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Developing and cross-validation of new equations to estimate fat mass in Italian population

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Abstract. – **OBJECTIVE:** **Obesity is a global burden that involves more than 500 million people. The objective of this work is to develop and cross-validate the new sex-specific equations to estimate fat mass, based on anthropometric parameters and to compare with other equations.**

PATIENTS AND METHODS: We evaluated 38762 subjects by dual-energy X-ray absorptiometry (DXA) and enrolled 1434 women and 640 men, aged between 18 and 65 years. Then, we randomized 480 men and 1080 women in developing set and 160 men and 354 women in the cross-validation set. Statistical analysis as multiple regression and Bland-Altman methods were performed.

RESULTS: Sex-specific equations were created based on developing set. Then, based on the cross-validating set, these equations were validated and were observed to agree with fat mass by DXA, better than other equations, such as BAI and RFM.

CONCLUSIONS: These new sex-specific equations represent an easy tool, since they require only two circumferences, to be used in clinical practice. In the next future, these equations could be validated and refine on specific Italian sub-populations, divided by gender and age, such as the military.

Key Words
Fat mass, Population, DXA.

Introduction

Obesity is a globally recognized pandemic involving more than 650 million people[1].

Although World Health Organization (WHO) has not yet defined obesity as a disease. Instead, scientific societies of different disciplines and geographical origin have already shared the definition of disease.

The World Obesity Federation reports that obesity is a chronic relapsing disease process, with an emphasis on the chronicity of excess weight and the risk of relapse in treatment. For this reason, it is important an accurate and precise classification, that is essential to obtain an appropriate diagnostic-therapeutic path. This must take into account the characteristics of the individual[2,3]. Several authors[2] have proposed a phenotypic classification of obesity on the evidence of the literature. The phenotype is defined by anthropometrics, skinfold, biochemical-clinical, genetic and body composition parameters.

The identification of the phenotypes at risk of non-communicable chronic-degenerative diseases (metabolically unhealthy obese, metabolically healthy obese, metabolically obese normal weight, normal weight obese) is a necessary clinical step to make prevention and to maximize the therapeutic result, contrarily to a reactive medicine[4].

In Italy, according to the classification with body mass index (BMI), the prevalence of overweight is equal to 22 million, while that of the obese is equal to 6 million, which translated into health care costs, loss of productivity, absenteeism and early mortality are equal to 9 billion euros[5]. Other studies[6] estimate that the costs go up to 22 billion, if we consider the overall costs of obesity-related pathologies[7].

De Lorenzo et al[8] have demonstrated that the evaluation of adiposity with Dual Energy X-Ray Absorptiometry (DXA) improves the identification of subjects at risk for cardiometabolic disorders in those who have a normal BMI. Further-

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more, they showed a high percentage of false negatives, especially in women, which were normal or overweight, already in the presence of excess of adiposity[7,8].

The costs and problems related to the diffusion and the lack of diagnosis of obesity no longer concern only medicine. This emergency has significant socioeconomic consequences such that the stigma of obesity threatens national security. At the U.S. Department of Defense was registered an economic loss of about $ 1.5 billion, estimated due to health care costs, replacement of unsuitable personnel and waste of resources. The cost due to excess of adiposity was underestimated since it referred back to 2007 and did not include costs related to disability. In addition to the economic costs, the functional impact is dramatic, also due to the days of leave, degradation of resilience, and delay in emergencies[9]. Furthermore, in order to give benefits to the public health and the economy, it is necessary to improve the prevention of cardiovascular and metabolic diseases, identifying early individuals at risk through the assessment of fat mass (FM)[10].

For example, 31% of Americans are excluded from military service due to obesity, which caused disagreements with medical fitness. In addition, it was observed that 33% of the soldiers in service had a higher risk of musculoskeletal injuries. These numbers are added to the 3.6 million accidents that occurred during active service between 2008 and 2017[11].

For this reason, simple and widespread methods must be developed to identify obesity through the FM percentage (%).

It can be a strategy to fight more efficiently obesity and the onset of non-communicable diseases related to chronic inflammation.

The first objective of the study is the development of a sex-predictive equation for the FM (kg), and its validation respect to that measured by the DXA. The second objective is to evaluate the capacity of phenotype classification with the new equation, compared to the BMI.

