

## RESEARCH ARTICLE

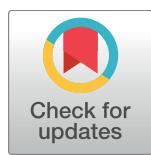
# Validation of two portable bioelectrical impedance analyses for the assessment of body composition in school age children

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## Abstract

## Background

Bioelectrical impedance analysis (BIA) is a convenient and child-friendly method for longitudinal analysis of changes in body composition. However, most validation studies of BIA have been performed on adult Caucasians. The present cross-sectional study investigated the validity of two portable BIA devices, the Inbody 230 ( $\text{BIA}_{8\text{MF}}$ ) and the Tanita BC-418 ( $\text{BIA}_{8\text{SF}}$ ), in healthy Taiwanese children.

## Methods

Children aged 7–12 years (72 boys and 78 girls) were recruited. Body composition was measured by the  $\text{BIA}_{8\text{SF}}$  and the  $\text{BIA}_{8\text{MF}}$ . Dual X-ray absorptiometry (DXA) was used as the reference method.

## Results

There were strong linear correlations in body composition measurements between the  $\text{BIA}_{8\text{SF}}$  and DXA and between the  $\text{BIA}_{8\text{MF}}$  and DXA. Both BIAs underestimated fat mass (FM) and percentage body fat (%BF) relative to DXA in both genders. The degree of agreement in lean body mass (LBM), FM, and %BF estimates was higher between  $\text{BIA}_{8\text{MF}}$  and DXA than between  $\text{BIA}_{8\text{SF}}$  and DXA. The Lin's concordance correlation coefficient ( $p_c$ ) for LBM<sub>8MF</sub> met the criteria of substantial to perfect agreement whereas the  $p_c$  for FM<sub>8MF</sub> met the criteria of fair to substantial agreement. Bland-Altman analysis showed a clinically acceptable agreement between LBM measures by  $\text{BIA}_{8\text{MF}}$  and DXA. The limit of agreement

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in %BF estimation by BIA and DXA were wide and the errors were clinically important. For the estimation of ALM, BIA<sub>8SF</sub> and BIA<sub>8MF</sub> both provided poor accuracy.

## Conclusions

For all children, LBM measures were precise and accurate using the BIA<sub>8MF</sub> whereas clinically significant errors occurred in FM and %BF estimates. Both BIAs underestimated FM and %BF in children. Thus, the body composition results obtained using the inbuilt equations of the BIA<sub>8SF</sub> and BIA<sub>8MF</sub> should be interpreted with caution, and high quality validation studies for specific subgroups of children are required prior to field research.

## Introduction

Growth monitoring is important for early detection of health and nutritional problems during child development. Growth charts of length-for-age, weight-for-age, and BMI-for-age are currently used to assess physical growth in children. These charts can provide a general clinical overview of the health and nutritional status of children. However, body composition undergoes dynamic changes throughout growth and development, and current growth charts only provide proxy measures for changes in body composition.

The techniques most commonly used to assess body composition in children are underwater weighing, isotope dilution, dual-energy X-ray absorptiometry (DXA), air-displaced plethysmography, and bioelectrical impedance analysis (BIA). Among these techniques, BIA employs portable equipment and is a safe, convenient, and child-friendly method that is suitable for measurement and tracking of body composition changes in children [1].

The two common BIA techniques are the whole-body and segmental modes, in which a current passes from hand-to-foot, foot-to-foot, or hand-to-hand, with subjects either in the supine position or standing [2]. Whole-body BIA employs four electrodes attached to different sides of the body for measurement of electrical resistance. Body composition parameters, such as fat free mass (FFM), lean body mass (LBM), fat mass (FM), and percentage body fat (%BF), are then calculated using specific equations based on recorded impedance, height, age, sex, anthropometric index, and other factors [3]. Multi-segmental BIA employs eight electrodes to calculate whole-body and regional body composition, and can provide information on the spatial distribution of different components of body composition and their changes over time [4]. Therefore, multi-segmental BIA is theoretically superior to classical BIA for studies of pediatric body composition. Moreover, multi-segmental BIA can provide an estimate of appendicular lean mass (ALM), which constitutes the majority of skeletal muscle mass (SM) and thus can be used as a proxy for SM [5, 6].

