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A novel approach to assess body composition in children with obesity from density of the fat-free mass

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Corresponding Author:	Veronica Luque, Dr Universitat Rovira i Virgili Reus, SPAIN
First Author:	Desirée Gutiérrez-Marín
Order of Authors:	Desirée Gutiérrez-Marín
	Joaquin Escribano
	Ricardo Closa-Monasterolo
	Natalia Ferré
	Michelle Venables
	Priya Singh
	Jonathan CK Wells
	Judit Muñoz-Hernando
	Marta Zaragoza-Jordana
	Mariona Gispert-Llauradó
	Carme Rubio-Torrents
	Mireia Alcázar
	Mercè Núñez-Roig
	Raquel Monné-Gelonch
	Albert Feliu
	Josep Maria Basora
	Ana Maria Alejos
	Veronica Luque, Dr
Abstract:	Background & Aims: Assessment of Fat Mass (FM) and fat free mass (FFM) using Air-displacement plethysmography (ADP) technique assumes constant density of FFM (DFFM) by age and sex. It has been recently shown that DFFM further varies according to body mass index (BMI), meaning that ADP body composition assessments of children with obesity could be biased if DFFM is assumed to be constant. The aim of this study was to validate the use of the calculations of DFFM (rather than constant density of the FFM) to improve accuracy of body composition assessment in children with obesity. Methods: cross-sectional validation study in 66 children with obesity (aged 8 to 14 years) where ADP assessments of body composition assuming constant density (FFMBODPOD and FMBODPOD) were compared to those where DFFM was adjusted in relation to BMI (FFMadjusted and FMadjusted), and both compared to the gold standard reference, the 4-component model (FFM4C and FM4C). Results: FFMBODPOD was overestimated by 1.50kg (95%CI -0.68kg, 3.63kg) while FFMadjusted was 0.71 kg (-1.08kg, 2.51kg) (percentage differences compared to FFM4C were 4.9% (±2.9%) and 2.8% (±2.1%), respectively (p<0.001)). Consistently, FM was underestimated by both methods, representing a mean difference between methods of 4.0% (±2.9%) and 6.8% (±3.8%),

	respectively, when compared to the reference method. The agreement and reliability of body composition assessments were improved when adjusted using calculations (adjusted models) rather than assuming constant DFFM. Conclusions: The use of constant values for fat-free mass properties may increase bias when assessing body composition (FM and FFM) in children with obesity by two-component techniques such as ADP. Using adjusted corrections as proposed in the present work may reduce the bias by half.

A novel approach to assess body composition in children with obesity from density of the fat-free mass

AUTHORSHIP: Desirée Gutiérrez-Marín[a], Joaquin Escribano[a,b], Ricardo Closa-Monasterolo[a,c], Natalia Ferré[a], Michelle Venables[d], Priya Singh[d], Jonathan CK Wells[e], Judit Muñoz-Hernando[a], Marta Zaragoza-Jordana[a], Mariona Gispert-Llauradó[a], Carme Rubio-Torrents[a], Mireia Alcázar[a], Mercè Núñez-Roig[a], Raquel Monné-Gelonch[f], Albert Feliu[b], Josep Maria Basora[f], Ana M Alejos[g], Veronica Luque[a,h].

[a] Paediatric Nutrition and Human Development Research Unit, Universitat Rovira i Virgili, IISPV. Address: C/ Sant Llorenç 21, 43201 Spain
[b] Hospital Universitari Sant Joan de Reus. Address: Av. del Dr. Josep Laporte, 2, 43204 Reus, Spain
[c] Hospital Universitari de Tarragona Joan XXIII. Address: C/Dr. Mallafré Guasch 4, 43005 Tarragona, Spain
[d] Stable Isotope Laboratory, NIHR BRC Nutritional Biomarker Laboratory and Wellcome Trust-MRC Institute of Metabolic Science, University of Cambridge, Cambridge, UK
[e] Childhood Nutrition Research Centre, UCL Great Ormond Street Institute of Child Health. Address: 30 Guilford St, Holborn, London WC1N 1EH, London, UK
[f] Unitat de Suport a la Recerca Tarragona-Reus, IDIAPJGol. Address: Camí de Riudoms 53-55, 43204 Reus, Spain
[g] Hospital Lleuger de Cambrils. Address: Plaça de l'Ajuntament, 2-3, 43850 Cambrils, Spain
[h] Serra Hunter Fellow

Corresponding author:

Veronica Luque
Paediatric Nutrition and Human Development Research Unit
C/ Sant Llorenç 21
43201 Reus
Veronica.luque@urv.cat