Patients and Methods

This study involved 38762 patients from 1999 to 2016, who were visited at the Section of Clinical Nutrition and Nutrigenomic, Department of Biomedicine and Prevention of the University of Rome “Tor Vergata”. We enrolled 1434 women and 640 men, aged between 18 and 65 years, without neoplastic pathologies or in treatment with corticosteroid drugs, as reported in the flow diagram (Figure 1). Each patient signed written informed consent, in accordance to the Ethical guidelines of the Declaration of Helsinki. All procedures followed were in accordance with the Ethical Standards of the Responsible Committee on Human Experimentation (Ethics Committee “Centro, Calabria Region” 30.11.02.2016). After

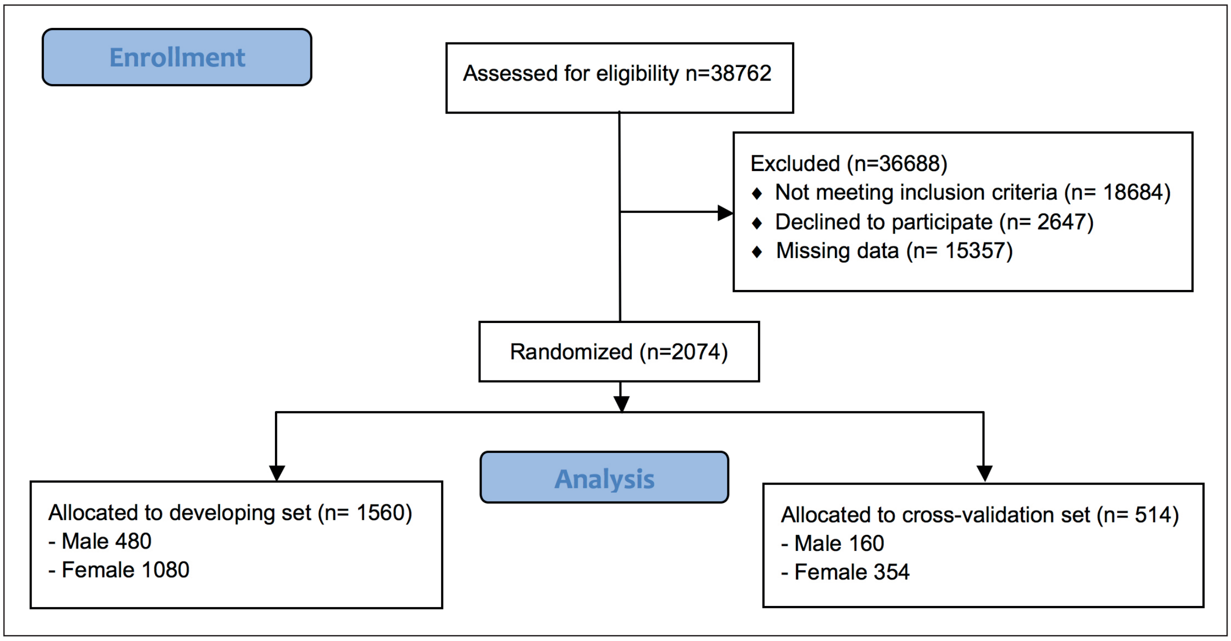

Figure 1. Study flow diagram.