Multi-segmental BIA is available in single-frequency and multi-frequency modes. Single-frequency BIA generally employs a 50 kHz current that passes through extracellular and intracellular fluids for estimation of total body water [7]. The multi-frequency method uses multiple frequencies to differentiate intracellular from extracellular fluid, and, therefore, provides a better estimation of total body water than the single frequency method [7]. However, there is controversy concerning whether multi-frequency BIA provides more accurate estimates of body composition in children compared with the single frequency method [3, 8, 9].

Previous BIA validation studies were conducted predominantly in adult Caucasians [7]. Pietrobelli et al. [10] demonstrated that appendicular electrical resistance had a strong positive correlation with ALM in white healthy adults, and could be used to estimate the lean mass of

the limbs. However, children are not simply “miniature adults”, thus, equations established for adults may not be applicable to children. Therefore, it is necessary to investigate the reliability and validity of different BIA devices before initiation of field studies on pediatric body composition.

This cross-sectional study of healthy Taiwanese children (age 7–12 years) examined the accuracy and validity of two portable multi-segmental BIA devices by comparing their results with those from DXA measurements.

## Materials and methods

### Study design

This cross-sectional study was approved by local Institutional Review Board of the Chang Gung Memorial Hospital (103-1027A3), and written informed consent was provided by the subjects and their parents. Subjects were recruited *via* hospital advertisements and word-of-mouth from February to December, 2015. All subjects were healthy Taiwanese children aged 7–12 years-old. None of the subjects were pregnant, had amputations, implants, or chronic illnesses, or were prescribed regular medication.

Participants were instructed to eat breakfast on the study day and then fasted completely for at least 2 h before reporting to the Chang Gung Memorial Hospital (Chiayi branch) between 8:30–11:00 am. Vigorous activities and alcohol were avoided for a minimum of 48 h before the study day. Girls were not given appointments during their menstrual cycle. On arrival, participants were asked to void and change into a hospital gown. All measurements including body weight, height, BIA, and DXA were completed on the same morning, with a total study time of approximately one hour. One measurement per subject was performed using each instrument. Body height (cm) and weight (kg) were measured with subjects wearing no shoes using a digital scale (Super-View, HW-3050, Taipei, Taiwan).

### Bioelectrical impedance analysis (BIA)

All BIA measurements were made by trained research assistants. Subjects were measured wearing hospital gowns (< 0.2 kg) and weight adjustment for clothing was not applied. A single-frequency (50 kHz, 500 μA) BIA device (Tanita BC-418, Tanita Corp., Tokyo, Japan), referred to as BIA<sub>8SF</sub>, was used to estimate LBM<sub>8SF</sub>, ALM<sub>8SF</sub>, FM<sub>8SF</sub>, and %BF<sub>8SF</sub> [11]. This method allows bioelectricity impedance measurement of the whole body and each part (right leg, left leg, right arm and left arm). The age limits for the BIA<sub>8SF</sub> are 7–99 years. After the sex, age and height information had been entered into the BIA<sub>8SF</sub>, subjects were asked to stand in a stable position with bare feet. Their toes and heels were placed in contact with the anterior and posterior electrodes of the weighting platform, respectively. The measurements began when the grips were grasped by both hands. With BIA<sub>8SF</sub>, electric current was supplied from the toe tips of both feet and the fingertips of both hands, and the voltage was measured on the heel of both feet and the thenar area of both hands. Finally, the inbuilt equation was used to convert the input impedance to body composition estimates. Test-retest reliability for whole body LBM and %BF estimates by BIA<sub>8SF</sub> were both ≥ 0.99 (n = 5) using the intra-class correlation coefficient (ICC).