Tel. 0034 977759365

ABSTRACT

Background & Aims: Assessment of Fat Mass (FM) and fat free mass (FFM) using Air-displacement plethysmography (ADP) technique assumes constant density of FFM (D_{FFM}) by age and sex. It has been recently shown that D_{FFM} further varies according to body mass index (BMI), meaning that ADP body composition assessments of children with obesity could be biased if D_{FFM} is assumed to be constant. The aim of this study was to validate the use of the calculations of D_{FFM} (rather than constant density of the FFM) to improve accuracy of body composition assessment in children with obesity. **Methods:** cross-sectional validation study in 66 children with obesity (aged 8 to 14 years) where ADP assessments of body composition assuming constant density (FFM_{BODPOD} and FM_{BODPOD}) were compared to those where D_{FFM} was adjusted in relation to BMI ($FFM_{adjusted}$ and $FM_{adjusted}$), and both compared to the gold standard reference, the 4-component model (FFM_{4C} and FM_{4C}). **Results**: FFM_{BODPOD} was overestimated by 1.50kg (95%CI -0.68kg, 3.63kg) while $FFM_{adjusted}$ was 0.71 kg (-1.08kg, 2.51kg) (percentage differences compared to FFM_{4C} were 4.9% (±2.9%) and 2.8% (±2.1%), respectively ($p<0.001$)). Consistently, FM was underestimated by both methods, representing a mean difference between methods of 4.0% (±2.9%) and 6.8% (±3.8%), respectively, when compared to the reference method. The agreement and reliability of body composition assessments were improved when adjusted using calculations (adjusted models) rather than assuming constant D_{FFM}. **Conclusions**: The use of constant values for fat-free mass properties may increase bias when assessing body composition (FM and FFM) in children with obesity by two-component techniques such as ADP. Using adjusted corrections as proposed in the present work may reduce the bias by half.

INTRODUCTION

Many health and disease conditions are related to body composition status and changes therein, both in adults and children (1). For this reason, important applications of body composition assessment include the diagnosis of disease, monitoring clinical progress and tailoring treatment.

Body mass index (BMI) is widely considered as the accepted clinical standard to classify nutritional status; it is commonly used as the screening tool for overweight and obesity and has been recommended for this purpose by the World Health Organization (WHO) due to it being inexpensive, simple and fast to carry out (2). BMI represents the ratio of body weight to height-squared; however, it cannot distinguish between body weight components, namely the fat-free mass (FFM) and fat mass (FM). In addition, BMI does not have a constant association with body composition across the range of age, sex or ethnicity (3), and this can lead to misclassification of nutritional status.

The gold standard method to assess body composition *in vivo* is the 4-component (4C) model, which divides body weight into fat, protein, mineral and water. To perform this analysis, several individual 2-component techniques are needed: air-displacement plethysmography (ADP) to obtain body volume (BV); dual-energy X-ray absorptiometry (DXA) to obtain bone mineral content (BMC); and isotopic dilution with deuterium (DD) to obtain total body water (TBW). Commonly, to simplify the protocol, these techniques are often used in isolation to assess body composition. However, this practice requires the use of several assumptions such as the assumption of constant FFM properties (density and hydration) (8). These assumptions can introduce a degree of bias in body composition assessment due to different physiological and pathological factors (9), including age (10), sex, ethnicity, hormone cycle, pregnancy, fasting, nutritional status (11–13), kidney or gastrointestinal diseases, etc. In fact, the current methods available have greater error in those with obesity, and this error tends to increase with obesity level (14).

ADP studies in adults have concluded that the individual variation in FFM properties such as hydration and density could influence the accuracy of body composition results (15,16). ADP has been validated to assess body composition in children with relatively high precision (17,18). However, a study comparing ADP with a 3-component model concluded that ADP showed high precision at group level, but indicated that biological individual characteristics such as hydration could increase bias at the individual level (17). The standard approach in densitometric methods such as ADP is to calculate body composition assuming that values for the density of fat mass

(FM) and FFM are constant by age and sex (19). Recently, it has been shown in children that the hydration of FFM increases, and the density of FFM decreases, with the degree of obesity (12). This study reported a predictive equation to estimate the density and hydration of FFM, which could be used when using a 2-component model to assess children and adolescents with different degrees of obesity. Our hypothesis is that calculating the density of the FFM adjusted in this way for BMI as well s age and sex (12), rather than using a constant value by age and sex,, may improve the body composition analyses in subjects with obesity.

The aim of this study was to validate the use of FFM density calculations in body composition assessmentsby air-displacement plethysmography (ADP) against the 4-component model to improve the accuracy and precision of the body composition predictions in children and adolescents with obesity.