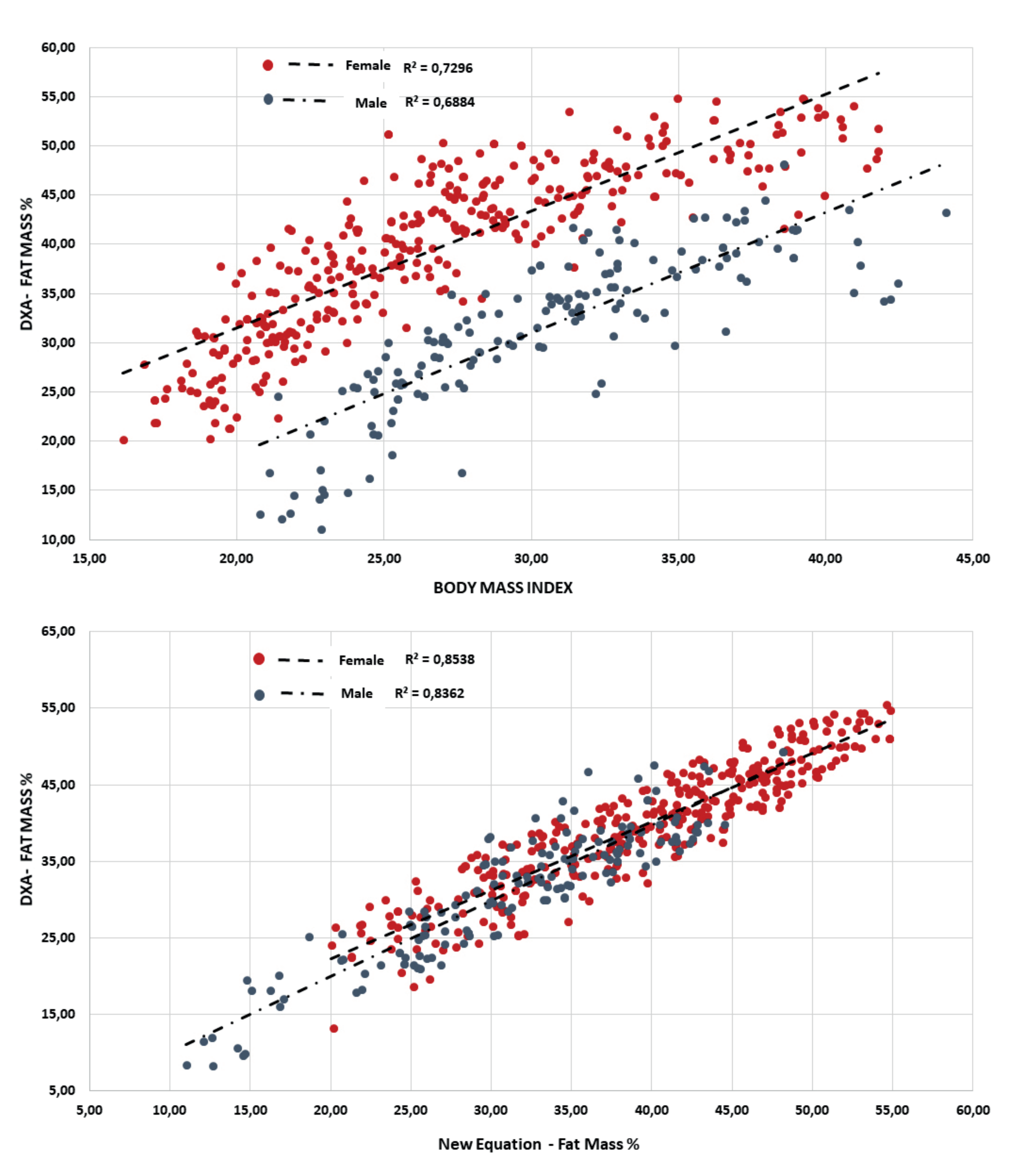

Figure 2. Prediction of BMI and Fat Mass % by our New Equation using linear regression in validation dataset. Divided by sex. Data plots correspond to DXA imputation.

a 12-h overnight fasting, subjects underwent anthropometric and DXA (i-DXA, GE Medical Systems) evaluations[12], for the determination of FM (kg), FM%.

Body height was evaluated standing without shoes using a stadiometer (SECA instruments, UK) and recorded to the nearest 0.1 cm. Body weight was evaluated using a scale (SECA instruments, UK), and recorded to the nearest 0.1 kg, the subjects wearing only the underwear. BMI was calculated by the formula: body weight (kg)/ height^2 (m)^2.

