

1 **Title page**

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3 Evaluation of bioelectrical impedance analysis in measuring body fat in 6-to-12-year-old boys
4 compared to air displacement plethysmography

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6 **Authors**

7 Ryan Mahaffey^{*1}

8 Nicola Brown¹

9 Mary Cramp²

10 Stewart C. Morrison³

11 Wendy I Drechsler⁴

12
13 * Corresponding author

14 Email: ryan.mahaffey@stmarys.ac.uk

15 Tel: +44 (0)7708258741

16 St Mary's University, Waldegrave Road, Twickenham, TW1 4SX

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18 ¹School of Sport, Health and Applied Sciences, St Mary's University, Twickenham, UK

19 ²Department of Allied Health Professions, University of the West of England Bristol, UK

20 ³School of Life Course and Population Sciences, King's College London, UK

21 ⁴Haemophilia Centre, East Kent Hospitals University NHS Trust, UK.

22
23 **Abbreviations**

24 Percentage fat mass (%FM), dual-energy x-ray absorptiometry (DXA), three-compartment model
25 (3C), four-compartment model (4C), air displacement plethysmography (ADP), limits of agreement
26 (LoA), bioelectrical impedance analysis (BIA), percentage fat mass measured by air displacement
27 plethysmography (%FM_{ADP}), percentage fat mass measured by bioelectrical impedance analysis
28 (%FM_{BIA}), intraclass correlation coefficients (ICCs), Technical error of the measurement (TEM), body
29 volumes (V_b), thoracic gas volumes (TGV), skin surface area (SSA), Effect size (ES), 95% confidence
30 intervals (95%CI).

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32 **Running Title**

33 Body fat by BIA v ADP in 6-12 year olds

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35 **Keywords**

36 Body composition, obesity, pediatric, concurrent validity, reliability

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56 **Evaluation of bioelectrical impedance analysis in measuring body fat in 6-to-12-year-old boys**
57 **compared to air displacement plethysmography**

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60 **Introduction**

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62 Childhood obesity is associated with significant morbidity and mortality.^{1,2} Comorbidities associated
63 with childhood obesity affect almost every body system, including, but not limited to, endocrine,
64 cardiovascular, cardiometabolic, and musculoskeletal systems.³ Worldwide prevalence of childhood
65 overweight and obesity increased from 12.8% in 2000 to 14.2% in 2013 and is expected to reach
66 15.8% in 2025.⁴ Growth trajectories for childhood obesity into adulthood indicate that 57.3% of
67 today's children and 75% of children currently with obesity will be obese at the age of 35.⁵
68 Monitoring and tracking of obesity in childhood appears critical to determine when preventative or
69 management interventions should be taken.

70

71 Obesity is defined as excess fat accumulation that may impair health.⁶ However, obesity is
72 commonly measured by Body Mass Index (BMI) which, in children, is transformed into BMI z-scores
73 to define age- and gender-specific cut-offs for overweight and obesity.⁷ Body Mass Index is useful for
74 tracking changes in obesity prevalence in populations, however, the relationship between BMI and
75 adiposity is not consistent across populations and assumes a linear increase in body mass and fat
76 mass through childhood.^{8,9} Measures of adiposity (i.e. fat mass relative to body mass [%FM]), rather
77 than weight relative to height, provide accurate assessment of obesity status and may provide
78 better indication of the effectiveness of weight loss programmes.^{10,11}

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80 Reference methods of measuring adiposity include computerised tomography, magnetic resonance
81 imaging, dual-energy x-ray absorptiometry (DXA), isotope dilution, and combinations of methods to
82 construct three (3C) and four (4C) compartment models. Reference methods are accurate
83 assessments of %FM (compared to 'gold-standard' cadaver analysis),¹² because measurements of
84 hydration status and mineral content are included in the %FM calculation.⁹ However, in comparison
85 to two compartment (2C) models of body composition, that partition the body into fat mass and fat-
86 free mass (e.g. air displacement plethysmography and bioelectrical impedance analysis), reference
87 methods are costly, time consuming, invasive, and may not be suitable for children.¹³ Although 2C
88 models of body composition are subject to error arising from variation in fat-free mass composition,⁹
89 they are more accessible to clinicians and researchers and less burdensome on participants.

