using the manufacturer equations [14] to obtain the body composition.

Statistical analysis

A student *t* test was applied in order to obtain a comparison of the age, weight, height and BMI between female and male subjects. The test revealed significant differences in weight, age and height between the two groups (Table 1). For this reason, the two groups were analysed separately.

Multiple regression analysis of independent and dependent variables was performed for both male and female groups:

BMI versus FM, FFMe versus BCM, FFMe versus TBW, FM versus FMe, FFM versus FFMe, BCM versus BCMe, and TBW versus TBWe. Null hypothesis: $r = 0$.

A *P*-value <0.05 was considered to indicate statistical significance.

The formula m × BMI + q (m = slope, q = intercept) obtained from the regression analysis was then used to calculate the estimated (e = estimated) fat mass (FMe). The estimated fat free mass (FFMe) was calculated as BW − FMe. To estimate the body cell mass (BCMe) and the total body water (TBWe), the FFMe was then used as the independent variable for the regression analysis with the BCM and the TBW measured with BIA.

A Bland and Altman plot [2] was used to assess the agreement between the estimated values obtained using regression analysis and the values obtained with the BIA analysis (FM − FMe; FFM − FFMe; BCM − BCMe; TBW − TBWe). For all the body masses analysed, the differences between the estimated and the measured values were regressed against the mean of these two values.

The limits of agreement were calculated as $d - 2s$ and $d + 2s$, where d is the mean difference between the measured and estimated values (bias) and s is the standard deviation of the differences between the measured and estimated values.

We determined the differences for all the measured masses versus the estimated masses, reported as % of the body weight, for the 95, 85 and 75° percentiles for the female and male group analyses. The differences between the measured versus the estimated masses were calculated as the percentage of body weight, and the module value was used for the percentile analysis.

Finally, we compared the Watson formulas [17], which are used to estimate the TBW, with our equations. The comparison concerned the Bland and Altman plots and the percentile analysis. For comparison with the Watson formulas, only subjects older than 17 years of age were considered.

Computations were performed with the Microsoft Excel software.

Results

Characteristics of the subjects

The mean values and standard deviation of age, weight, height, BMI and body masses are shown in Table 1.

Regression analysis of BMI versus FM

Regression analyses using BMI as the independent variable and the FM as the dependent variable were performed (Fig. 1, Table 2). Females and males were

Table 1 Description of sample

	Ages by decades			
	10–20	20–40	40–60	60–80
Females (%)	21.41	47.51	30.20	6.16
Males (%)	14.22	66.35	22.75	1.18

	Females	Males	*P*-value*
Age (years)	34.19 ± 14.03	32.46 ± 12.19	0.01
Weight (kg)	61.06 ± 12.16	77.87 ± 12.29	<0.0001
Height (cm)	162.84 ± 6.10	176.87 ± 8.38	0.01
BMI	23.04 ± 4.64	24.90 ± 3.85	<0.0001
% FM	28.2 ± 7.97	16.7 ± 4.64	<0.0001
% FFM	71.8 ± 7.97	83.7 ± 4.64	<0.0001
% BCM	34.3 ± 4.78	41.9 ± 3.51	<0.0001
% TBW	53.8 ± 5.24	60.4 ± 3.2	<0.0001
% Underweight (BMI < 18.5)	3.81	1.65	0.9
% Normal weight (BMI 18.5–24.9)	75.07	64.45	<0.0001
% Overweight (BMI 25.0–29.9)	13.19	26.06	0.5
% Obese (BMI > 29.9)	7.33	6.16	0.6

Value are given as mean ± standard deviation
**P*-values for females vs. males (Student *t* test)

