



Original Article

Development and validation of anthropometric equations to estimate body composition in adult women

Desarrollo y validación de ecuaciones antropométricas para estimar la composición corporal en mujeres adultas

Juan C. Aristizabal^{1,2}, Alejandro Estrada-Restrepo^{2,3} and Argenis Giraldo García²

¹Physiology and Biochemistry Research Group-PHYSIS, Universidad de Antioquia, Medellín, Colombia.

²School of Nutrition and Dietetics, Universidad de Antioquia, Medellín, Colombia.

³Demography and Health Research Group, Universidad de Antioquia, Medellín, Colombia.

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Abstract

Objective: To develop anthropometric equations to predict body fat percentage (BF%).

Methods: In 151 women (aged 18-59) body weight, height, eight-skinfold thickness (STs), six- circumferences (CIs), and BF% by hydrodensitometry were measured. Subjects data were randomly divided in two groups, equation-building group (n= 106) and validation group (n= 45). The equation-building group was used to run linear regression models using anthropometric measurements as predictors to find the best prediction equations of the BF%. The validation group was used to compare the performance of the new equations with those of Durnin-Womersley, Jackson-Pollock and Ramirez-Torun.

Results: There were two preferred equations: Equation 1= $11.76 + (0.324 \times \text{tricipital ST}) + (0.133 \times \text{calf ST}) + (0.347 \times \text{abdomen CI}) + (0.068 \times \text{age}) - (0.135 \times \text{height})$ and Equation 2= $11.37 + (0.404 \times \text{tricipital ST}) + (0.153 \times \text{axilar ST}) + (0.264 \times \text{abdomen CI}) + (0.069 \times \text{age}) - (0.099 \times \text{height})$. There were no significant differences in BF% obtained by hydrodensitometry (31.5 ± 5.3) and Equation 1 (31.0 ± 4.0) and Equation 2 (31.2 ± 4.0). The BF% estimated by Durning-Womersley (35.8 ± 4.0), Jackson-Pollock (26.5 ± 5.4) and Ramirez-Torun (32.6 ± 4.8) differed from hydrodensitometry ($p < 0.05$). The interclass correlation coefficient (ICC) was high between hydrodensitometry and Equation 1 (ICC= 0.77), Equation 2 (ICC= 0.76), and Ramirez-Torun equation (ICC= 0.75). The ICC was low between hydrodensitometry and Durnin-Womersley (ICC= 0.51) and Jackson-Pollock (ICC= 0.53) equations.

Conclusion: The new Equations-1 and 2, performed better than the commonly used anthropometric equations to predict BF% in adult women.

Resumen

Objetivo: Desarrollar ecuaciones antropométricas para predecir el porcentaje de grasa corporal (% GC).

Métodos: En 151 mujeres (18-59 años) se midieron peso corporal, estatura, ocho pliegues cutáneos (PCs), seis perímetros (PEs) y el %GC por hidrodensitometría. Se formaron dos grupos al azar, desarrollo de ecuaciones (n= 106) y validación (n= 45). En el grupo desarrollo de ecuaciones se calcularon modelos de regresión lineal, con las medidas antropométricas como predictores, para encontrar la mejor ecuación de predicción del %GC. El grupo validación se utilizó para comparar el desempeño de las nuevas ecuaciones con las de Durnin-Womersley, Jackson-Pollock y Ramírez-Torun.