A multi-frequency (20 kHz and 100 kHz) BIA device using eight-point tactile electrode system (Inbody 230, Biospace Corp., Seoul, Korea), referred to as BIA<sub>8MF</sub>, was used to measure LBM<sub>8MF</sub>, ALM<sub>8MF</sub>, FM<sub>8MF</sub>, and %BF<sub>8MF</sub> [12]. The BIA<sub>8MF</sub> is suitable for individuals aged 3–99 years-old according to the manufacturer. The BIA<sub>8MF</sub> produces 10 impedance values by using two different frequencies to measurement the five segments of the body (right leg, left leg, right arm, left arm and the trunk). The measurement procedure for BIA<sub>8MF</sub> was similar to that for BIA<sub>8SF</sub>, except thumb should be placed on the electrode pad on the top surface of the

handle for BIA<sub>8MF</sub>. Body composition estimates were calculated by using the manufacturer's software (Lookin'Body 120, Biospace Corp., Seoul, Korea). Test-retest reliability for whole body LBM and %BF estimates by BIA<sub>8MF</sub> were both  $\geq 0.99$  ( $n = 5$ ) using ICC.

### Dual-energy X-ray absorptiometry (DXA)

DXA is the reference method for assessment of body composition. Whole body DXA was performed using a fan-beam system (Delphi A, QDR series, Hologic, Bedford, MA, USA) configured with software version 12.5. The scanner was equipped with switched pulse dual-energy x-ray tube, operating at 100 kVp and 140 kVp. The *in vivo* precision of the scanner for whole body measurement was 1.0%, according to the product specification. The scanner was calibrated daily with the Hologic spine and body composition step phantoms before scanning the subject. Then, subjects were instructed to lie supine on the scanning bed. The DXA operator manually assisted subjects to position within the scanning zone with their head, neck and torso parallel to the long-axis of the scanning bed; arms at their sides; palms down; legs internally rotated about 25° until the toes touched; and feet fixed together using strapping tape. Subjects were instructed to remain still and breathe normally during the scan. All DXA scans were analyzed by the same operator who followed the manufacturer's instructions and used the pediatric mode and standardized cutoff for regional measurements [13]. The subregions were defined as the head, trunk, right arm, left arm, right leg, left leg. DXA measured regional and whole body composition, including LBM<sub>DXA</sub>, ALM<sub>DXA</sub>, FM<sub>DXA</sub>, and %BF<sub>DXA</sub>.

### Statistical analysis

The statistical software package SPSS version 17.0 (SPSS Inc., Chicago, IL, USA) was used for data analysis. All data are reported as means  $\pm$  SDs. Analysis of variation (ANOVA) with Student's independent *t*-test (two-sided) was applied for analysis of repeated measurements to compare the different testing methods. The statistical significance level was set at  $\alpha = 0.05$ . Pearson's product moment correlation and ordinary least products regression analysis were used to examine the relationship between the BIA and DXA and to determine the proportional bias and fixed bias [14]. The correlation coefficient ( $r$ ) and determination coefficient ( $r^2$ ) from linear regression analysis were used to define the strength of linear association. The standard error of the estimate (SEE), a measure of the accuracy of predictions made with a linear regression, was used to assess the statistical conformity of the two BIA methods.

To assess the degree of agreement between BIA and DXA measurements, three statistical techniques were used: the ICC, Lin's concordance correlation (CCC) and Bland-Altman plot. The ICC coefficient ( $r_1$ ) (with two-way random and single measure) was used to assess the agreement between BIA and DXA methods [15]. An  $r_1$  value  $\geq 0.8$  was considered a strong level of agreement. The CCC coefficient ( $\rho_c$ ) was used to assess how close the data from BIA and DXA methods was about the line of best fit and also how far that line was from the 45-degree line through the origin [16]. The  $\rho_c$  and a concordance scale used including ratings of almost perfect:  $\rho_c > 0.99$ ; substantial:  $0.99 \geq \rho_c > 0.95$ ; fair:  $0.95 \geq \rho_c \geq 0.9$ ; poor:  $\rho_c < 0.9$  were used to assess the concordance of the two BIA methods [17]. Bland-Altman plot with a regression analysis using ordinary least squares regression was used to display the difference between a pair of measurements against the mean of the pair [18]. Limits of agreement (LOA) were used to assess the agreement between two readings obtained by BIA and DXA on the same variable.