MATERIALS and METHODS

Design

This is a cross-sectional validation study, secondary to a clustered randomized clinical trial on a motivational intervention to treat children with obesity. To perform the present validation study, we used the baseline body composition data of the participants enrolled in the OBEMAT2.0 clinical trial (20).

Participants

Data from 66 children with obesity (35 males; 31 females) aged 8 to 14 years were obtained from the clinical trial OBEMAT2.0 at baseline. Children were recruited from June 2016 to March 2018 from primary healthcare centres belonging to the “Camp de Tarragona” healthcare area. Obesity was categorised according to BMI values ≥97th percentile of the Hernández references from 1988 (21) defined by the national Guidelines for Clinical Practice on the Prevention and Treatment of Childhood and Adolescent Obesity (22). At recruitment, patients were excluded from the motivational intervention if they had known eating disorders according to the primary care paediatrician (such as bulimia), were participating in another randomized clinical trial, were receiving corticoid or ADHD treatment, or presented with neuropathies and/or endocrinopathies (Cushing Syndrome, Prader Willi Syndrome, hypothyroidism, etc. previously known by the paediatrician or revealed by blood sample analyses at the baseline visit).

Body composition analyses

Examinations were taken between 8:00 a.m. and 10:00 a.m. after an overnight fast. The physical examination consisted of basic anthropometric measurements: weight (HT), height (HT) and body mass index (BMI); and body composition assessment using: DXA which was performed by a specialist trained technician using a General Electric (GE) Lunar Prodigy Advance (Madison, Wi, USA) with GE, Axial Lunar Prodigy Full Advance (encore 2014 version 15.20.002) software to obtain BMC; ADP with a BOD POD® device (COSMED, Life Measurements, Inc, Concord, CA) to obtain BV, $\text{FM}_{\text{BODPOD}}$ and $\text{FFM}_{\text{BODPOD}}$; and DD analysis where the participants had an oral dose equivalent to 1g/kg body weight of deuterium oxide (D_2O, 99.8 %, CK Isotopes Ltd., Ibstock, Leicestershire, UK). Urine samples collected over the following 5 days were analysed by isotope ratio mass spectrometry (Sercon ABCA-Hydra 20-22, Sercon Ltd, Crewe, Cheshire, UK) to obtain TBW with a precision of 0.94 L. Further, FM and FFM were calculated by the 4C model using the equation of Fuller (1992) (23):

$$\text{FM}_{4C} = (2.747 \text{ x BV}) - (0.710 \text{ x TBW}) + (1.460 \text{ x BMC}) - (2.050 \text{ X WT})$$

where FM = fat mass in kg; BV= body volume (L) from ADP; TBW= total body water volume (L) from deuterium dilution; BMC = bone mineral content (kg) from DXA and WT = body weight (kg). FFM_{4C} was then calculated as the difference of FM from body weight, in kg.

Body composition measures from ADP ($\text{FM}_{\text{BODPOD}}$ and $\text{FFM}_{\text{BODPOD}}$) assuming a constant density of the FFM (D_{FFM})was compared to body composition measures based on predicted density of the FFM ($\text{FM}_{adjusted}$ and $\text{FFM}_{adjusted}$) and both compared to the gold standard reference 4C model (FM_{4c} and FFM_{4c}).

Steps for the calculation of adjusted measures of body composition from Air Displacement Plethysmography

Derived values for the density of fat-free mass (D_{FFM}) were used with an assumed constant density of fat mass to generate age specific constants (C1 and C2), which are needed in the generic Siri equation (24) to calculate the percentage of body fat (%BF) as follows.

1. *Density of the fat-free mass (predicted)*

Density of the FFM ($D_{\text{FFM})}$ was calculated using the following predictive equation (12):

$$D_{FFM} = 1.0791 + (0.009 \text{ x age}) + (0.0021 \text{ x gender}) - (0.0014 \text{ x BMISDS})$$

where age is in years; gender 1 = male and 2 = female; BMISDS = body mass index in z-score.

2. *C1 and C2* were calculated as (25):

$$\mathrm{C1} = \frac{(\mathrm{D_{FFM}\ x\ D_{FM}})}{(\mathrm{D_{FFM}} - \mathrm{D_{FM}})}$$

$$C2 = \frac{(\mathrm{D_{FM}})}{(\mathrm{D_{FFM}} - \mathrm{D_{FM}})}$$

where D_{FM} = 0.9007 kg/L (assumed constant) and D_{FFM} was predicted in the previous step.

3. *Percentage of body fat (%BF) calculated using the generic Siri equation* (24)*:*

$$\%\mathrm{BF} = \left(\frac{\mathrm{C1}}{\mathrm{BD}} - \mathrm{C2}\right) \mathrm{x}\ 100$$

where BD = body density, and was calculated as:

$$\mathrm{BD} = \frac{\mathrm{WT}}{\mathrm{BV}}$$

where BV = body volume in L, obtained from the BOD POD output.