Resultados: Se seleccionaron dos ecuaciones: Ecuación-1= $11.76 + (0.324 \times \text{tríceps PC}) + (0.133 \times \text{pantorrilla-medial PC}) + (0.347 \times \text{abdomen PE}) + (0.068 \times \text{edad-años}) - (0.135 \times \text{estatura})$ y Ecuación-2= $11.37 + (0.404 \times \text{tríceps PC}) + (0.153 \times \text{axilar PC}) + (0.264 \times \text{abdomen PE}) + (0.069 \times \text{edad-años}) - (0.099 \times \text{estatura})$. No hubo diferencias significativas en el %GC obtenido por hidrodensitometría (31.5 ± 5.3) y Ecuación-1 (31.0 ± 4.0) o Ecuación-2 (31.2 ± 4.0). Los %GC estimados por Durning-Womersley (35.8 ± 4.0), Jackson-Pollock (26.5 ± 5.4) y Ramírez-Torun (32.6 ± 4.8) fueron diferentes del obtenido por hidrodensitometría ($p < 0.05$). El coeficiente de correlación intraclass (ICC) fue alto entre hidrodensitometría y las Ecuaciones 1 (ICC= 0.77), 2 (ICC= 0.76), y Ramírez-Torun (ICC= 0.75). El ICC fue bajo entre hidrodensitometría y Durnin-Womersley (ICC= 0.51) y Jackson-Pollock (ICC= 0.53).

Conclusión: Las nuevas ecuaciones 1 y 2 presentaron mejor rendimiento que las ecuaciones tradicionales para predecir el %GC en mujeres adultas.

Corresponding author:

Juan C. Aristizabal, Ph.D. Escuela de Nutrición y Dietética. Carrera 75 N° 65-87, Bloque 44. Universidad de Antioquia, Medellín-Colombia. Phone: +57 4 219 9227 Fax: +57 4 230 5007. Email: juan.arsitizabal@udea.edu.co

Introduction

Colombian adult women (age range 18 to 64 years) had a high prevalence of overweight (35.0%) and obesity (20.1%) that coexists with less proportion of underweight people (3.0%)¹. These prevalences are based on the body mass index (BMI) application¹. The BMI is a body weight-height index that does not differentiate the fat mass from the fat free mass^{2,3}. This is relevant since it is the excess of fat mass, nor necessarily the excess of body weight, that represents higher risk of developing cardiovascular diseases and type 2 diabetes^{2,4}. Correspondingly, is the deficit of fat free mass, frequently observed in underweight, but also in normal weight and overweight people, that associates with negative clinical outcomes, lower functional capacities, and impairment of overall health⁵. Therefore, in sceneries looking to prevent, diagnose, and treat underweight, overweight, and obesity, the application of methods to assess body composition (i.e. fat mass and fat free mass) are preferred than the body weight-height indices like BMI^{2,3}.

Anthropometric equations are widely used to estimate body composition and recently new equations have been developed for specific populations⁵⁻⁹. The equations are developed following three general steps¹⁰. First, body composition is determined in a group of people by a reference method (i.e. a highly acute laboratory method). Second, in the same group of people measurements such as body weight, height, skinfold thickness and circumferences are collected. Third, the collected body measurements are used as predictors to obtain the best equation estimating the quantities of fat mass or fat free mass¹⁰. In general, anthropometric equations are population specific, given that the relation between body measurements and body components (i.e. fat mass and fat free mass calculated from body density) are modified by age, sex, and ethnicity^{2,11}. Therefore, an anthropometric equation should not be applied to a population different from it was derivate without a previous validation^{2,11}. Durning-Womersly¹² and Jackson-Pollock¹³ are traditional equations commonly used to evaluate body composition worldwide. These equations and the more recently published by Ramirez-Torun¹⁴ have shown poor validity to estimate body composition in Colombian women¹⁵.

This study aimed to develop and validate practical anthropometric equations to estimate body composition in women living in Medellín, Colombia. The study hypothesized the new equations will perform better in Colombian women than the equations developed in foreign countries.

Materials and Methods

Study design and participants

This is a cross-sectional study with a convenience sample of 151 women with ages between 18 to 59 years. Participants were students, teachers and volunteers attending the outreach programs from the University of Antioquia, Medellín, Colombia. No athletes were included in the study or women with implants (e.g. silicon, plastic, metal), in pregnancy or having any other physiological conditions that might have altered the results. The study was approved by the Bioethics Committee of the Faculty of Medicine from the University of Antioquia and was performed according to the Helsinki Declaration. Written consent was obtained from each participant.