## Results

A total of 150 children (72 boys and 78 girls) with a mean age of  $9.3 \pm 1.5$  years were enrolled. Subject demographics and body composition estimates are shown in Table 1. There were no

**Table 1.** Anthropometric characteristics and body composition measurements of Taiwanese children (age 6 to 12 years) determined by DXA (reference method), BIA<sub>8MF</sub>, and BIA<sub>8SF</sub>.

	Boys (n = 72)			Girls (n = 78)			Total (n = 150)		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Age (years)	9.4	1.6	7.1–12.7	9.2	1.5	7.1–12.1	9.3	1.5	7.1–12.7
Height (cm)	138.0	11.0	114.7–164.9	137.5	11.3	112.2–159.1	137.7	11.1	112.2–164.9
Weight (kg)	35.6	11.9	19.2–73.1	33.0	9.5	19.3–60.4	34.2	10.8	19.2–73.1
BMI	18.3*	4.3	13.4–30.0	17.1	3.0	12.3–26.6	17.7	3.7	12.2–30.0
LBM (kg)									
DXA	24.3	5.7	15.2–40.6	22.4	5.5	13.6–38.1	23.3	5.7	13.6–40.6
BIA <sub>8MF</sub>	24.1	5.7	14.9–39.0	22.8	5.6	13.9–38.6	23.4	5.7	13.9–39.0
BIA <sub>8SF</sub>	26.4**	5.3	17.2–39.6	24.8**	5.4	16.1–40.0	25.6**	5.4	16.1–40.0
FM (kg)									
DXA	10.9	7.6	3.6–35.7	10.2	4.9	4.3–24.7	10.6	6.3	3.6–35.7
BIA <sub>8MF</sub>	9.6**	7.2	2.8–34.6	8.5**	4.4	3.0–21.8	9.1**	5.9	2.8–34.6
BIA <sub>8SF</sub>	7.9**	7.6	1.1–35.2	6.9**	4.2	2.0–21.0	7.4**	6.1	1.1–35.2
%BF (%)									
DXA	27.3	10.3	13.4–48.2	29.2	7.1	17.7–47.6	28.3	8.8	13.4–48.2
BIA <sub>8MF</sub>	24.3**	10.5	11.6–47.2	24.7**	7.1	14.4–42.9	24.5**	8.8	11.6–47.2
BIA <sub>8SF</sub>	18.5**	12.6	4.7–48.0	19.5**	6.7	9.3–36.9	19.0**	10.0	4.7–48.0
ALM (kg)									
DXA	10.4	2.9	5.3–19.0	9.4	2.6	5.3–16.5	9.9	2.8	5.3–19.0
BIA <sub>8MF</sub>	13.3**	3.7	7.5–22.8	12.4**	3.5	6.8–22.5	12.9**	3.6	6.8–22.8
BIA <sub>8SF</sub>	12.3**	3.5	6.9–22.3	10.8**	2.5	7.0–18.4	11.5**	3.1	6.9–22.3

Abbreviations: ALM, appendicular lean mass; BIA<sub>8SF</sub>, Tanita BC-418; BIA<sub>8MF</sub>, Inbody 230; BMI, body mass index; DXA, dual-energy X-ray absorptiometry; FM, fat mass; LBM, lean body mass; SD, standard deviation; %BF: percent body fat.