90

91 Air displacement plethysmography (ADP) is an indirect method to determine body volume, using a
92 volumetric chamber into which a participant is introduced, by recording pressure changes under
93 isothermal and adiabatic conditions.¹⁴ Equations that include assumed densities of fat and lean
94 tissues are used to calculate %FM. Bioelectrical impedance analysis (BIA) is an indirect measure of
95 total body water from which an empirical relationship with fat-free mass can be derived using
96 subject-specific regression equations. Previous studies generally indicate that measures of %FM by
97 ADP (%FM_{ADP})^{11,15, 16}, rather than BIA (%FM_{BIA})^{9,17}, have better agreement with reference measures in
98 paediatric populations. However, age, gender, BMI, and BIA device all impact the estimation of
99 %FM, and should therefore be considered in %FM prediction equations.^{11,18}

100

101 Few studies have compared measures of %FM derived from ADP and BIA in paediatric populations,¹⁹
102 generally finding that %FM_{ADP} was greater than %FM_{BIA}^{20,21}. Whilst these studies benefit from large
103 sample sizes, comparisons between methods were not distinguished based on weight status which
104 can impact estimates of body composition.²² One study which did compare %FM_{ADP} and %FM_{BIA} in
105 both participants with and without obesity²³, measured %FM_{BIA} using a foot-to-foot device
106 (measuring only part of the body) and %FM_{ADP} using general,²⁴ rather than child-specific regression
107 equations.^{11,25} Comparisons between %FM methods should be made using age-specific equations,
108 controlling for gender and weight status.^{16,26,27}

109

110 Reliability of %FM measurements in children have been conducted, showing intraclass correlation
111 coefficients (ICCs) of >0.90 from BIA,¹² and >0.93 from air displacement plethysmography.²⁸ Vicente-
112 Rodriguez et al²⁹ reported intra-day reliability of %FM_{ADP} and %FM_{BIA} in 84 adolescents (13-to-17-
113 years-old). Technical error of the measurement (TEM) was 1.07% and 0.74% for ADP and BIA
114 respectively, with correlation coefficients of 0.989 and 0.993 for ADP and BIA respectively. However,
115 there is a paucity of research that has assessed the reliability of ADP and BIA methods in one cohort,
116 with no studies investigating this in a cohort of children < 12 years.

117

118 A recent systematic review suggests that ADP has similar validity to DXA and isotopic dilution
119 methods to assess %FM in children with obesity.³⁰ ADP has been considered as a 'standard' method
120 of body composition assessment²³ to which BIA methods can be compared for validity and
121 reliability.^{20,21} Measures of body fat by ADP offers greater agreement with reference measures, but
122 BIA offers faster, more convenient and inexpensive field-based measures of body fat. Therefore, the
123 aim of this study was to measure concurrent validity and reliability of %FM_{ADP} and %FM_{BIA} in 6-to-12-
124 year-old children with and without obesity. We hypothesise that %FM_{BIA} will be underestimated
125 compared to %FM_{ADP}, and that in boys with obesity, %FM_{BIA} will be underestimated to a greater
126 extent compared to boys without obesity. Compared to studies that have not used age-specific
127 equations for body composition, we expect to find less difference between %FM_{ADP} and %FM_{BIA}.
128 Finally, we hypothesise that both %FM_{ADP} and %FM_{BIA} methods will be reliable, in keeping with
129 literature involving older children. The findings will help practitioners determine whether %FM_{ADP}
130 and %FM_{BIA} can be used interchangeably and reliably in children.