4. *Calculation of* $\mathrm{FM}_{adjusted}$ *and* $\mathrm{FFM}_{adjusted}$:

FM (kg) derived from the density of FFM and ADP body volume measurements ($\mathrm{FM}_{adjusted}$) was further calculated as:

$$FM_{adjusted} = \frac{\%\mathrm{BF\ x\ WT}}{100}$$

where WT = body weight in kg.

Then, $\mathrm{FFM}_{adjusted}$ was calculated as the difference of $\mathrm{FM}_{adjusted}$ from body weight, in kg.

Statistical analysis

All statistical analyses were performed using IBM SPSS Statistics for Windows (version 25.0; IBM Corp., Armonk, NY, USA). Descriptive characteristics for the overall sample (weight, height, BMI, BMI SDS, body volume, total body water, FFM density and FM and FFM from the different methods used) are shown as Mean ± Standard Deviation (SD). The Kolmogorov-Smirnov test for normality was applied to assess the distribution of the variables. Differences between boys and girls in anthropometric and body composition parameters were explored using Student's T-test or Mann Whitney U-Test, depending on the distribution. The degree of difference between techniques was given as mean percentage with limits of agreement calculated as ±2 standard deviations of the bias. We assessed the linear association between FFM and FM measurements from BodPod output (FM_{BODPOD} and FFM_{BODPOD}) and calculations derived from the predicted density of FFM ($FM_{adjusted}$ *and* $FFM_{adjusted}$), with the reference method (4C) by Pearson correlation coefficients. Reliability was obtained from Cronbach's α analysis. Concordance was given as the intraclass correlation coefficient (ICC) with a confidence interval (CI) of 95%. Bland and Altman plots were performed to assess agreement between methods and bias trends, and the limits of agreement for FM and FFM against the reference method (4C) were calculated.

Ethics

The study followed the rules of the Declaration of Helsinki (26). Ethical committees of all involved study centres (CEIC Hospital Universitari de Tarragona Joan XXIII, CEIC Hospital Universitari Sant Joan de Reus (29th January 2016, code 16-01-28/1ass2), CEIC IDIAP Jordi Gol (26th November 2015, code PI14/116)) approved the protocol. All parents or legal guardians signed informed consent prior to study enrolment. Children aged 12 years or above also gave written informed assent.

RESULTS

Physical characteristics of the participants are shown in **Table 1**. Children were of white European ancestry, with an average age of 10.7 ± 1.5 y (8 to 13.3 years) and BMI SDS ranging from 1.86 to 3.08 SDS. We only found statistically significant differences between males and females in BMI SDS ($p = 0.038$) and D_{FFM} ($p<0.001$).

Differences between $FFM_{adjusted}$ and FFM_{BODPOD} were analysed compared to the reference method (FFM_{4C}) (**Figure 1**). $FFM_{adjusted}$ was slightly overestimated by 0.71 kg (limits of agreement -1.08 kg, 2.51 kg) showing a mean difference of 2.8% ± 2.1% $p<0.001$). FFM_{BODPOD} was overestimated by 1.50kg (limits of agreement -0.68kg, 3.63kg), showing a two-fold percentage of difference when compared to 4C (4.9% ± 2.9%; $p<0.001$) than $FFM_{adjusted}$.

Consistently, FM was underestimated by both methods, $FM_{adjusted}$ by -0.71kg (limits of agreement 1.1kg, -2.5kg) and FM_{BODPOD} -1.4kg (limits of agreement 0.9kg, -3.6kg) representing a mean difference of 4.0% ± 2.9% and 6.8% ± 3.8%, respectively, when compared to the reference method (FM_{4C}) (**Figure 1**) (**Table 2**). This meant that the degree of bias from the method following adjustment for density of FFM ($FM_{adjusted}$) was two-fold lower than the FM_{BODPOD} (consistently with FFM measures).

Table 3 displays the correlations and reliability coefficients of both techniques, showing that when body composition measurements were adjusted for FFM density, the concordance and reliability of the assessment were improved as compared to the gold standard method.

DISCUSSION

The aim of the present study was to assess the accuracy of body composition assessment in patients with obesity using ADP, following a correction for FFM density compared to not following the correction. To assess the accuracy of both methods, we used the gold standard method to assess body composition *in vivo*, the 4-component model. To our knowledge, this is the first study to include individual calculations for the density of fat-free mass when assessing body composition using ADP, and to then compare the results with the 4-component model in children with obesity.