Hydrodensitometry and anthropometric measurements were done in the Human Body Composition Laboratory, at the School of Nutrition and Dietetics from the University of Antioquia, Medellín, Colombia. Participants were scheduled to attend the laboratory a day that did not include five days before or after menses. Volunteers were asked to avoid intense physical activity and food that produces gases (e.g. beans, broccoli, and cabbage) the day before the test. Participants arrived at the laboratory between 7:00 am and 9:00 am after a fast period of at least four hours. After urinating/defecating volunteers removed garments, jewels, and wore a bathing suit for anthropometric and hydrodensitometry measurements.

Anthropometry

Measurements were carried out by two trained anthropometrists following the standard techniques described by Lohman, *et al*¹⁶. Body weight was measured to the nearest 0.05 kg using a digital scale (Detecto CN20LS, USA). Height was measured to the nearest 0.1 cm using an anthropometer (GPM 101, Switzerland). Arm, waist, abdominal, hip, thigh, and calf circumferences were measured to the nearest 0.1 cm using a metal tape (Lufkin W606PM, USA). Skinfold thickness was measured to the nearest 0.2 mm with a caliper (Harpender CE0120, England) including biceps, triceps, subscapular, midaxillary, suprailiac, abdominal, medium thigh, and medial calf. Anthropometric measurements were done at least by duplicate or by triplicate when the difference between the first and the second values were higher than 0.05 kg in body weight, 0.5 cm in height, 1% in circumferences, and 5% in skinfold thickness. Body composition was calculated using Durning-Womersly¹², Jackson-Pollock¹³, and Ramirez-Torun¹⁴ equations.

Hydrodensitometry

Body density was determined by underwater weighing with simultaneous measurement of residual lung volume. Volunteers entered to a tank filled with water at $36 \pm 0.2^\circ \text{C}$ and sat on a plastic chair suspended from a scale with 0.02 kg of sensitivity (Chatillon, C-103616, USA). Participants submerged completely in water using a nose clip and breathing through a mouthpiece connected to a spirometer (Sensor Medics, VMAX 22, USA). Residual lung volume and underwater weight were recorded simultaneously at the end of a maximal exhalation. Body volume was calculated by subtracting underwater body weight (UBW) from body weight, and dividing the difference by water density at 36°C [i.e. body volume = (body weight - UBW) / water density]. Then, body volume was adjusted by subtraction of the residual lung volume and 0.1 L of estimated intestinal gas, as recommended¹⁷. Body density was calculated dividing body weight by the adjusted body volume. The whole procedure was repeated at least twice or up to obtain two body densities with a difference $\leq 0.002 \text{ g/mL}$ in each participant. The selected body densities were averaged and the BF% was calculated with the Siri equation, $\text{BF\%} = 4.95 / \text{body density} - 4.50$ ¹⁷.

Statistical analysis

Normal distribution of data was tested with the Kolmogorov-Smirnov test. Means, standard deviation and range were calculated for all variables. Participants' data were randomly divided in two groups; equation-building group (n= 106) and validation group (n= 45). Multiple linear regression models were