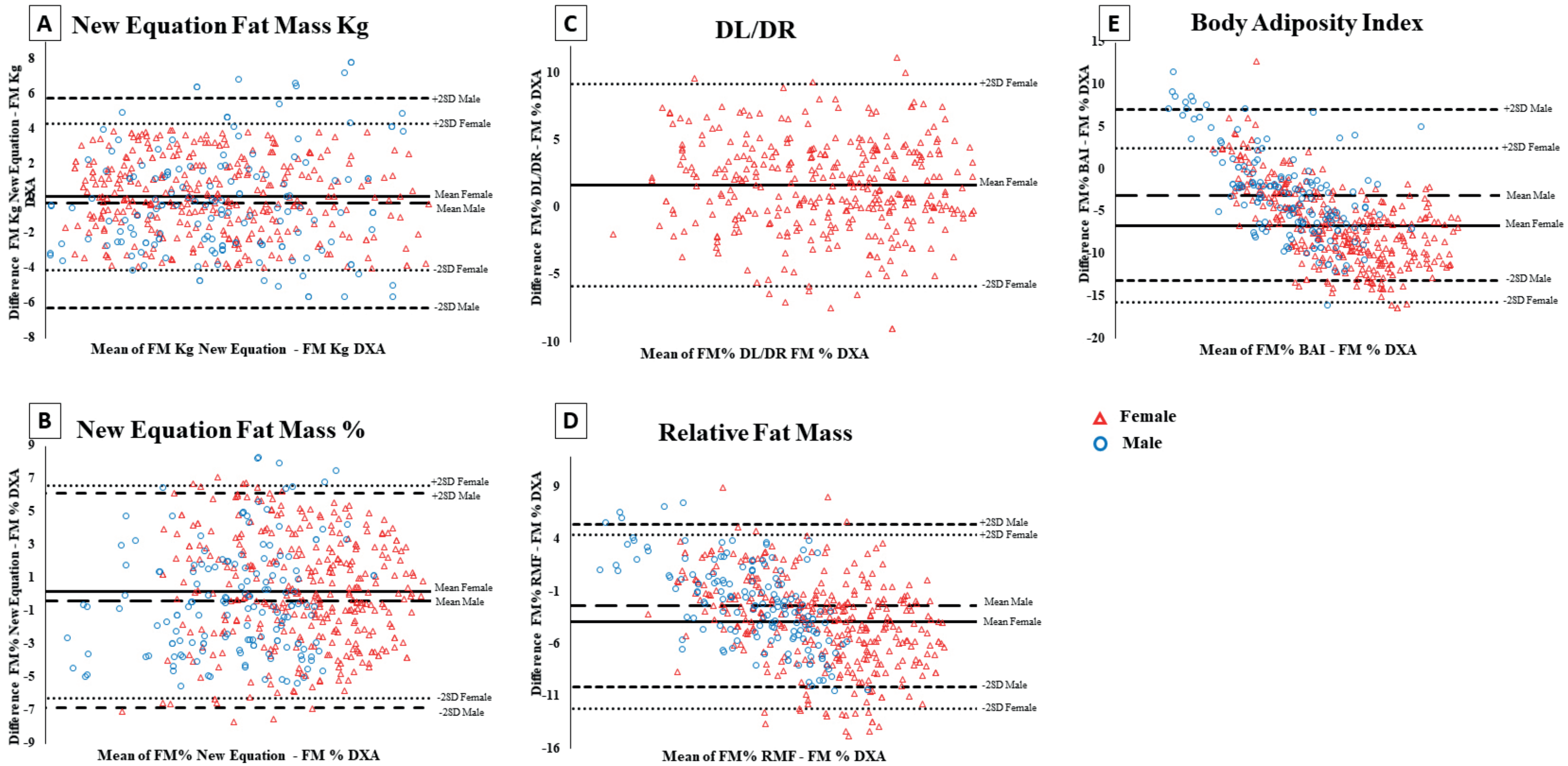

Figure 3. FM: Fat mass; DXA: dual energy x-ray absorptiometry. ***A***, Bland-Altman representation of individual differences between predicted FM kg by the new equation and measured FM (Kg) by DXA, plotted against the avarage of measured FM (Kg) values and predicted FM (Kg) values. **B-C-D-E**, Bland-Altman representation of individual differences between predicted FM% by the our equation, other predictive methods and measured FM (%) by DXA, plotted against the average of measured FM (%) values and predicted FM (%) values.

Four circumferences are measured: neck, abdomen, waist, hip. The measurement of the minimum neck circumference is detected below the laryngeal prominence, with the subject standing and with the head positioned according to the horizontal plane of Frankfurt, with a minimum contact pressure, without skin compression. The measurement of the maximum circumference of the abdomen is performed with the subject in an upright position, feet together, relaxed abdomen, arms hanging around the sides of the trunk. At the end of a normal exhalation, the point of greater anterior extension of the abdomen is measured, without compressing the skin. Waist circumference (WC) was measured with the subject standing, midway between the last rib and the upper edge of the iliac crest. Hip circumference (HC) was measured at the greater gluteal point. The measurements were taken with inelastic centimeter to the closest 0.1 cm[13]. Subjects were classified, according to De Lorenzo et al[14], as obese with BMI≥30 kg/m^2 both male and female and as obese with FM%≥25 for men and FM%≥30 for women. Moreover, to compare the results obtained, the adiposity was also evaluated with Body Adiposity Index (BAI)[15], Relative Fat Mass (RFM) [16], and De Lorenzo-Di Renzo (DL-DR) equation only for female[17].

Statistical Analysis

Since in the analyzed data some continuous variables had a nonparametric distribution, it is preferred to show the summary statistics with the median, the first and the third quartile (Q1, Q3). Categorical variables have been described by absolute and correlated frequencies. The continuous covariates were compared with the t-test or, in the case of a significant shift from normality, with Mann-Whitney. In the development of the predictive equation of FM (kg), height, WC, HC, abdominal circumference and neck were considered possible predictors. Correlation analysis (Pearson or Spearman) was performed to study the associations between the measured FM (kg) and the possible predictors chosen. The final predictors of FM (kg) were identified by a non-automated backward selection and also taking into account the interpretation, the clinical choices and the correlation structure among the co-variants. Graphs of residuals smoothed with respect to the continuous covariate were used to evaluate linearity and poorly predicted observations were identified by studentized residuals. The new sex specific equations have been cross-validated against external groups according to Bland and Altman[18]. Analyses of the operational characteristics of the receiver (Receiver Operating Characteristic - ROC) were performed in order to verify the accuracy between the FM% by DXA, the FM% calculated by the new equations and the BMI. The curves were constructed considering the FM% from the DXA as a criterion and the indices as diagnostic tests. To compare the ROC curves of the BMI and FM% from the new equations, a nonparametric statistical analysis was performed on the differences between the areas in the corresponding curves, according to DeLong et al[19]. The area under the curve (AUC) was obtained from the ROC analysis for both sexes. The AUC values range from 0.5 to 1.0, where 1.0 represents a perfect screening test that is able to discriminate between subjects with and without high adiposity. Cohen's Kappa was used with binary data to measure the agreement between adiposity classification according to the FM% criterion measured by DXA, the adiposity classification based on the FM% calculated by the new equation and the BMI. According to Landis and Koch[20] Cohen's Kappa (κ) values could indicate an agreement: poor ($\kappa<0.00$), light ($0.00\leq\kappa\leq0.20$), discrete ($0.21\leq\kappa\leq0.40$), moderate ($0.41\leq\kappa\leq0.60$), substantial ($0.61\leq\kappa\leq0.80$) or near-perfect ($\kappa>0.80$). Furthermore, the false-positive rate and false-negative rate were calculated for the different classification methods. The analyses were performed using the SPSS software (version 23.0, IBM, Armonk, NY, USA). The null hypotheses were rejected at the probability level of 0.05.