Children with obesity may have a significantly lower density of FFM than normal weight children (12), however, the BOD POD internal algorithms assume constant values of FFM density by age and sex. Our study has demonstrated that this assumption may increase the degree of bias when assessing body composition in children with obesity.

Previously published data has suggested that assumptions of the properties of FFM could be the cause of bias in the evaluation of FM by ADP (15,17). However, there are few studies which have used a multi-compartment model to compare ADP measurements, and furthermore, most of the previous studies were conducted in adults.

In a study of 42 healthy British females, Fields *et al.* (15) reported that, compared to the 4C model, body fat percentage measured using BOD POD calculations was underestimated, although both techniques were well correlated. They also investigated the relative hydration of FFM as a possible explanation for such differences and found that indeed the hydration of FFM was associated with the magnitude of the difference between the techniques.

In agreement with Fields *et al.*, Millard-Stafford *et al.* (16) conducted a similar study in 50 young, healthy adults of varying ethnicity (males n= 40: Caucasians n = 35; African-Americans n = 15) and found that %FM obtained from BOD POD was underestimated when compared to the 4C model and other methods such as under water weighing (UW) or DXA. They concluded that FFM density and its fractional components (i.e. minerals, water and protein), were important considerations when determining FM and FFM. These findings are consistent with the findings of our present study in children.

To our knowledge, the only existing study comparing BodPod ADP and other techniques with the 4C model was conducted by Fields and Goran (27) with 25 healthy British children. They did not find significant bias between ADP and 4C, but no BMI data was included in their analysis. Furthermore, the sample was homogenous in age (11.4 ± 1.4y) and anthropometric characteristics.

Wells *et al.* (17) evaluated 28 British healthy children aged 5 to 7 years using ADP and compared it to the 3C model. They found high accuracy of ADP when compared to the 3C model for body composition measurements in groups but highlighted the need to improve bias in individuals. They concluded that the bias between methods could be due to methodological precision or biological variability in hydration. In addition, according to an earlier finding, Wells *et al.* (8) reported that the calculated density of FFM was slightly increased for both sexes, but significantly so only for girls, when compared to Lohman's 1989 reference data. Thus, they showed significant bias in %FM compared to the 3C model when using predicted values for the density of FFM. This implies that BOD POD calculations should be adjusted by specific FFM properties to increase its accuracy. A recent publication from a large dataset compiled from several UK studies confirmed that FFM hydration and density varied according to age and BMI (12). In the present study we have shown how to apply this recent knowledge to increase the accuracy of more simple techniques to assess body composition in children with obesity.

The results of our work are consistent with those previously presented by Wells *et al* (8). FM and FFM assessment had a narrower agreement with 4C model measurements when calculations were adjusted by specific FFM density than BOD POD outputs, which did not consider the nutritional status of the subjects and assumed a constant density of FFM. Thus, this study demonstrates and validates the use of corrections of FFM for density when using BOD POD. As the 4-component model is not usually feasible in clinical settings nor in big epidemiology studies, ADP correcting for FFM properties might be one of the best 2-component models in children, especially in children with obesity. The translation of the present results to a clinical setting could be easily done by simple calculations as shown in steps 1 to 4 in the methods section. First, calculating the predicted density of D_{FFM} according to BMI z scores; second, using the predicted D_{FFM} values in the C1 and C2 equations (rather than using constant values) and third, using those C1 and C2 values in the customized version of Siri's equation, together with body density (derived from body volume provided by the ADP device), to estimate body fat percentage. To facilitate calculations, we provide an excel file with all the steps as supplementary online material.

In addition, using these adjustments would lalso improve the longitudinal assessment of patients with obesity; if the degree of error for the Bod Pod outputs ranged 4.1 to 7.5% for FM and FFM, these biases could be greater than real changes between visits in a follow up. If this bias could be minimized to 2.3 to 4.7% by applying the proposed corrections, this would improve the sensibility of the method to changes in energy balance and improve clinical assessment.

The small sample size is a possible limitation of the present study; however, it remains one of the biggest sample sizes published for this type of analysis in children.

The main strength of the present study is the high quality of the methodology used: we used a highly precise technique to assess body composition, and compared it to the gold standard 4-component model in order to reduce the bias of ADP in children with obesity. In addition, the conditions of the measurements were highly controlled as all the measurements being performed at the same time between 8 and 10:00 a.m. after an overnight fast.

In conclusion, the use of constant values for fat-free mass properties may increase bias when assessing body composition in children with obesity using two-component based techniques like air-displacement plethysmography. Using corrections for the density of fat-free mass (as proposed with the 4 steps in the methodology section) reduces the bias in fat mass and fat-free mass measurements derived from ADP in children with obesity. This approach should be considered not only in children with obesity. Further studies should demonstrate whether this approach would improve assessments in the general population and in longitudinal studies where small changes between repeated measures should be quantified with reduced bias.