Table 1. Subject characteristics by group

Characteristics	Equation-building group (n= 106)		Validation group (n= 45)		p-value
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	
Age (yrs)*	33.5 $\pm$ 12.9	18-59	35.0 $\pm$ 11.9	19-59	0.656
Body weight (kg)*	58.6 $\pm$ 8.0	42-83	59.6 $\pm$ 8.2	43-72	0.669
Height (cm)	157.6 $\pm$ 6.5	143-175	158.5 $\pm$ 6.4	143-174	0.309
Body mass index (kg/m ²)*	23.6 $\pm$ 3.0	18-31	23.7 $\pm$ 3.4	19-32	0.833
Arm circumference (cm)*	27.7 $\pm$ 2.6	22-34	28.2 $\pm$ 3.1	23-36	0.333
Waist circumference (cm)*	74.4 $\pm$ 7.8	59-93	74.5 $\pm$ 8.4	61-89	0.851
Abdominal circumference (cm)*	84.2 $\pm$ 7.6	69-105	85.4 $\pm$ 6.9	69-101	0.528
Hip circumference (cm)	97.5 $\pm$ 5.6	84-105	97.9 $\pm$ 5.7	84-112	0.726
Medium-thigh circumference (cm)	49.4 $\pm$ 4.0	41-60	49.9 $\pm$ 3.6	41-58	0.456
Calf circumference (cm)	35.3 $\pm$ 2.5	30-44	35.8 $\pm$ 2.5	31-42	0.391
Bicipital skinfold (mm)*	10.2 $\pm$ 3.4	4-25	10.5 $\pm$ 4.7	4-17	0.372
Tricipital skinfold (mm)	19.5 $\pm$ 4.9	11-32	21.3 $\pm$ 5.7	9-30	0.072
Subscapular skinfold (mm)*	22.5 $\pm$ 8.8	8-47	22.9 $\pm$ 9.1	8-50	0.085
Midaxillary skinfold (mm)*	17.7 $\pm$ 7.0	7-38	18.5 $\pm$ 7.6	7-36	0.801
Suprailiac skinfold (mm)	34.0 $\pm$ 8.0	18-52	34.8 $\pm$ 7.6	12-52	0.187
Abdominal skinfold (mm)*	28.2 $\pm$ 7.8	14-59	27.4 $\pm$ 7.1	14-51	0.723
Medium-thigh skinfold (mm)	27.1 $\pm$ 7.9	11-48	29.7 $\pm$ 9.8	13-51	0.092
Medial-calf skinfold (mm)	19.5 $\pm$ 6.4	6-33	19.8 $\pm$ 7.9	5-43	0.866
Body density (g/mL)	1.028 $\pm$ 0.012	1.003-1.055	1.029 $\pm$ 0.013	1.005-1.055	0.820
Body Fat (%)	31.2 $\pm$ 5.9	19-44	31.3 $\pm$ 6.1	21-44	0.975

Differences between groups were calculated by T-test.

*In non-normally distributed variables the Mann-Whitney U test was used.

ran using anthropometric data in the equation-building group as predictors, to identify the best prediction equations of the BF%. The equations were ascertained by identifying the models that meet the normality, collinearity, variance homogeneity and the Durbin Watson's criterion. The Akaike information criterion (AIC) that estimates the quality of the statistical models was also calculated for each equation. Two selected equations using two skinfold thickness, one circumference, height, and age, showed a good adjusted determination coefficient (adjusted r^2) and a low standard error of the estimate (SEE). Using the same criteria, a third equation that did not include skinfold thickness among the predictors was also selected. These equations were used to estimate the BF% in the validation group and the adjusted r^2 and the SEE were obtained. Averages of BF%, fat mass, and fat free mass estimated by the new equations and those of Durnig-Womersley, Jackson-Pollock and Ramirez-Torun were compared with hydrodensitometry using paired t-test. Pearson correlation coefficient and intraclass correlation coefficient (ICC) for BF% were also calculated. Data analyses were made using The Statistical Package for Social Sciences for Windows (SPSS. 22.0, 2013, SPSS, Inc, Chicago, IL).

Results

Twelve subjects did not successfully complete the underwater

weighing test, mainly for being unable to breathe underwater through the mouthpiece. These subjects were excluded from the analysis and did not differ in any anthropometric measurements from the participants used to develop and validate the equations. Complete anthropometric measurements and underwater weighing were obtained in 151 women, ranging from 18 to 59 years old. Participants' data were randomly divided in two groups, equation-building group (n=106) and validation group (n= 45). There were not significant differences between groups in age (33.5 $\pm$ 12.9; 35.0 $\pm$ 11.9 y, p = 0.656), BMI (23.6 $\pm$ 3.0; 23.7 $\pm$ 3.4 kg/m², p = 0.833), BF% (31.2 $\pm$ 5.9; 31.3 $\pm$ 6.1, p = 0.975) or any anthropometric measurement (Table 1). The BF% ranged between 19% to 44% in the equation-building group, and between 21% to 44% in the validation group (Table 1).