Results

Among the enrolled, data from 1560 individuals (69% women) were used for the new equation development group and data from 514 individuals (69% women) were used for cross validation. Figure 1 shows the selection scheme for participation in development and validation groups. The characteristics of the participants studied are described in Table I. The main anthropometric, body composition and fat prediction parameters of both groups are presented, divided by gender, in Table I. Among the development and cross validation groups for both sexes, there were no statistical differences ($p>0.05$) in the comparative analysis for weight, stature, BMI, WC, HC. In addition, FM (kg) and FM% data from DXA did not show significant differences ($p>0.05$).

Table I. Comparisons between developing and cross-validation set divided by gender.

	Female			Male		
n	**Developing Set [median (Q1; Q3)] 1080**	**Cross Validation Set [median (Q1; Q3)] 354**	***p***	**Developing Set [median (Q1; Q3)] 480**	**Cross Validation Set [median (Q1; Q3)] 160**	***p***
Age	27.00 (42.00; 58.00)	26.00 (40.00; 57.00)	0.654	32.00 (22.00; 53.00)	31.00 (21.00; 54.00)	0.574
Weight (kg)	68.70 (58.30; 78.44)	65.95 (57.43; 78.68)	0.101	86.44 (77.14; 99.5)	88.75 (78.85; 100.95)	0.188
Height (cm)	160.00 (156.00; 164.15)	160.5 (157; 164.63)	0.563	173.00 (167.63; 179.38)	173.00 (167.00; 180.00)	0.526
BMI (kg/m^2)	26.52 (22.92; 31.13)	26.07 (21.87; 30.91)	0.092	29.10 (25.38; 33.3)	28.90 (25.21; 33.10)	0.073
WC (cm)	82.50 (73.25; 93.00)	80.50 (70.88; 90.00)	0.062	100.05 (90.50; 108.88)	101.25 (92; 110.75)	0.058
HC (cm)	104.00 (96.50; 112.00)	103.00 (95.00; 112.00)	0.317	105.00 (98.00; 112.00)	105.00 (98.50; 112.78)	0.067
FM DXA (kg)	28.71 (21.26; 36.47)	28.27 (20.63; 35.56)	0.063	28.64 (20.60; 37.19)	28.98 (21.36; 37.60)	0.553
FM DXA (%)	41.73 (35.00; 46.84)	41.02 (34.46; 46.54)	0.095	32.81 (26.22; 37.85)	32.80 (26.07; 37.73)	0.842
BAI ($cm/m^{1.5}$)	51.18 (47.21; 55.94)	50.91 (46.29; 55.39)	0.222	46.02 (42.37; 49.58)	46.45 (42.62; 49.79)	0.503
BAI FM (%)	32.71 (29.02; 37.14)	32.46 (28.16; 36.62)	0.222	27.01 (22.51; 31.22)	28.31 (24.75; 31.41)	0.503
RFM (%)	36.97 (30.98; 42.03)	35.09 (29.59; 40.55)	0.031*	28.75 (25.34; 28.54)	30.35 (25.87; 33.29)	0.026*
DL-DR FM (%)	42.63 (36.59; 47.76)	42.01 (34.59; 47.76)	0.137	//	//	

BMI: Body Mass Index; WC: waist circumference; HC: hip circumference; FM: fat mass; DXA: Dual energy X-ray absorptiometry; BAI: Body Adiposity Index; RFM: Relative Fat Mass; DL-DR: De Lorenzo-Di Renzo. All values are presented as median (first quartile and third quartile). *$p<0.05$.