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132

133 **Method**

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135 *Participants*

136 Seventy-one boys underwent assessment of body composition by BIA and ADP (age: 10.1 ± 1.70
137 years, height: 1.43 ± 0.11 m, mass: 39.4 ± 11.2 kg). Ten boys took part in the intra-day reliability
138 analysis of BIA and ADP (age: 10.0 ± 2.63 years, height 1.39 ± 0.17 m, mass 33.8 ± 10.8 kg). This
139 study was conducted according to the guidelines laid down in the Declaration of Helsinki and all
140 procedures involving human subjects/patients were approved by the host institution (Ref No.
141 ETH/13/11). Written and verbal informed consent were obtained from parents and children (verbal
142 consent was witnessed and formally recorded). Parents completed a health medical questionnaire
143 prior to data collection; all participants were reportedly healthy at the time of the study. Obesity
144 was defined as an %FM >25%.²³

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Procedure

Participants were tested in pairs and a randomised, cross over design was used whereby pairs were randomly assigned to be tested by either ADP or BIA, after which they completed the other test procedure immediately after the first. Each participant wore tight fitting swimming shorts with no shoes or socks throughout both testing procedures. Participants were instructed not to eat, drink, or exercise two hours before the measurement and to void their bladder 30 minutes before testing. Estimates of %FM from ADP (%FM_{ADP}) and BIA (%FM_{BIA}) were measured within the same day by the lead author. For assessment of reliability, %FM_{ADP}, %FM_{BIA}, body volume, and resistance measurements were repeated within 10 minutes of the first test in order to avoid biological variation in hydration and temperature.

ADP

Air displacement plethysmography (ADP) was measured using the Bodpod device following manufacturer's protocols.¹⁴ Each participant wore a swim cap to cover and compress head hair. The Bodpod weighing scale was calibrated before each testing session with known 20kg weights; all calibrations were within ± 0.01 kg. The chamber was calibrated against a known volume cylinder (50.024l) before each testing session. Five repeated measures of cylinder volume were made during the calibration procedure. The average estimated volume was 50.047 ± 0.007 l, within the accuracy and variability range of repeated measures previously reported for volumetric measures by the Bodpod.¹⁴

The ADP procedure involved three successive measurements of raw body volume, the total procedure time was less than one minute. If body volume differed by more than 0.015L between the measures the procedure was repeated. The mean of the three raw body volumes (V_b) was corrected for isothermal conditions of air in the lungs and around the skin surface. Raw V_b was corrected for thoracic gas volumes (TGV) (and skin surface area [SSA]) using child specific equations detailed in Table 1. Body density was calculated by dividing the corrected body volume by body mass and converted to %FM using gender- and age specific equations published by Lohman²⁵ (Table 1).

Table 1.

BIA

A multi-frequency BIA device (Quantum II, RJL systems, Inc. Clinton Township, Michigan, USA) was used to measure body impedance in the participants. The BIA device was calibrated before each testing session using known resistance and reactance. The device recorded mean resistance figures of $384 \pm 0.34\Omega$ and reactance of $44.9 \pm 1.22\Omega$ which were within the manufacturer's guidelines.

The participants were instructed to lay supine on a portable couch for five minutes prior to testing as per the manufacturer's instructions to allow extracellular water to level out across the body.

189 Electrodes were placed on the ipsilateral bony prominences of the wrist and ankle (metacarpal and
190 metatarsal lines) ensuring the electrodes were 5 cm apart.

191

192 Reactance (X) and resistance (R) were outputted for each participant for calculation of %FM based
193 on gender- and age-specific equations. The equation of Horlick et al³³ was chosen to estimate FFM
194 (Table 1) based on regression analysis of impedance measures from the same manufacturer (RJL)
195 used in the current study and has shown to be valid in paediatric populations.¹⁹ FFM was then
196 converted to %FM (Table 1).