The selected anthropometric equations for estimating BF% are showed in Table 2. Equation 1 includes the measurements of body height, abdominal circumference, triceps- and calf- skinfold thickness plus age. Equation 2 includes the same measurements than Equation 1 except for the calf skinfold that was replaced by the midaxillary skinfold. Equation-3 included body weight, height and abdominal circumference measurements. Equations 1 and 2 had similar determination coefficients and SEE in the equation-building group (Table 2). Equation 1 showed a slightly better

Table 2. Developed anthropometrics equations to predict body fat percentage

Equations	Equation-building group [§]			Validation group	
	Adjusted r^2	SEE	AIC	r^2	SEE
1: Body fat (%) = 11.76 + (0.324 x triceps ST) + (0.133 x calf ST) + (0.347 x abdomen CI) + (0.068 x age in years) - (0.135 x height in cm)	0.72	3.12	549	0.71	2.84
2: Body fat (%) = 11.37 + (0.404 x triceps ST) + (0.153 x midaxillary ST) + (0.264 x abdomen CI) + (0.069 x age in years) - (0.099 x height in cm)	0.72	3.08	547	0.67	3.06
3: Body fat (%) = 27.39 + (0.264 x body weight in kg) + (0.381 x abdomen CI) - (0.279 x height in cm)	0.66	3.44	569*	0.55	3.55

SEE: Standard error of estimate. AIC: Akaike Information Criterion. r^2 : determination coefficient. ST: skinfold thickness in mm, CI: circumference in cm.*Different from Equation 1 and Equation 2 (p < 0.001).§Assumption models (p value).

Equation 1: Shapiro Wilk test= 0.9543; Durbin-Watson test= 0.9023; Homogeneity of variances test= 0.4803; Variance Inflation Factor <2.8.

Equation 2: Shapiro Wilk test= 0.1318; Durbin-Watson test= 0.9535; Homogeneity of variances test= 0.8445; Variance Inflation Factor <3.4.

Equation 3: Shapiro Wilk test= 0.1489; Durbin-Watson test= 0.8721; Homogeneity of variances test= 0.5135; Variance Inflation Factor <4.5.

Table 3. Comparison of body fat percentage obtained by hydrodensitometry and anthropometric equations.

Validation group (n= 45)	Body fat (%)	Differences from Hydro†	Pearson correlation	Intraclass correlation
Hydrodensitometry	31.5 ± 5.3	---	---	---
Equation 1	31.0 ± 4.0	0.50	0.81**	0.77**
Equation 2	31.2 ± 4.0	0.31	0.79**	0.76**
Equation 3	31.0 ± 4.6	0.49	0.74**	0.73**
Durnin-Womersley	35.8 ± 4.0	4.26**	0.75**	0.51**
Jackson-Pollock	26.5 ± 5.4	-5.03**	0.77**	0.53**
Ramirez-Torun	32.6 ± 4.8	1.10*	0.77**	0.75**

†Differences from hydrodensitometry calculated by paired T-test.

p* <0.05. *p* <0.001.

performance than Equation 2 during the validation process with a higher determination coefficient (0.71 vs 0.67) and lower SEE (2.84 vs 3.06). Equation 3 had lower determination coefficient and higher SEE than Equations 1 and 2, in both, equation-building and validation group (Table 2). The Akaike information criterion was similar between Equation 1 and 2 (549 vs 547). The Equation 3 had higher AIC than Equations 1 and 2 (AIC=569; *p* <0.001) presenting a lower quality statistical model (Table 2).

The BF% obtained by hydrodensitometry and anthropometric equations in the validation group are shown in Table 3. There were not significant differences (*p* >0.05) between the BF% assessed by hydrodensitometry (31.5 ± 5.3) and the estimated by Equation 1 (31.0 ± 4.0), Equation 2 (31.2 ± 4.0) and Equation 3 (31.0 ± 4.6). The BF% was over estimated by the equations of Durning-Womerley (+4.26; *p* <0.001) and Ramirez-Torun (+1.10; *p* <0.05) and underestimated by the equation of Jackson-Pollock (-5.03; *p* <0.001) (Table 3). The BF% estimated by the anthropometric equations significantly correlated (*p* <0.001) with the hydrodensitometry results, the higher correlations were observed for Equation 1 (*r* = 0.81; *p* <0.001, ICC= 0.77; *p* <0.001) and Equation 2 (*r* = 0.79; *p* <0.001, ICC= 0.76; *p* <0.001) (Table 3).