For the adiposity prediction, only the RFM was statistically significant for both sexes. In particular, for females, there was an overestimation in the development group (p=0.031), while for men in the cross-validation group (p=0.026). In order to obtain a model to evaluate the FM (kg), we have combined the anthropometric parameters as potential predictors. Multivariate linear regression analysis had identified four significant independent variables to predict FM (kg) in males: WC, HP, neck and abdomen, while in females there were the same variables except for the neck circumference. To improve the prediction and to facilitate the application and dissemination of the model we tried predictive observations less and less used. The inspection of residues led to the identification of abdominal circumference in females, which was the variable with a lower predictive capacity (>5%). To make the models homogeneous, respecting the influential predictors in the final model, it was decided to use the WC and HC in both sexes. To test the robustness of the model, this observation was excluded from the analysis and the model was repaired. Based on this final model, shown in Table II, the following predictive equations are proposed for the evaluation of FM (kg) in the Italian adult population:

Equation for Female
$$FM\% = -63.82 + (WC(cm)\times 0.35) + (HC(cm)\times 0.61) \quad (1)$$

Equation for Male
$$FM\% = -75.84 + (WC(cm)\times 0.38) + (HC(cm)\times 0.64) \quad (2)$$

In females, R^2 of the final model was 0.951, with a mean square root error of 1.55. In males, R^2 was 0.870, with an average square root error of 2.03 (Table II). The new predictive equations were cross-validated compared to independent groups of females and males (Table III). In females, the average difference between the FM (kg) predicted by our equation and the measured one was 0.11 kg, with an average percentage error of 0.43%. In males, the average difference was -0.47 kg, with a mean percentage error of -0.71%. In females, the average difference between the measured FM% and that obtained from the application of our equation was 0.20% with an average percentage error of 0.5%. The measured FM% were compared with the DL-DR equation, with BAI and with the RFM, obtaining the average difference of 1.88%, -6.14% and -3.79%, respectively, with an average percentage error of 4.5%, -18.67% and -10.61%, respectively. In females, according to the Bland-Altman method, there was an agreement between the FM both in kg and in %, measured with those predicted by new equation (FM (kg) p>0.324; FM% p>0.247), while it was not present in the remaining equations tested (p<0.05). In males, the average difference between the measured FM% and that predicted by new equation was -0.22%, with an average percentage error of -0.71%. The measured FM% were compared with the DL-DR equation, with BAI and with the RFM, obtaining respectively the average difference of -3.03%, -7.9% and -2.32%, with an average percentage error of -10.62%, -18.67% and -7.92%, respectively. In males, according to the

Table II. Multivariable regression analysis with final model for predicting Fat Mass kg, divided by sex.

				Regression coefficient – Female			
Predictor	**β**	**SE**	**PC**	***p*-value**	**R^2**	**RMSE**	***p*-model**
Intercept	-63.820	0.816		0.000			
WC (cm)	0.35	0.011	0.744	0.000			
HC (cm)	0.61	0.013	0.851	0.000			
Overall Model					0.951	1.55	0.0001
				Regression coefficient – Female			
Predictor	**β**	**SE**	**PC**	***p*-value**	**R^2**	**RMSE**	***p*-model**
Intercept	-75.84	1.868		0.000			
WC (cm)	0.38	0.028	0.674	0.000			
HC (cm)	0.64	0.019	0.620	0.000			
Overall Model					0.870	2.03	0.0001

β: Unstandardized regression coefficient; SE: standard error; PC: Partial Correlation; RMSE: root mean square error; R2: r-squared value; p model: significance level for model; WC: waist circumference; HC: hip circumference.

Table III. Comparison of Fat Mass Kg-% estimated by our equation and other predictive methods with Fat Mass Kg-% measured by DXA in the cross-validation set divided by sex.

Equations		FM (kg) [median (Q1; Q3)]	Difference (kg) [median (Q1; Q3)]	Agreement *p*-value
New Equations	Female	27.56 (19.56; 35.68)	0.04 (-1.47; 1.82)	0.324
	Male	28.73 (20.32; 37.73)	-0.56 (-2.51; 1.56)	0.589
Equations		**FM (%) [median (Q1; Q3)]**	**Difference (%) [median (Q1; Q3)]**	**Agreement *p*-value**
New Equations	Female	40.62 (33.71; 46.2)	0.55 (-2.18; 2.75)	0.247
	Male	32.88 (25.46; 37.59)	-0.66 (-2.94; 1.85)	0.414
DL-DR	Female	42.01 (34.59; 47.76)	1.62 (-0.43; 3.95)	0.046*
RFM	Female	36.09 (30.59; 40.55)	-3.44 (-6.67; -1.21)	0.000*
	Male	30.35 (25.87; 33.29)	-2.51 (-5.32; 0.61)	0.000*
BAI	Female	32.46 (28.16; 36.62)	-6.46 (-9.39; -2.83)	0.000*
	Male	28.31 (24.75; 31.41)	-3.33 (-6.78; -0.90)	0.000*

FM: Fat Mass; DL-DR: De Lorenzo-Di Renzo; RFM: Relative Fat Mass; BAI: Body Adiposity Index. Difference (kg-%) corresponds to Fat Mass estimated by predictive methods minus Fat Mass measured by Dual energy X-ray absorptiometry (DXA). Agreement *p*-value was performed by one sample t-test for total sample. $^*p<0.05$.