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Obemat2.0 Study Group: Closa-Monasterolo R, Feliu-Rovira A, Escribano J, Ferré N, Luque V, Zaragoza-Jordana M, Gispert-Llauradó M, Rubio-Torrents MC, Gutiérrez-Marín D, Muñoz-Hernando J, Núñez-Roig M, Alcázar M, Sentís S, Esteve M (Pediatric Nutrition and Human Development Research Unit, Universitat

Rovira i Virgili, IISPV, Reus). Monné-Gelonch R, Basora JM, Flores G, Hsu P, Rey-Reñones C, Alegret C (IDIAP Jordi Gol i Gurina, USR Reus); Guillen N, Alegret-Basora C, Ferre R (Hospital Universitari Sant Joan de Reus); Arasa F (Hospital Verge de la Cinta de Tortosa, Institut Català de la Salut); Alejos AM, Diéguez M, Serrano MA, Mallafré M, González-Hidalgo R, Braviz L, Resa A, Palacios M, Sabaté A, Simón L (Hospital Lleuger de Cambrils, Sagessa); Losilla AC, De La Torre S, Rosell L, Adell N, Pérez C, Tudela-Valls C, Caro-Garduño R, Salvadó O, Pedraza A, Conchillo J, Morillo S (CAP Llibretat, Reus, Institut Català de la Salut); Garcia S, Mur EM, Paixà S, Tolós S, Martín R, Aguado FJ, Cabedo JL, Quezada LG (CAP Marià Fortuny, Reus, Sagessa); Domingo M, Ortega M, Garcia RM, Romero O, Pérez M, Fernández M, Villalobos ME (CAP Salou, Institut Català de la Salut); Ricomà G, Capell E, Bosch M, Donado A, Sanchis FJ, Boix A, Goñi X, Castilla E, Pinedo MM, Supersaxco L, Ferré M, Contreras J (CAP Rambla Nova, Institut Català de la Salut, Tarragona); Sanz-Manrique N, Lara A, Rodríguez M, Pineda T, Segura S, Vidal S, Salvat M (CAP Les Borges del Camp-Montroig del Camp, Institut Català de la Salut); Mimbrero G, Albareda A, Guardia J, Gil S, Lopez M (CAP Sant Pere, Reus, Institut Català de la Salut); Ruiz-Escusol S, Gallardo S (CAP Bonavista-La Canonja, Tarragona, Institut Català de la Salut); Machado P, Bocanegra R (CAP Torreforta-La Granja, Tarragona, Institut Català de la Salut); Espejo T, Vendrell M (ABS Vandellòs-L'Hospitalet de l'Infant, Sagessa); Solé C, Urbano R, Vázquez MT, Fernández-Antuña L (CAP Muralles, Tarragona); Barrio M, Baudoin A, González N (CAP El Morell, Institut Català de la Salut); Olivé R, Lara RM, Dinu C, Vidal C (CAP Sant Pere i Sant Pau, Tarragona, Institut Català de la Salut); González S, Ruiz-Morcillo E, Ainsa ME, Vilalta P, Aranda B (CAP Sant Salvador, Tarragona, Institut Català de la Salut); Boada A, Balcells E (ABS Alt Camp Est, Vilarodona, Institut Català de la Salut);

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TABLES

Table 1. Descriptive characteristics of the participants.

	Male (n = 35)		**Female (n = 31)**	
	Mean ±SD	Range	Mean ±SD	Range
Age (y)	10.6 ± 1.6	8.0 - 13.3	10.7 ± 1.4	8.3 - 13.3
Weight (kg)	55.1 ± 11.2	37.8 - 83.1	57.5 ± 11.4	37 - 81.8
Height (cm)	146.4 ± 10.0	131.6 - 167.0	147.2 ± 10.7	125.5 - 170.3
BMI (kg/m^2)	25.6 ± 2.60	21.7 - 32.5	26.2 ± 2.4	21.9 - 30.6
BMI SDS (WHO 2007)[†]	2.72 ± 0.45	1.86 - 4.20	2.52 ± 0.31	1.89 - 3.08
Body Volume (BodPod - L)	54.8 ± 11.3	37.5 - 83.7	57.4 ± 11.2	36.1 - 81.1
Density FFM predicted (kg/L)[‡]	1.087 ± 0.002	1.083 - 1.091	1.089 ± 0.001	1.087 - 1.092
$FM_{D\&BV}$ (kg)	21.6 ± 5.9	13.0 - 38.2	23.8 ± 5.2	11.- -32.1
$FFM_{D\&BV}$ (kg)	33.5 ± 6.1	23.7 - 46.2	33.7 ± 7.8	20.2 - 53.7
FM_{BODPOD} (kg)	21.3 ± 6.0	12.7 - 38.4	22.7 ± 5.0	11.4 – 30.4
FFM_{BODPOD} (kg)	34.0 ± 5.9	24.1 - 46.2	34.8 ± 7.5	21.2 – 51.9
FM_{4C} (kg)	22.1 ± 6.0	12.5 - 38.7	24.7 ± 5.3	11.6 - 33.8
FFM_{4C} (kg)	33.0 ± 6.1	23.5 - 45.6	32.8 ± 7.4	20.3 - 50.6
Total Body Water (DD-kg)	25.0 ± 4.6	17.9 - 34.9	24.3 ± 5.3	15.7 - 36.5