\*P < 0.05, by repeated-measures ANOVA with Student's independent t-test;

\*\*P < 0.01, by repeated-measures ANOVA with Student's independent t-test

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significant differences in age, height or weight between boys and girls. However, the boys had significantly higher BMI compared with the girls ( $18.3 \pm 4.3$  in boys and  $17.1 \pm 3.0$  in girls,  $p = 0.038$ ). Based on DXA results, FM and %BF showed no significant difference between boys and girls whereas the boys had significantly higher LBM and ALM than the girls. For both boys and girls, all body composition results by BIA<sub>8MF</sub> and BIA<sub>8SF</sub> were significantly different from the results by DXA (\*\*P < 0.001, Table 1), except for LBM by BIA<sub>8MF</sub>.

Table 2 shows the Pearson product moment correlations coefficient ( $r$ ) and the regression equation used to predict DXA results from BIA readings. There were strong linear correlations between the two BIA methods and DXA in the measurement of LBM, ALM, FM, and BF% ( $r \geq 0.9$  for all comparisons). However, there was a proportional bias and/or a fixed bias for each BIA measurement, except for LBM<sub>8MF</sub>. The scatter plots of body composition data by BIA and DXA methods showed BIA underestimated FM and %FM relative to DXA in both genders (Figs 1 and 2).

Pearson correlation was used to quantify the strength of linear association between two methods of measuring the same variable, and it should not be used to assess agreement between methods. Therefore, the agreement of BIA<sub>8SF</sub> and BIA<sub>8MF</sub> with DXA was further examined using three statistical techniques: ICC, CCC and Bland-Altman plot (Table 3). In general, an ICC value ( $r_1$ )  $\geq 0.8$  is considered a strong level of agreement. This study showed

**Table 2. Correlation of body composition estimates using Pearson product moment correlation and ordinary least products regression.**

Method	r	a	95% CI	b	95% CI	Fixed bias	Proportional bias	SEE
Boys (n = 72)								
LBM <sub>8SF</sub>	0.971	-3.533	-5.188, -1.877	1.053	0.991, 1.115	Yes	No	1.368
LBM <sub>8MF</sub>	0.989	0.354	-0.509, 1.217	0.991	0.957, 1.026	No	No	0.839
FM <sub>8SF</sub>	0.986	3.248	2.813, 3.683	0.974	0.934, 1.014	Yes	No	1.283
FM <sub>8MF</sub>	0.993	0.854	0.508, 1.200	1.050	1.020, 1.078	Yes	Yes	0.876
%BF <sub>8SF</sub>	0.949	12.962	11.586, 14.339	0.776	0.715, 0.838	Yes	Yes	3.285
%BF <sub>8MF</sub>	0.976	3.880	2.530, 5.229	0.964	0.913, 1.014	Yes	No	2.256
ALM <sub>8SF</sub>	0.922	1.115	0.265, 2.178	0.748	0.673, 0.823	Yes	Yes	1.116
ALM <sub>8MF</sub>	0.970	0.287	-0.337, 0.912	0.758	0.713, 0.804	No	Yes	0.698
Girls (n = 78)								
LBM <sub>8SF</sub>	0.982	-2.354	-3.469, -1.329	0.996	0.952, 1.042	Yes	No	1.043
LBM <sub>8MF</sub>	0.994	0.213	-0.373, 0.800	0.972	0.947, 1.002	No	No	0.616
FM <sub>8SF</sub>	0.976	2.375	1.911, 2.840	1.132	1.074, 1.189	Yes	Yes	1.064
FM <sub>8MF</sub>	0.991	0.822	0.492, 1.153	1.102	1.068, 1.137	Yes	Yes	0.666
%BF <sub>8SF</sub>	0.897	10.609	8.407, 12.810	0.954	0.847, 1.061	Yes	No	3.141
%BF <sub>8MF</sub>	0.925	5.336	3.638, 7.434	0.984	0.892, 1.077	Yes	No	2.707
ALM <sub>8SF</sub>	0.956	-1.408	-2.190, -0.627	0.920	0.848, 0.989	Yes	Yes	0.783
ALM <sub>8MF</sub>	0.974	0.383	-0.110, 0.876	0.727	0.668, 0.765	No	Yes	0.596