Bland-Altman method, there was an agreement between the FM both in kg and in % measured with those predicted from our new equation (FM (kg) $p>0.589$; FM% $p>0.414$), while it was not present for the remaining ones ($p<0.05$). In the comparison between the ROC curves, male and female obese were defined with a BMI≥30 kg/m^2, females with FM%≥30% and males with FM%≥25%. For obesity classified according to the FM% derived from the new equation, a significantly higher AUC was found and the comparison in pairs between the FM% derived from new equation (FM% Neq) and BMI curves for both sexes was significant $p<0.001$. In females for FM% Neq, the AUC was 0.835 (95% CI, 0.761-0.909, $p<0.000$) and for BMI the AUC was 0.646 (95% CI, 0.577-0.714, $p<0.001$). In males, for FM% Neq the AUC was 0.891 (95% CI, 0.811-0.971, $p<0.000$) and for BMI the AUC was 0.646 (95% CI, 0.727-0.874, $p<0.001$). For each sex the diagnostic accuracy of the obesity of the FM% Neq and the BMI was compared with the FM% DXA. The results of the test are shown in Table IV. The classification based on the FM% Neq presented a high κ-value of Cohen and statistically significant for both sexes (Female κ=0.676, $p<0.000$, Male κ=0.721, $p<0.000$). The percentage of FP was lower in females (4.0%), while that of FN was lower in males (2.5%). The BMI-based classification presented a lower and statistically significant Cohen κ-value for both sexes (Female κ=0.114, $p<0.000$, Male κ=0.362, $p<0.000$). The percentage of FP was higher in females (57.0%), while that of FN was equal in both sexes to 0.6% (Table V).

In Table VI was shown a FM% classification, divided by gender, adapted from results reported by De Lorenzo et al[22].

Discussion

WHO defined obesity as "abnormal or excessive fat accumulation that presents a risk to health[1]", placing the emphasis on FM and not on excess body weight.

In order to move towards the current direction of precision medicine and the need to prevent non-communicable diseases, the two objectives of the work have been achieved. First, FM (kg) prediction equation was developed on a representative sample of the Italian population, between 18 and 65 years, and then cross-validated on an external sample with the same characteristics. The development of new equations, population and sex specific, adapted to the current socioeconomic condition, is a necessity reported in numerous works in the literature[21-23]. The age range chosen is in line with the desire to evaluate an excess of adiposity in a population considered active and also to carry out prevention programs.

Subsequently, the fit of the new equation was evaluated compared to BMI in the cross-validation set. A simpler and more accurate tool reflects the needs of clinical practice to start targeted and personalized dietetic interventions on the subject.

The limit in the sensitivity of BMI in the definition of obese subjects is known, given the high number of false positives that are obtained using it [24].

Table IV. Validation analysis: classification according to Fat Mass by DXA, predicted by our new equation and BMI divided by sex.

	Female	DXA				Male	DXA		
		FM% <30	FM% ≥ 30	Total			FM% <25	FM% ≥ 25	Total
BMI	< 30	51 (14.4%)	202 (57.1%)	253 (71.5%)	BMI	< 30	27 (16.9%)	48 (30.0%)	75 (46.9%)
	≥ 30	2 (0.6%)	99 (28.0%)	101 (28.5%)		≥ 30	1 (0.6%)	84 (52.5%)	85 (53.1%)
	Total	53 (15.0%)	301 (85.0%)	354 (100%)		***Total***	28 (17.5%)	132 (82.5%)	160 (100%)
	Female	**DXA**				**Male**	**DXA**		
		FM% <30	**FM% ≥ 30**	**Total**			**FM% <25**	**FM% ≥ 25**	**Total**
New Equation	FM%<30	38 (10.7%)	14 (4.0%)	52 (14.7%)	New Equation	FM%<30	24 (15.0%)	10 (6.3%)	34 (21.3%)
	FM%≥30	15 (4.2%)	287 (81.1%)	302 (85.3%)		FM%≥30	4 (2.5%)	122 (76.3%)	126 (78.8%)
	Total	53 (15.0%)	301 (85.0%)	354 (100%)		***Total***	28 (17.5%)	132 (82.5%)	160 (100%)

BMI: Body Mass Index, FM: Fat Mass; DXA: Dual energy X-ray absorptiometry. All values are presented as numbers (percentage).

Table V. AUC, Sensibility, Specificity and κ coefficient of BMI and New Equation for indicating the validity of obesity classification in Italian adults population.