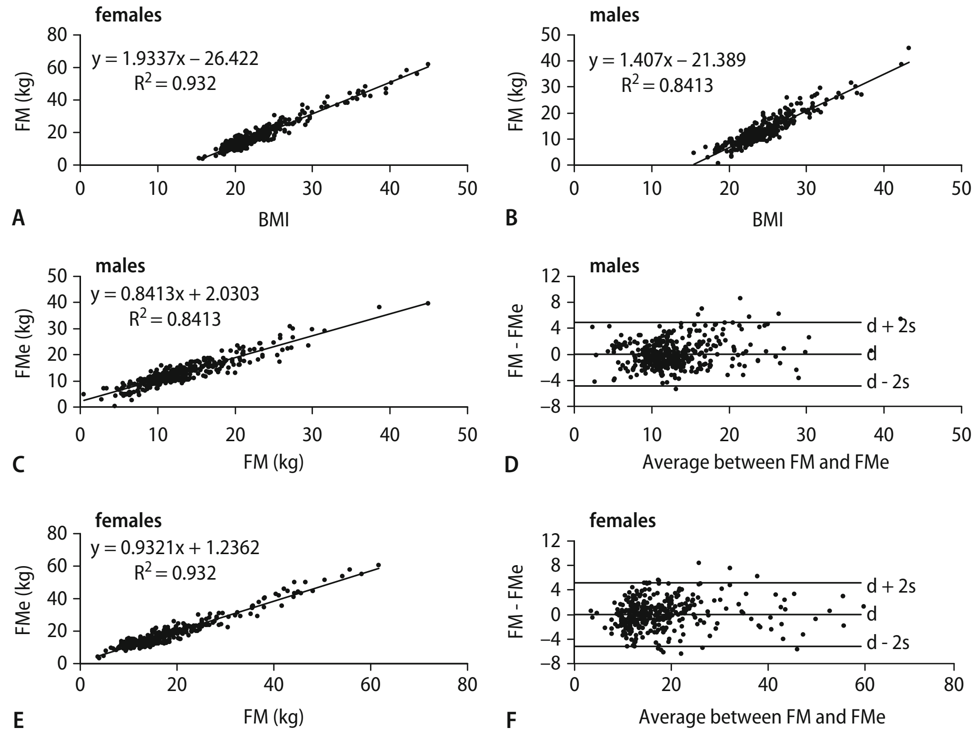

Fig. 1 **a** Correlation between BMI and FM in the female group, $P < 0.0001$. **b** Correlation between BMI and FM in the male group, $P < 0.0001$. **c** Correlation between the measured FM and the estimated FMe in the male group, $P < 0.0001$. **d** Bland and Altman plot of FM and FMe in the male group, $d = 0.000363$, $2s = 4.10$. **e** Correlation between the measured FM and the estimated FMe in the female group, $P < 0.0001$. **f** Bland and Altman plot of FM and FMe in the female group, $d = -0.00065$, $2s = 4.84$

analysed separately. BMI and FM were positively correlated, with R^2 of 0.93 for females and 0.84 for males. The P value was <0.0001 in both the cases.

Regression analysis of FFMe versus BCM

The estimated fat mass (FMe) and the fat free mass (FFMe) for any subject were calculated:

$$\text{Females}: \text{FMe} = 1.9337 \times \text{BMI} - 26.422$$

$$\text{Males}: \text{FMe} = 1.407 \times \text{BMI} - 21.389$$

$$\text{FFMe} = \text{body weight} - \text{FMe}$$

The FFMe values were then used as the independent variable for regression analysis, with the body cell mass measured with BIA as the dependent variable.

The R^2 value for the regression analysis of FFMe and BCM in females was only 0.43, which suggests a low correlation between the two masses considered. However, the regression analysis showed a P value <0.0001 (Table 2).

The R^2 value for the male group was 0.71, and the regression analysis showed that the FFM significantly correlated with the BCM, $P < 0.0001$ (Table 2).

Regression analysis of FFMe versus TBW

The FFMe values were then used as the independent variable for regression analysis, with TBW as the dependent variable.

As expected, both groups showed a significant correlation between the FFM and the TBW. Indeed, BIA values determined the FFM from the TBW. We determined the fat free mass (FFMe) from the BMI through the FMe: the high correlation between TBW and FFMe confirms the significant correlation between BMI and FM.

Bland and altman plots

To assess if the values obtained with the regression analysis were comparable to those measured with BIA, regression analyses together with Bland and Altman plots were made. The limits of agreement were calculated as $d - 2s$ and $d + 2s$, where d is the mean difference (Bias) and s is the standard deviation of the differences. The mean ± $2s$ indicates the 95% limit of agreement. This means that the difference between measurements using these two methods should lie within the limits of agreement approximately 95% of the time. In all analyses, random point scatter was reported between the upper and lower confidence limits.