Significance: [†]p = 0.038; [‡]p < 0.001.

Abbreviations: BMI = body mass index; SDS = standard deviation score; FM = fat mass; FFM = fat free mass; D&BV = measurements derived from the density of FFM calculated with the new equation and body volume; 4C = four-component model; DD = deuterium dilution.

Table 2. Analyses of differences (%) between body composition outcomes extracted from the BodPod (adjusted using calculated values for the density of fat free mass) versus the reference 4-component model (n=66).

	MEAN DIFFERENCE (max, min 95% CI; p-value)	**SD**
$\mathrm{FFM}_{adjusted}$	2.80% (2.29-3.30; p<0.001)	±2.06%
$\mathrm{FM}_{adjusted}$	3.97% (3.25-4.69; p<0.001)	±2.92%
$\mathrm{FFM}_{\mathrm{BODPOD}}$	4.87% (4.15-5.59; p<0.001)	±2.92%
$\mathrm{FM}_{\mathrm{BODPOD}}$	6.77% (5.60-7.45; p<0.001)	±3.77%

Table 3. Correlations and reliability of fat-free mass measurements against the 4-component model (n=66).

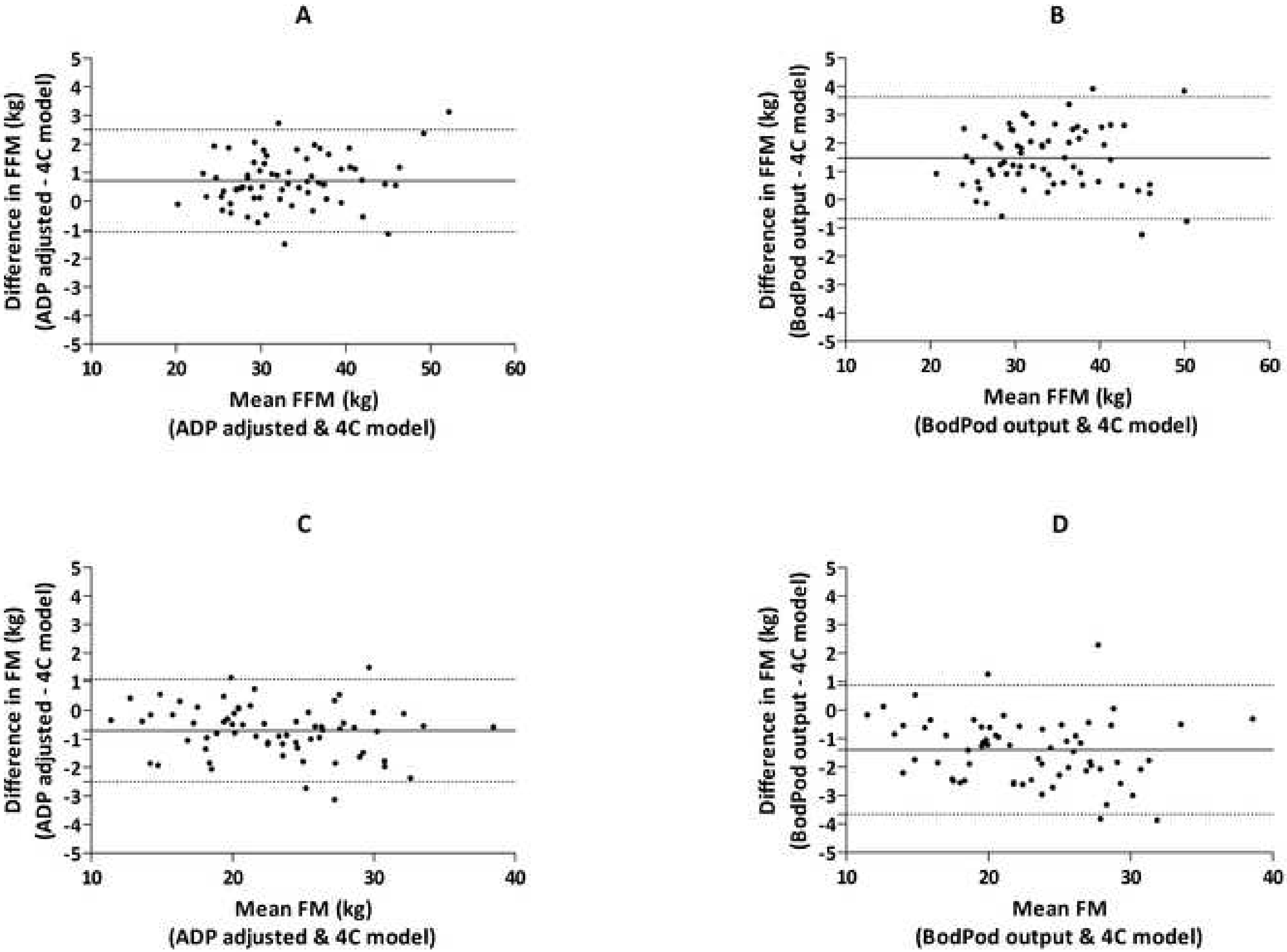
	Correlation coefficient (p-value)	**Cronbach's alfa**	**ICC (CI 95%; p-value)**
$\mathrm{FFM}_{adjusted}$	0.992 (p<0.001)	0.996	0.993 (IC 95% 0.967-0.997; p<0.001)
$\mathrm{FFM}_{\mathrm{BODPOD}}$	0.987 (p<0.001)	0.993	0.981 (IC 95% 0.640-0.995; p<0.001)