Body composition obtained by hydrodensitometry and anthropometric equations in the validation group are shown in Table 4. There were not significant differences (*p* >0.05) between the kilograms of fat mass and fat free mass obtained by hydrodensitometry (19.0 ± 4.9; 40.5 ± 4.2, respectively) and those estimated by Equation 1 (18.7 ± 4.4; 40.8 ± 3.7, respectively), Equation 2 (18.8 ± 4.4; 40.7 ± 3.6, respectively) and Equation 3 (18.7 ± 4.8; 40.7 ± 3.4, respectively). The equations of Durning-Womerley, Jackson-Pollock and Ramirez-Torun estimated quantities of fat mass and fat free mass significantly different (*p* <0.05) from those obtained by the reference method (Table 4).

Discussion

The objective of this study was to develop and validate anthropometric equations to estimate body composition in adult women. Two equations including measurements of body height, abdominal circumference, and two skinfolds thickness were developed and validated. These equations are advised to be applied in clinical settings. A third equation without skinfold thickness measurement was also developed and it is suggested to be use in epidemiological settings. The three equations meet the criteria that good anthropometric equations should have according to Heyward and Stolarczyk¹⁸, as follows: a) the use of an acceptable reference method like hydrodensitometry, b) the use of a large

Table 4. Comparison of body fat mass and fat free mass obtained by hydrodensitometry and anthropometric equations.

Validation group (n=45)	Fat Mass (kg)		Fat Free Mass (kg)	
	Mean (±SD)	Diff. from Hydro†	Mean (±SD)	Diff. from Hydro†
Hydrodensitometry	19.0 ± 4.9	---	40.5 ± 4.2	---
Equation 1	18.7 ± 4.4	-0.30	40.8 ± 3.7	0.30
Equation 2	18.8 ± 4.4	-0.18	40.7 ± 3.6	0.18
Equation 3	18.7 ± 4.8	-0.24	40.7 ± 3.4	0.23
Durnin-Womersley	21.5 ± 4.5	2.50**	38.0 ± 3.7	-2.50**
Jackson-Pollock	16.0 ± 4.8	-2.96**	43.4 ± 4.2	2.96**
Ramirez-Torun	19.7 ± 5.1	0.72*	39.7 ± 3.1	-0.73*

†Differences from hydrodensitometry calculated by paired T-test.

p* <0.05. *p* <0.001.

sample size higher than 100 subjects, c) to show high multiple correlations between the reference method and the predicted scores, d) to have a small SEE, and e) to be cross-validated on additional, independent sample from the population¹⁸.

The developed anthropometric equations meet statistical and practicality criteria. Multiple anthropometric equations were identified by combining age with the sixteen body measurements collected (Table 1). First, the equations were ascertained by identifying the models that meet the statistical criteria (see statistical analysis section). Then, looking for practical equations, those that included lower body measurements were selected. Equations 1 and 2 used the same number of measurements, but Equation 1 is the first option since includes skinfold measurement at triceps and calf, sites that are easier to access than the midaxillary skinfold required for Equation 2. In addition, Equation 1 showed a slightly better performance than Equation 2 in the validation group. Nonetheless, both equation are classified as very good, according to the Lohman's classification system to evaluate new methods, given their SSE of 3.12 and 3.08, respectively¹⁹. Equations 1 and 2 explained 72% of the variance in BF%, probably due to the lower number of body measurements they included; two skinfolds and one circumference. This theory is supported by the findings of Ramirez-Torun who developed equations in Guatemalan women; they reported that models including three skinfolds and two circumferences explain up to 88% of the variance in BF%, and equations with lower body measurements explained lower variances¹⁴. Equation 3 is the easiest to be applied since it uses only three body measurements and does not include skinfold thickness. Although this equation with an SEE of 3.44 is classified as good according to the Lohman's classification system¹⁹ its performance in the validation group was lower than Equations 1 and 2, and it had also a lower quality statistical model. The Equation 3 was design to be applied in epidemiological settings where it is harder to have trained anthropometrics for skinfold measurements and to maintain good quality- calibrated calipers.