Abbreviations: r, Pearson product moment correlation coefficient; a, b, coefficients in ordinary least products regression model: E(A) = a + b(B); a, (y axis) intercept; b, slope; fixed bias, if 95% confidence interval (CI) for a does not include 0; proportional bias, if 95% confidence interval (CI) for b does not include 1; SEE, standard error of the estimate.

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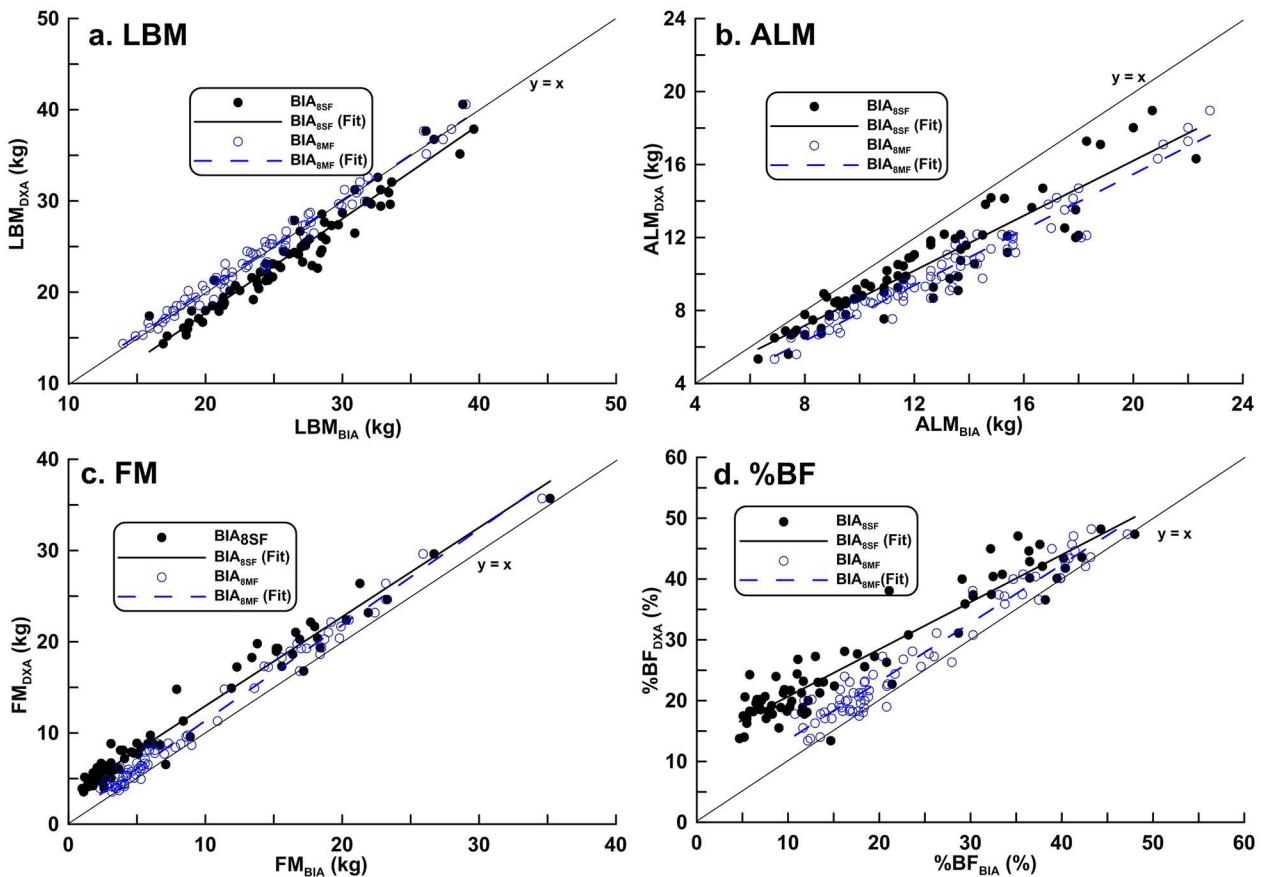
that all BIA parameters had  $r_1 \geq 0.9$  except for LBM<sub>8SF</sub> in boys, which was 0.887, indicating a strong agreement between the measures by BIA and DXA.