197

198 *Statistical analysis*

199

200 *Concurrent validity*

201 With obesity and without obesity group differences for age, height, body mass, raw body volume
202 (m^3), resistance (Ω), %FM_{ADP}, and %FM_{BIA} were assessed by independent t tests. Comparisons
203 between %FM_{ADP}, and %FM_{BIA} were made for the full sample, and within the with obesity and
204 without obesity groups. Differences between %FM_{ADP} and %FM_{BIA} were assessed by paired samples t
205 tests. Effect sizes (ES) were calculated based on Cohen's d and defined as <0.2 weak, 0.2 to 0.49
206 small, 0.5 to 0.79 medium, and >0.79 large.³⁴ Pearson correlation coefficients were performed to
207 measure the strength of association between %FM_{ADP} and %FM_{BIA}, with 95% confidence intervals
208 (95%CI). Correlation coefficients <0.29 were defined as weak, between 0.3 and 0.49 moderate, and
209 >0.5 strong.³⁴ Agreement between %FM_{ADP} and %FM_{BIA} were analysed using Bland-Altman analysis.³⁵
210 This involved the calculation of the mean difference between two methods together with LoA, based
211 on 95% confidence intervals (95%CI), calculated from the SD of the mean difference for each
212 participant (multiplied by 1.96). Proportional bias, error affected by the magnitude of measurement,
213 were determined by Pearson's correlation coefficient $r > 0.5$.³⁶ Predicting %FM_{ADP} is considered the
214 'standard' method for this study, to which %FM_{BIA} was compared. To address clinical acceptability, a
215 minimal acceptable standard for estimating %FM of $\pm 3.5\%$ (group-level difference) from the
216 reference measure was employed.³⁷ The sample size of 71 was calculated based on the minimal
217 acceptable standard,³⁷ standard error of measurement for BIA,¹² with 80% power and two-sided
218 significance of 0.05.

219

220 *Reliability*

221 For comparison with previous literature on the reliability of %FM measures, three reliability statistics
222 were calculated; technical error of the measurement (TEM and TEM%), coefficient of reliability (r_{xx}),
223 and ICC as detailed in Table 2.

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225 Table 2.

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229 **Results**

230

231 Table 3 presents data for all participants, and for the with obesity and without obesity groups. No
232 significant differences were found between groups for age ($t_{(69)} = 1.85$, $p = 0.069$), height ($t_{(69)} = 1.09$,

233 p = 0.212), and resistance ($t_{(69)} = 0.32$, $p = 0.748$). The with obesity group were significantly heavier
234 ($t_{(69)} = 2.36$, $p = 0.021$), had a higher BMI ($t_{(69)} = 4.97$, $p < 0.001$), greater raw body volume ($t_{(69)} = 0.75$,
235 $p = 0.004$), and a higher %FM_{ADP} ($t_{(69)} = 14.15$, $p < 0.001$), and %FM_{BIA} ($t_{(69)} = 8.80$, $p < 0.001$).

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238 Table 3.

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241 Concurrent validity

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243 Table 4 presents the mean difference and LoA of %FM_{ADP} and %FM_{BIA} for all participants, the with
244 obesity group, and the without obesity group. Compared to %FM_{BIA}, %FM_{ADP} was significantly higher
245 in all participants ($t_{(70)} = 5.11$, $p < 0.001$, $ES = 0.42$) and in the without obesity group ($t_{(45)} = 2.98$, $p =$
246 0.005 , $ES = 0.52$; Table 3); although mean differences observed were clinically acceptable ($< 3.5\%$), LoA
247 were 22.3% and 21.8% in all participants and those without obesity, respectively. In the with
248 obesity group, %FM_{ADP} was significantly higher compared to %FM_{BIA} ($t_{(24)} = 4.76$, $p < 0.001$, $ES = 0.90$;
249 Table 3), with the mean difference ($-5.20 \pm 5.46\%$) exceeding the clinically acceptable threshold of
250 3.5%, and LoA of 21.8%. A strong, significant positive correlation was found between %FM_{ADP} and
251 %FM_{BIA} when examining all participants ($r = 0.80$, $p < 0.001$, 95%CI 0.64 to 0.95). and participants
252 with obesity ($r = 0.60$, $p = 0.001$, 95%CI 0.11 to 1). In the without obesity group, a moderate,
253 significant positive correlation was found ($r = 0.44$, $p = 0.003$, 95%CI 0.26 to 1). Figure 1 presents
254 Bland-Altman plots of %FM_{ADP} and %FM_{BIA} for all participants, those with obesity, and those without
255 obesity. No proportional bias was detected ($r = 0.001$) meaning agreement between measures was
256 not affected by the magnitude of %FM.

257

258 Table 4.

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261 Figure 1.

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264 Reliability

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266 Reliability analysis revealed that ADP resulted in lower error of %FM measures compared to BIA,
267 with TEMs of 0.55% and 0.65%, respectively. Coefficient of reliability and ICCs were also higher in
268 %FM_{ADP} measures (0.92 and 0.95, for r_{xx} and ICC respectively) compared to %FM_{BIA} measures (0.89
269 and 0.93; Table 5).