The developed anthropometric equations performed better than the foreign equations estimating body composition in adult Colombian women. The Equations 1, 2 and 3 produced body composition results similar to hydrodensitometry, and they showed substantial correlation and agreement with this reference method according to Landis criteria²⁰. Contrarily, the equations of Durning-Womersley, Jackson-Pollock and Ramirez-Torun showed significant differences with the reference method, results in agreement with previous studies^{9,14,15,21-23}. The poor results of the foreign equations could be due to differences among ethnic groups in density of body components, body fat distribution or

body segment proportions, characteristics that affect equations' performance⁹⁻¹¹. It seems that the equations of Durnin-Womersley and Jackson-Pollock developed in Caucasian, and the Ramirez-Torun designed in Guatemalan people (a mixture of European and Amerindian) are not appropriated for Colombian women who are described as a mixture of European, African and Native American^{24,25}.

According to the authors' knowledge, this study is unique in developing and validating anthropometric equations to estimate BF% in women living in Colombia and using hydrostatic weighing. Another strength of this study is the development of an anthropometric equation without skinfold thickness measurement, which is suggested to be applied in epidemiological settings where skinfold thickness is not commonly measured. The study has some limitations. The use of a convenience sample, given that hydrostatic weighing is a demanding test where voluntaries remain underwater during 2 to 4 minutes breathing through a mouthpiece. This makes the reference test unfeasible for representative population samples. Therefore, careful interpretation of the results from the new equations is recommended when they are applied to general population, particularly to individuals who significantly differ from the participants of this study; differences in anthropometric measurements, ethnicity and physical activity level should be especially considered. Another study limitation is the use of a two-compartmental model that assumes constant densities of the fat mass and the fat free mass; it is known that there are variations in the density of these components with age, ethnicity and fitness level¹⁷. The use of a four-compartmental model would overcome this difficulty but it was not applied in this study due to unavailability of resources. It is important to highlight that the Equations 1, 2 and 3 showed good performance in the validation group with averages of BMI and BF% of 23.7 kg/m² and 31.3%, respectively. Future studies should validate these equations in groups of women with wider BMI and fat mass distribution.

In summary, the new developed Equations 1 and 2 performed better than the commonly used anthropometric equations to predict body composition in women from Medellin, Colombia. The Equation 3 has a higher SEE and lower quality statistical model than Equations 1 and 2, and it was design to be applied in epidemiological settings. Careful interpretation of the equations' results is recommended when they are applied to individuals with physical characteristics that significantly differ from the participants of this study.

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Conflicts of interest:

The authors declare no conflict of interest.

References

1. Instituto Colombiano de Bienestar Familiar (ICBF). Encuesta Nacional de la Situación Nutricional en Colombia 2010. Bogotá, Colombia: Da Vinci Editores & CÍA S N C; 2011.

2. Cornier MA, Després JP, Davis N, Grossniklaus DA, Klein S, Lamarche B, *et al.* Assessing adiposity: a scientific statement from the American Heart Association. *Circulation*. 2011; 124(18): 1996-2019.

3. Thibault R, Genton L, Pichard C. Body composition: why, when and for who? *Clin Nutr*. 2012; 31(4): 435-47.

4. Grundy SM. Adipose tissue and metabolic syndrome: too much, too little or neither. *Eur J Clin Invest*. 2015;45(11):1209-17.

5. Kanellakis S, Skoufas E, Khudokonenko V, Apostolidou E, Gerakiti L, Andrioti MC, *et al.* Development and validation of two equations based on anthropometry, estimating body fat for the Greek adult population. *Obesity*. 2017; 25(2):408-16.