FM versus FMe

For the male group, there was a significant correlation between the measured and estimated FM, with $R^2 = 0.84$ and $P < 0.0001$.

For the female group, there was a higher correlation than for the male group between the measured and the estimated FM, with $R^2 = 0.93$ and $P < 0.0001$.

Table 2 Multiple regression analysis, bland and altman plot values and equations

	Regression analysis					Bland and altman plot values	
	b	SE	*P*-value	Intercept	R^2	*d*	2*s*
Males BMI − FM	1.4069	2.05	<0.0001	−21.38	0.84	/	/
Females BMI − FM	1.9336	2.42	<0.0001	−26.42	0.93	/	/
Males FFMe − BCM	0.4484	2.26	<0.0001	3.35	0.71	/	/
Females FFMe − BCM	0.3654	2.27	<0.0001	4.86	0.43	/	/
Males FFMe − TBW	0.6996	1.76	<0.0001	1.45	0.90	/	/
Females FFMe − TBW	0.5862	1.86	<0.0001	7.17	0.74	/	/
Males FM − FMe	0.8413	1.88	<0.0001	2.03	0.84	0.00036	4.10
Females FM − FMe	0.9320	2.34	<0.0001	1.23	0.93	−0.00065	4.84
Males FFM − FFMe	1.0146	2.05	<0.0001	−0.93	0.93	−0.00036	4.10
Females FFM − FFMe	1.0208	2.42	<0.0001	−0.90	0.80	0.000649	4.84
Males BCM − BCMe	0.7126	1.91	<0.0001	2.49	0.71	6.703588	4.51
Males BCM − BCMe + d	/	/	/	/	/	0	4.51
Females BCM − BCMe	0.4389	1.50	<0.0001	11.61	0.43	−0.000023	4.54
Males TBW − TBWe	0.9084	1.68	<0.0001	4.22	0.90	−0.00076	3.52
Females TBW − TBWe	0.7492	1.61	<0.0001	8.16	0.74	−0.00086	3.72
Males TBW − TBW Watson	0.6825	1.49	<0.0001	12.89	0.87	−1.77486	4.75
Females TBW − TBW Watson	0.8352	1.28	<0.0001	3.32	0.85	−2.04384	2.84

	Equations	
	Females	Males
FM	FM = 1.9337 BMI − 26.422	FM = 1.407 BMI − 21.389
FFM	FFM = BW − FM	FFM = BW − FM
BCM	BCM = 0.3655 FFM + 4.865	BCM = 0.4485 FFM + 3.3534
TBW	TBW = 0.5863 FFM + 7.1732	TBW = 0.6997 + 1.4567

SE standard error, *b* regression coefficient *d* bias, *s* standard deviation of the differences between measured and estimated values

Although the regression analysis shows that the estimated and measured fat masses were more correlated in females, the plots reveal that the difference between the two values was higher in the female group than in the male group, with $2s = 4.84$. Indeed, in the male group, the $2s$ value was 4.10, which means that the estimation of the FM in males is more accurate than in females (Fig. 1).

FFM versus FFMe

We then analysed the limit of agreement between the estimated and measured FFM.

Since the estimated FFM was obtained by the estimated FM, the determination of FFM is subject to the same error as that of the FM. This error was found to be higher in the female group than in the male group, with $2s = 4.84$ in the female group compared to 4.10 in the male group, with $P < 0.0001$.

BCM versus BCMe

We then analysed the limits of agreement between the estimated and measured BCM.

Even when the BCMe was estimated from the FFMe with a low correlation, the estimated BCMe and the measured BCM were significantly correlated, with $P < 0.0001$ (Table 2).

For the male group, the bias was higher than 0, which means that the absolute values were underestimated and therefore, as suggested by Bland and Altman, the estimated BCMe was calculated as BCMe + d.

As expected, because all the values were derived from the FM, as was the case in the estimation of BCM, the error was higher in the female group than in the male group. The $2s$ value was 4.54 compared with the male value of 4.51. Also in this case, the lower correlation (R^2) corresponded to the higher error.