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271 Table 5.

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276 **Discussion**

277

278 The aim of this study was to compare validity of %FM_{BIA} to the 'standard' %FM_{ADP} and assess intra-
279 day reliability of both methods in the same cohort. Compared to ADP, BIA underestimated %FM in
280 the study population, but there was no bias in differences between methods relating to obesity
281 status (i.e. magnitude of %FM). Despite the significant correlation, there was a significant difference
282 and large limits of agreement between measures of %FM_{BIA} and %FM_{ADP}. The reliability findings
283 reported in this study reveal that %FM_{ADP} is a more reliable measure compared %FM_{BIA}, but both
284 methods were highly reliable in the cohort.

285

286 **Concurrent Validity**

287

288 Underestimation of %FM_{BIA} compared %FM_{ADP} in the current study is in general agreement with
289 previous studies.^{20,21,23,40} Previous studies have shown %FM_{BIA} to be underestimated by 0.5 – 5.6% in
290 children and adolescents compared to %FM_{ADP}; although some %FM_{BIA} prediction equations have
291 resulted in an overestimation.²¹ The mean underestimation of 3.4% found in the present study is
292 within the range previously reported. The differences between %FM_{BIA} and %FM_{ADP} within the with-
293 and without obesity groups also agree with Azcona et al²³ who reported mean underestimation of
294 %FM_{BIA} compared to %FM_{ADP} among the full sample (3.39%), without obese (2.49%) and with obesity
295 groups (5.01%). Despite different BIA devices and %FM equations used between the current study
296 and Azcona et al,²³ the mean differences between %FM_{BIA} and %FM_{ADP} are similar.

297

298 Compared to the clinically acceptable differences reported by Heyward and Wagner,³⁷ %FM
299 differences in the without obesity group were within the $\pm 3.5\%$ clinically acceptable threshold, but
300 in the with obesity group differences would be deemed clinically unacceptable ($> 3.5\%$). Despite no
301 significant bias in differences between devices detected across levels of body fat, it does appear that
302 BIA underestimates %FM to a greater extent. Furthermore, the LoA found in the current study are in
303 general agreement with values of 15.3-20.6% reported in previous studies.^{20,21,23} Whilst no
304 consensus has been reached on what level of LoA is clinically acceptable (a range of 2 to 20% has
305 been reported in the literature),^{30,41,42} the large LoA in the current study indicates that BIA and ADP
306 cannot be used interchangeably to measure an individual's %FM. Assessment of body composition
307 must be accurate on an individual basis to correctly identify overweight and obesity.⁴³

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310 **Reliability**

311

312 The findings from the current study suggest that repeated measurements of %FM from ADP and BIA
313 are highly reliable in young children. These findings are comparable to other studies examining the
314 intra-day reliability of %FM_{ADP} and %FM_{BIA} in older children. Vicente-Rodriguez et al²⁹ measured
315 intra-day reliability in 84 adolescents (13-17 years old), finding %FM_{ADP} TEM of 1.07% FM and $r_{xx} =$
316 0.99, and %FM_{BIA} TEM of 0.74% and $r_{xx} = 0.99$. Resistance and body volume reliability in the current
317 study also compare well with values of Vicente-Rodriguez et al²⁹; resistance TEM of 10.2 Ω and $r_{xx} =$
318 0.99, and body volume TEM of 0.58m³ and $r_{xx} = 0.99$. Comparable reliability in the current younger
319 cohort to adolescents reveals that children were able to adhere to the BIA and ADP procedures and
320 follow instructions.