6. Waidyatilaka I, de Silva A, de Lanerolle-Dias M, Atukorala S, Lanerolle P. A field tool for prediction of body fat in Sri Lankan women: skinfold thickness equation. *J Health Popul Nutr*. 2016;35(1):31.

7. Hastuti J, Kagawa M, Byrne NM, Hills AP. Development and validation of anthropometric prediction equations for estimation of body fat in Indonesian men. *Asia Pac J Clin Nutr*. 2013;22(4):522-9.

8. Stevens J, Ou FS, Cai J, Heymsfield SB, Truesdale KP. Prediction of percent body fat measurements in Americans 8 years and older. *Int J Obes (Lond)*. 2016;40(4):587-94.

9. Nevill AM, Metsios GS, Jackson AS, Wang J, Thornton J, Gallagher D. Can we use the Jackson and Pollock equations to predict body density/fat of obese individuals in the 21st century? *Int J Body Compos Res*. 2008;6(3):114-21.

10. Bellisari A, Roche AF. Antropometría y ecografía. In: Heymsfield SB, Lohman TG, Wang Z, Going S (editors). *Composición Corporal*. Mexico, D.F.: McGraw-Hill; 2007. p. 109-128.

11. Deurenberg P, Deurenberg-Yap M. Validity of body composition methods across ethnic population groups. *Acta Diabetol*. 2003;40(Suppl 1):S246-9.

12. Durnin JV, Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. *Br J Nutr*. 1974;32(1):77-97.

13. Jackson AS, Pollock ML. Practical assessment of body composition. *Physician Sport med*. 1985;13(5):76-90.

14. Ramirez-Zea M, Torun B, Martorell R, Stein AD. Anthropometric predictors of body fat as measured by hydrostatic weighing in Guatemalan adults. *Am J Clin Nutr*. 2006;83(4):795-802.

15. Aristizabal JC, Restrepo MT, Lopez A. Validación por hidrodensitometría de ecuaciones de pliegues cutáneos utilizadas para estimar la composición corporal en mujeres. *Biomedica*. 2008;28(3):404-13.

16. Lohman T, Roche A, Martorell R. Anthropometric Standardization reference manual. Human Kinetics Publishers; 1988. p. 2-80.

17. Going S. Hidrodensitometría y pletismografía de desplazamiento de aire. In: Heymsfield SB, Lohman TG, Wang Z, Going S, editors. *Composición Corporal*. Mexico, D.F.: McGraw-Hill; 2007. p. 17-34.

18. Heyward VH. Practical body composition assessment for children, adults, and older adults. *Int J Sport Nutr.* 1998;8(3):285-307.
19. Lohman T. *Advances in Body Composition Assessment.* Champaign, IL. Human Kinetics Publishers; 1992. p. 1-5.
20. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics.* 1977;33(1):159-74.
21. Sandhu J, Giniya G, Shenoy S. Estimation of body composition in Indian population using skin-fold thickness and body-mass-index-based prediction equations: comparison and validation using under-water weighing machine. *Internat J Body Composition Res.* 2010; 8(2): 51-56.
22. Medoua GN, Nana ES, Essa 'a VJ, Ntsama PM, Matchawe C, Rikong HA, *et al.* Body composition of Cameroonian lactating women determined by anthropometry, bioelectrical impedance, and deuterium dilution. *Nutrition.* 2011;27(4):414-9.
23. Jackson AS, Ellis KJ, McFarlin BK, Sailors MH, Bray MS. Cross-validation of generalised body composition equations with diverse young men and women: the Training Intervention and Genetics of Exercise Response (TIGER) Study. *Br J Nutr.* 2009;101(6):871-8.
24. Rojas W, Parra MV, Campo O, Caro MA, Lopera JG, Arias W, *et al.* Genetic make up and structure of Colombian populations by means of uniparental and biparental DNA markers. *Am J Phys Anthropol.* 2010;143(1):13-20.
25. Price AL, Patterson N, Yu F, Cox DR, Waliszewska A, McDonald GJ, *et al.* A genomewide admixture map for Latino populations. *Am J Hum Genet.* 2007;80(6):1024-36.