Female	AUC* (CI 95)	Sens	Spec	κ*
BMI	0.65 (0.58; 0.71)	0.33	0.69	0.114
New Equation	0.83 (0.76; 0.90)	0.95	0.72	0.676
Male	**AUC* (CI 95)**	**Sens**	**Spec**	**κ***
BMI	0.65 (0.58; 0.71)	0.33	0.69	0.114
New Equation	0.83 (0.76; 0.90)	0.95	0.72	0.676

BMI: Body Mass Index. All AUC and κ have *p-values were <0.001.

Table VI. Classification of FM%, by gender, adapted by De Lorenzo et al[21].

Age (years)	Gender	FM%		
		Acceptable	Pre-obese	Obese
18-29	M	8.0-23.0	23.1-24.9	≥ 25.0
	F	13.0-28.0	28.1-29.9	≥ 30.0
30-39	M	8.0-24.0	24.1-28.9	≥ 29.0
	F	13.0-29.0	29.1-33.9	≥ 34.0
40-49	M	8.0-25.0	25.1-29.9	≥ 30.0
	F	13.0-30.0	30.1-34.9	≥ 35.0
> 50	M	8.0-26.0	26.1-39.9	≥ 31.0
	F	13.0-31.0	31.1-35.9	≥ 36.0

FM: Fat Mass. All values of FM are presented as percentage.

The advantage to use the new equation respects to risk indicators, such as BMI and circumferences, recognized by WHO[1], is that predicts FM, which remains the central core in the definition of obesity and that can be compared with the national and international reference values.

In addition to BMI, we proceeded to compare the results obtained with the new equation respect to BAI, RFM and DL-DR equation (only for women), to quantify the agreement with the DXA.

In the development of the equation, the choice of the final predictors, such as WC and HC circumferences, was guided by the simplicity and repeatability of the physical landmarks, in order to spread the practice. Moreover, through the WC and HC it is possible to determine the distribution of FM, cardiovascular risk, adiposopathy and metabolic diseases [25-28]. Our predicted FM (kg) and, consequently, FM%, are in agreement with DXA results, in cross-validation set. This shows that through simple anthropometric measurements it is possible to estimate the FM with relative accuracy. In particular, in women there is an overestimation, both in FM (kg) and FM%, attributable to the greater importance of hip in the regression model. For the DL-DR equation, the agreement is not statistically significant, even if the average % error does not exceed 2%. This is related to the development set of the DL-DR equation, mainly composed of obese women to evaluate a specific obesity-related cardiovascular disease risk. Differently, the new equation wants to evaluate a wider FM distribution, in both sexes. In predicting the FM with RFM and BAI on our Italian population, we observe a missed agreement together with an important and significant underestimation. This is due to the different population, in the specific cases American population, which has different ranges of obesity, just think of the metabolic syndrome criteria, defined by the National Cholesterol Education Program [29]. From the analysis of the validation of the obesity classification, it emerged that the false positives percentage was equal to 57.1% in females and 30.0% in males, according to the BMI. This denotes the lack of sensitivity of the method in correctly classifying subjects with excess of adiposity and at risk of developing obesity-related diseases [30]. On the contrary, according to the new equation, the percentages of false positives decreased to 4.0% in females and 6.3% in males. Furthermore, the validity of the classification was confirmed by the higher value of the AUC with a significant increase in sensitivity, compared to the BMI. Lastly, the validity of the classification, according to the new equation, was evidenced by the significant increase in κ-value, compared to that obtained for BMI, which does not exceed 0.4, indicating a discrete agreement.

Conclusions

The importance of this work lies in placing an easy tool at the disposal, since it requires only two circumferences, to be used in clinical practice.

In the future it will try to improve the equation thanks to a larger sample, with which we can also compare equations that take into account other anthropometric parameters.

Moreover, based on a correct evaluation of the fat, it will then be possible to prepare personalized diet plans [31-34], which also aim to maintain the lean mass [35-37], essential to performance.

In particular, it will be possible to validate and refine the equation on specific Italian sub-populations, divided by gender and age, such as the military. This also in relation to the need to have immediate tools that make it possible to better assess the medical fitness and to provide plans for personalized prevention of personnel enlisted in the military forces.

Obesity is a threat to the national security of all States. Accurate and precise measures of FM are a crucial need to obtain accepted and shared standards that make population less vulnerable.

Authors' declaration of personal interests

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

Author Contributions

ADL designed the research; PG collected the data; LR analyzed the data; ADL, MS, SG, LR, PG, MM, GM and CC contributed to the discussion of results; CC had primary responsibility for the final content. All authors read and approved the submitted and the final version of the manuscript. All the authors agree to be personally accountable for the author's own contributions and for ensuring that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and documented in the literature.

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