TBW versus TBWe

We then analysed the limit of agreement between the estimated and measured TBW.

Again, as for the other body masses, the TBW could be estimated with more precision in males than females, as revealed by the $2s$ values, which were 3.52 and 3.72, respectively, with $P < 0.0001$.

TBW versus Watson TBW

Finally, the equations proposed here were compared with the Watson formulas, which are well known and used to estimate the TBW. We first evaluated the correlation between the data obtained and the BIA, and then, using the Bland and Altman plot, we assessed the differences between the measured values and the Watson estimated values.

Watson formulas:

$$\text{Female TBW}: -2.097 + (0.1069 \times \text{Height}) + (0.2466 \times \text{BW})$$

$$\text{Male TBW}: 2.447 - (0.09156 \times \text{age}) + (0.1074 \times \text{Height}) + (0.3362 \times \text{BW})$$

The Bland and Altman plots show that the Watson equations underestimated the TBW, both for females and males. In fact, d was found to be −1.77 for the male group and −2.04 for the female group.

Moreover, the underestimation plus the $2s$ values for the Watson formula were higher than the $2s$ values obtained upon estimating the TBW with our formulas (Table 2).

Differences of estimated versus measured values

We then determined the differences between the measured and estimated values, reported as % of the subject's body weight, for the 95, 85 and 75° percentiles of the two groups examined. The results are shown in Table 3.

From the BMI, it was possible to estimate the fat mass and the fat free mass of a male subject with a difference of ±5.5% of the body weight in 95% of the males. The body cell mass could be estimated with a difference of ±4.7% of the body weight in 95% of the males. The TBW could be estimated with a difference of ±5.1% of the body weight in 95% of the males. It was possible to estimate the fat mass, the free mass and the body cell mass of a female subject from the BMI index with a difference of ±8.2% of the body weight in 95% of the females. The total body water could be estimated with a difference of ±5.7% of the body weight in 95% of the females. For both groups, our formulas estimated the TBW with a higher precision than the Watson equations.

Discussion

The BMI is a convenient and easy method used as indicator of overweight and obesity. It is simply calculated by weight and height, and it is reproducible and routinely measured by clinicians. Several studies have been carried out to relate the anthropometric measurements to the body fat and to determine the entire body composition [8, 12, 17]. These studies show different correlations dependent on the sample analysed, the methods used to assess the body composition, and the statistical analysis of the collected data. In this study, we determined the body composition from the BMI in a large sample of Italian females and males. We used BIA to assess the body composition of the subjects. BIA has been demonstrated to give very similar results to other body composition measurement methods, such as dual-energy X-ray absorptiometry (DXA), total body electrical conductivity (TOBEC) and bioelectrical impedance spectroscopy (BIS). These methods showed a high correlation in determining body composition [1, 3–7, 9, 10, 13–16]. In this work, we used a very large sample. The same number of data cannot be collected using different approaches. Indeed, similar studies performed with DXA or Tobec used smaller sample sizes. Since equations are derived from correlation analysis, the use of a small sample negatively affects the results. Although BIA has been validated by hundreds of studies and recognized as adequate for home use and epidemiological studies, techniques such as DXA are more appropriate for clinical practice. Since our equations are to be used for epidemiological studies, the use of such a large sample size compensates for the decrease in accuracy of BIA. The same conclusion was reached by other researchers such as Jaffrin et al. [9]. They compared BIA with DXA and concluded that BIA is adequate to assess FFM in groups of subjects and for home use.

Several studies aimed at the estimation of body masses do not report a Bland and Altman analysis. Indeed, as clearly shown by these authors, correlation is not sufficient to assess the agreement between two measures. In fact, as we demonstrated, a high correlation is not related to a low difference between esti-

Table 3 Maximal differences, as % of the subject body weight, for three different percentiles of the samples studied

Percentile	Sex	FM − FMe	FFM − FFMe	BCM − BCMe	TBW − TBWe	TBW − Watson's TBW
95°	Females	±8.2	±8.2	±8.2	±5.7	±7.4
95°	Males	±5.5	±5.5	±4.7 (BCMe + d)	±5.1	±6.5
85°	Females	±5.7	±5.7	±4.4	±4.0	±6.2
85°	Males	±3.7	±3.7	±3.3 (BCMe + d)	±3.2	±5.4
75°	Females	±4.3	±4.3	±3.4	±3.2	±5.1
75°	Males	±2.9	±2.9	±2.4 (BCMe + d)	±2.5	±4.6

mated and measured values. We performed the Bland-Altman plots to compare the values obtained using regression with those measured with BIA. The results of the plots are generally interpreted informally, without further analyses.