Figures

Figure 1. Agreement between methods. Bland and Altman plots of the difference between fat-free mass (FFM) and fat mass (FM) (kg) as obtained from the BodPod assuming constant values of the FFM (FFM$_{BODPOD}$ and FM$_{BODPOD}$) (B and D) or obtained from body volume from air displacement plethysmography and further corrections using adjusted density of the fat free mass) (A and C), all compared to the reference method, 4C model (four component model).

Bland and Altman plots show that body composition measures derived from air displacement plethysmography adjusted using the calculated density of the fat free mass have narrower limits of agreement than when assuming a constant density of the fat free mass.

Figure


A
Difference in FFM (kg)
(ADP adjusted - 4C model)
5
4
3
2
1
0
-1
-2
-3
-4
-5
10
20
30
40
50
60
Mean FFM (kg)
(ADP adjusted & 4C model)
B
Difference in FFM (kg)
(BodPod output - 4C model)
Mean FFM (kg)
(BodPod output & 4C model)
C
Difference in FM (kg)
(ADP adjusted - 4C model)
Mean FM (kg)
(ADP adjusted & 4C model)
D
Difference in FM (kg)
(BodPod output - 4C model)
Mean FM
(BodPod output & 4C model)

Body Composition Analysis
Adjusted fat free mass properties
in Air Displacement Plethysmography

Step 0 Complete the subjects characteristics

Age (years), decimal points can be used		*years*
Body weight		*kg*
Height		*m*
Add the BMI z score of the subject		*sds*
Gender (1 if a boy, 2 if a girl)		
Body volume (L) from BodPod		*L*

Automatic calculations from that point onwards, please do not modify cells.

Step 1 Density of the fat-free mass (predicted)

Density of the fat-free mass (predicted)	1.0791	*kg/L*

Step 2 C1 and C2 calculation

C1	5.4481
C2	5.0488

Step 3 Body Fat (%)

Body density	#DIV/0!
Body Fat (%)	#DIV/0!

Step 4 Adjusted Fat Mass and Fat Free Mass (kg)

Fat Mass (kg)	#DIV/0!	*kg*
Fat Free Mass (kg)	#DIV/0!	*kg*
Fat Mass Index (kg/m^2)	#DIV/0!	*kg/m^2*
Fat Free Mass Index (kg/m2)	#DIV/0!	*kg/m^2*

Reference: Gutiérrez-Marín D, Escribano J, Closa-Monasterolo R, Ferré N, Venables M, Singh P, Well JCK, Muñoz-Hernando J, Zaragoza-Jordana M, Gispert-Llauradó M, Rubio-Torrents C, Alcázar M, Núñez-Roig M, Monné-Gelonch R, Feliu A, Basora JM, Alejos AM, Luque V. A novel approach to assess body composition in children with obesity from density of the fat-free mass. Clin Nutr 2020.