321

322 The intra-day reliability of body fat mass measures from ADP and BIA are dependent on
323 environmental conditions, instructor competence, and participant adherence to the procedures.
324 Environmental variation includes pressure changes within the laboratory (from opening doors or
325 drafts) during the procedure that can affect ADP reliability and, temperature changes in the ten
326 minutes between repeated measures that can affect BIA reliability. Correct electrode placement on
327 the ipsilateral bony prominences of the wrist and ankle (the metacarpal and metatarsal lines)⁴⁴ can
328 be subjective. Electrode placement variability can alter impedance readings by 4%,⁴⁵ and would
329 have reduced reliability in this study. Variability due to procedural adherence includes movement of
330 the participant in the Bodpod chamber or irregular breathing. These can cause pressure changes
331 within the Bodpod influencing raw body volumes.⁴⁶ For this reason, ADP measures from Bodpod
332 were taken in triplicate and, if the raw body volumes differed by >0.015L, the procedure was started
333 again. In order to maximise intra-day reliability of %FM_{ADP} and %FM_{BIA} measures environmental
334 conditions, protocols and participant preparation should be strictly monitored throughout testing
335 procedures.

336

337 Limitations of the current study comprise the use of predicted lung volumes in ADP measurements
338 which may impact the accuracy of %FM_{ADP}. However, young children struggle with the protocol for
339 lung volume measurement and error in the correction of raw body volume for air in the lungs is
340 relatively small.⁴⁷ Other age- and gender-specific %FM equations are available for ADP that account
341 for changes in hydration status with age and gender.¹¹ However, the Lohman²⁵ equation has been
342 validated against 4C⁴⁸ and, in boys, compares well with more recent equations for %FM_{ADP}.¹¹ The
343 relatively short duration of food and drink abstinence may have affected BIA measurements.
344 However, longer abstinence may be unethical and impractical.⁴⁹ We could not collect pubertal status
345 from our sample and it is acknowledged that pubertal status may have improved the accuracy of
346 both %FM_{ADP} and %FM_{BIA}. Particularly for %FM_{BIA} measurements, puberty/maturation status has an
347 impact on total body water (TBW), but the current study used standardised procedures and age-
348 appropriate equations to limit extraneous variation. Indeed, as reported by Horlick et al³³ when
349 developing the BIA equation used in the current study, including Tanner stage to the regression
350 model for TBW had little effect on the predictive power above measures of age, height, mass and
351 gender.

352

353

354 **Conclusion**

355 The results of the intra-day reliability tests revealed that both %FM_{ADP} and %FM_{BIA} are highly reliable
356 in boys age 6-to-12-years-old. %FM_{BIA} was significantly correlated with %FM_{ADP} in children with and
357 without obesity. However, %FM_{BIA} was significantly underestimated in both groups, but only in the
358 with obesity group was it beyond the minimal acceptable standard of $\pm 3.5\%$. Therefore, BIA may be
359 suitable for determining %FM in boys without obesity age 6-to-12 years-old. Similar to the findings
360 of previous studies that have used different devices (e.g. foot-to-foot BIA), %FM equations
361 (proprietary or adult), sample age (e.g. adolescents), and do not consider obesity status, the large
362 limits of agreement between %FM_{ADP} and %FM_{BIA} in the current study indicate that the devices
363 cannot be used interchangeably in boys age 6-to-12-years-old.

364

365 **Conflicts of Interest statement**

366 The authors declare no conflict of interest in relation to this study.

367

368 **Author Contributions**

369 All authors contributed to conceptualisation, study design, data analysis, data interpretation,
370 presentation of tables and figures, writing of the manuscript and manuscript revisions. Ryan
371 Mahaffey collected data.

372

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524 **Tables**

525

526 Table 1. Equations used in ADP and BIA procedures

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Equations	Reference
Used in ADP procedure	
$TGV = 0.00056Ht^2 - 0.02442Ht + 8.15194$	Fields et al ³¹
$SSA = (0.024265Wt^{0.5378})(Ht^{0.3964})100$	Haycock et al ³²
$\%FM = 100\left[\left(\frac{k_1}{D_b}\right) - k_2\right]$	Lohman ²⁵
Used in BIA procedure	
$FFM = \frac{(3.474 + 0.459 \frac{Ht^2}{R} + 0.064Wt)}{(0.769 - 0.009A - 0.016S)}$	Horlick et al ³³
$\%FM = \frac{Wt - FFM}{Wt} 100$	

528 *TGV*, thoracic gas volume; *Ht*, height in cm (derived by height in m x 100); *SSA*, skin surface area; *Wt*, body mass in kg;
 529 *%FM*, percent fat mass; *k₁* and *k₂*, gender and age specific constants; *D_b*, body density; *FFM*, fat free mass; *R*, resistance; *A*,
 530 age in years; *S*, gender specific constants.