The results obtained with our samples showed limits of agreement that could not be useful for clinical evaluation but sufficient for epidemiological studies. In fact, our equations provide more accurate results than those obtained by currently used formulas such as the Watson formulas.

In order to find an algorithm useful for epidemiological studies, we analysed a large and inhomogeneous sample. The equations obtained are therefore independent by variables such as age, life-style, body structure and physical activity. Our sample set was composed of elite athletes, obese individuals, housewives, and manual labourers, among others, each with different energy expenditure, diet, physical activity and also body structure.

In statistics and epidemiology, large samples are used to exclude the maximal number of variables that could affect the prediction of values. In this work, our aim was to determine equations independent of the maximal number of variables. Indeed, we sampled 341 females and 422 males, 11–80 years of age, with very different body compositions and daily energy expenditures.

Nevertheless, our equations estimate body masses with more accuracy than the Watson formulas, which were obtained considering the age of the subjects. However, in the male Watson formula, the age is not included. This means that the age variable is not necessary to establish a correlation between BMI and body composition.

Instead, since females and males have a different body structure, we considered the sex variable. We found a statistically significant correlation of the BMI with the FM, both in women and men ($P < 0.0001$). However, the Bland and Altman plots showed that the estimation of the FM in women was subjected to a higher error compared to males. These results were confirmed by the percentile analyses. The correlation between the estimated FFM and the measured BCM in the female group, even if statistically significant, was much lower ($R^2 = 0.43$) than the correlation in the male group ($R^2 = 0.71$). This probably because females present a higher percentage of FM, whereas males present a higher percentage of BCM, as shown in Table 1. However, despite the low correlation, the estimation of the BCM in females is subject to the same error than the estimation of the FM and FFM. It is interesting to note that, even if the estimated body masses were derived from the estimated FM, the errors remained essentially constant for the evaluation of all other body masses. Most of the equations reported in the literature only allow for the calculation of the FM and the FFM on the basis of a two-compartment model. However, it is now widely accepted that a three-compartment model better describes the body composition, especially its change in relation to diet and physical activity. Beyond FM and FFM, the three-compartment model also considers the BCM. The evaluation of the BCM is important because this body mass is responsible for a subject's energy expenditure. Nutritionists are now aware that, during a diet program, it is important that the reduction of the FM correspond to an increase of the BCM in order to enhance the metabolism and ensure a stable weight loss. Our equations estimate the BCM with the same accuracy of the FM and FFM, and they are, therefore, useful for studies aimed at describing body composition based on a three-compartment model. We were also interested in comparing our equations with those reported in the literature. The Watson equations are widely known. They are used to calculate the TBW, and thus the FFM and FM, from parameters such as age, weight, sex and height. Despite the fact that our formulas only consider the sex variable, they are affected by a lower error in determining the TBW of the subjects, thus indicating that their limit of agreement can be acceptable for epidemiological studies. The Watson equations were compared only considering subjects older than 17 years of age. The maximal differences between the estimated and measured values obtained using our equations were lower than those obtained using the Watson equations (Table 3).

We showed that our equations allowed for the determination of body composition in young, adult and aged individuals. The studied sample also included people with different habits and jobs. The equations can therefore be used for the entire Italian population. We also believe that the equations can be applied to the rest of the European population, but further studies are needed to prove this. In a small sample, we aimed to validate the equations using a different approach for body composition measurements, such as skinfold thicknesses, circumferences, DXA, etc.

Overall, these results show that it is possible to estimate the body composition from the BMI, without considering any other parameter, with an acceptable precision for epidemiological studies wherein an inevitable inaccuracy must be expected.

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