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Table 2. Equations used to assess reliability of data

Equation	Reference
$TEM = \sqrt{\frac{(\sum d^2)}{2n}}$	
$\%TEM = \left(\frac{TEM}{x}\right) 100$	
$r_{xx} = 1 - \left(\frac{TEM^2}{SD^2}\right)$	Ulijaszek & Kerr ³⁸
$ICC(3, k) = \frac{BMS - EMS}{BMS}$	Shrout & Fleiss ³⁹

547 TEM, technical error of measurement; *d*, difference between measurements; *n*, number of individuals measured; *x*, mean
548 percentage fat mass (%FM); *r_{xx}*, reliability coefficient; *SD*, standard deviation; *ICC*, intraclass correlation coefficient; *k*,
549 number of measurements; *BMS*, between subject variance; *EMS*, error (residual) mean square variance.
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569 Table 3. Age and anthropometric variables according to weight status

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	All participants (n = 71)		Without obesity (n = 46)		With obesity (n = 25)	
	Mean	SD	Mean	SD	Mean	SD
Age (years)	10.1	1.70	10.3	1.94	9.56	0.96
Mass (kg)	39.4	11.2	37.1	11.0	43.5	10.6*
Height (m)	1.43	0.11	1.42	0.12	1.43	0.07
Body mass index (kg/m ²)	18.7	3.70	17.3	2.76	21.2	3.83*
Raw body volume (m ³)	36.6	10.9	34.0	10.2	41.5	10.7*
Resistance (Ω)	674	96.2	677	101	669	89.5
%FM _{ADP}	21.6	9.00 [†]	16.1	4.03 [†]	32.2	5.49* [†]
%FM _{BIA}	18.2	8.87	13.7	6.14	27.0	6.59*

571 %FM_{BIA}, percentage body fat measured by bioelectrical impedance analysis; %FM_{ADP}, percentage body fat measured by air

572 displacement plethysmography

573 * denotes significant difference between non-obese and obese groups at 0.05 level

574 [†] denotes significant difference within group between ADP and BIA methods at 0.05 level

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593 Table 4. Differences in %FM measured by ADP and BIA (%FM_{BIA} - %FM_{ADP})

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	All participants (n = 71)	Without obesity (n = 46)	With Obesity (n = 25)
	%FM	%FM	%FM
Mean ± SD	-3.38 ± 5.60	-2.40 ± 5.45	-5.20 ± 5.46
95% CI	-4.30, -2.46	-3.51, -1.28	-6.71, -3.68
LoA	-14.5, 7.78	-13.3, 8.50	-16.1, 5.73

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%FM, percentage fat mass. 95% CI; 95% confidence interval; LoA, Limits of Agreement

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619 Table 5. Mean, SD and within-day test re-test for intra-day reliability of %FM measures (n=10)

	Session 1		Session 2		TEM	TEM%	r _{xx}	ICC (95%CI)
	Mean	SD	Mean	SD				
%FM _{BIA}	11.4	7.92	12.5	7.86	0.65	-	0.89	0.93 (0.78-0.98)
%FM _{ADP}	13.3	9.16	14.1	8.17	0.55	-	0.92	0.95 (0.85-0.98)
Resistance (Ω)	670	83.3	685	71.3	5.72	1.63	0.90	0.95 (0.85-0.98)
Raw body volume (m ³)	30.7	10.3	30.8	10.2	0.11	0.34	0.92	0.99 (0.98-1.00)

620 %FM_{BIA}, percentage body fat measured by bioelectrical impedance analysis; %FM_{ADP}, percentage body fat measured by air
621 displacement plethysmography. TEM% is not presented for %FM since the units are already a percentage

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644 **Figure Titles**

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646 Figure 1. Bland-Altman plot of percentage fat mass (%FM) from ADP and BIA. Black circles
647 represent the without obese group, and open circles represent the with obesity group. Dashed line is
648 mean difference (bias), solid lines are limits of agreement (± 1.96 SD). Dotted line is the line of best
649 fit (proportional bias).