In general, the CCC values ( $\rho_c$ ) for LBM, FM, and %BF were higher between BIA<sub>8MF</sub> and DXA than between BIA<sub>8SF</sub> and DXA (Table 3), indicating a better agreement between BIA<sub>8MF</sub> and DXA measures. In both sexes, the  $\rho_c$  values for LBM, FM, and %BF were  $\geq 0.9$  between BIA<sub>8MF</sub> and DXA, except for %BF<sub>8MF</sub> in girls (Table 2). The  $\rho_c$  for LBM<sub>8MF</sub> met the criteria for substantial to perfect agreement ( $\rho_c > 0.95$ ) whereas the  $\rho_c$  for FM<sub>8MF</sub> met the criteria for fair to substantial agreement ( $0.99 > \rho_c \geq 0.9$ ). For the %BF estimations, only the  $\rho_c$  values obtained by BIA<sub>8MF</sub> in the boys ( $\rho_c = 0.936$ ) met the criteria for fair agreement with DXA and the rest of the %BF estimations showed poor agreement (Table 3).

Bland-Altman plots were used to determine bias and LOA between BIA and DXA methods in boys (Fig 3) and girls (Fig 4). The LOAs were greater for the BIA<sub>8SF</sub> and DXA measurements than for the BIA<sub>8MF</sub> and DXA measurements, except for the ALM measures in girls (Table 3). Similar to the results by CCC, Bland-Altman analysis showed a good and clinically acceptable agreement between LBM measures by BIA<sub>8MF</sub> and DXA (LOA = -1.82 to 1.52 kg in boys and LOA = -0.88 to 1.63 kg in girls, Table 3).

In the human body, the FM is the total body weight minus LBM. Indeed, the LOAs of FM measures by BIA<sub>8MF</sub> and DXA (-3.21 to 0.55 kg in boys and -3.30 to -0.10 kg in girls, Table 3) showed similar ranges to that of LBM but with different plus-minus sign (negative values in FM). In this study, the mean FM was about half of the LBM in children (Table 1) and thus, the degree of error was larger in FM estimation by BIA<sub>8MF</sub> and DXA compared with that in LBM.

Regarding %BF estimation, BIA<sub>8SF</sub> measurements underestimated %BF by 8.82% in boys and 9.72% in girls, whereas the BIA<sub>8MF</sub> measurements underestimated %BF by 3.00% in boys



**Fig 1. Correlation between dual-energy X-ray absorptiometry results and estimates of body composition in boys obtained with either BIA<sub>8SF</sub> or BIA<sub>8MF</sub>.** (a) LBM: BIA<sub>8SF</sub>:  $r^2 = 0.940$ , BIA<sub>8MF</sub>:  $r^2 = 0.979$  (b) ALM: BIA<sub>8SF</sub>:  $r^2 = 0.858$ , BIA<sub>8MF</sub>:  $r^2 = 0.944$  (c) FM: BIA<sub>8SF</sub>:  $r^2 = 0.940$ , BIA<sub>8MF</sub>:  $r^2 = 0.979$  (d) %BF: BIA<sub>8SF</sub>:  $r^2 = 0.898$  BIA<sub>8MF</sub>:  $r^2 = 0.951$ .

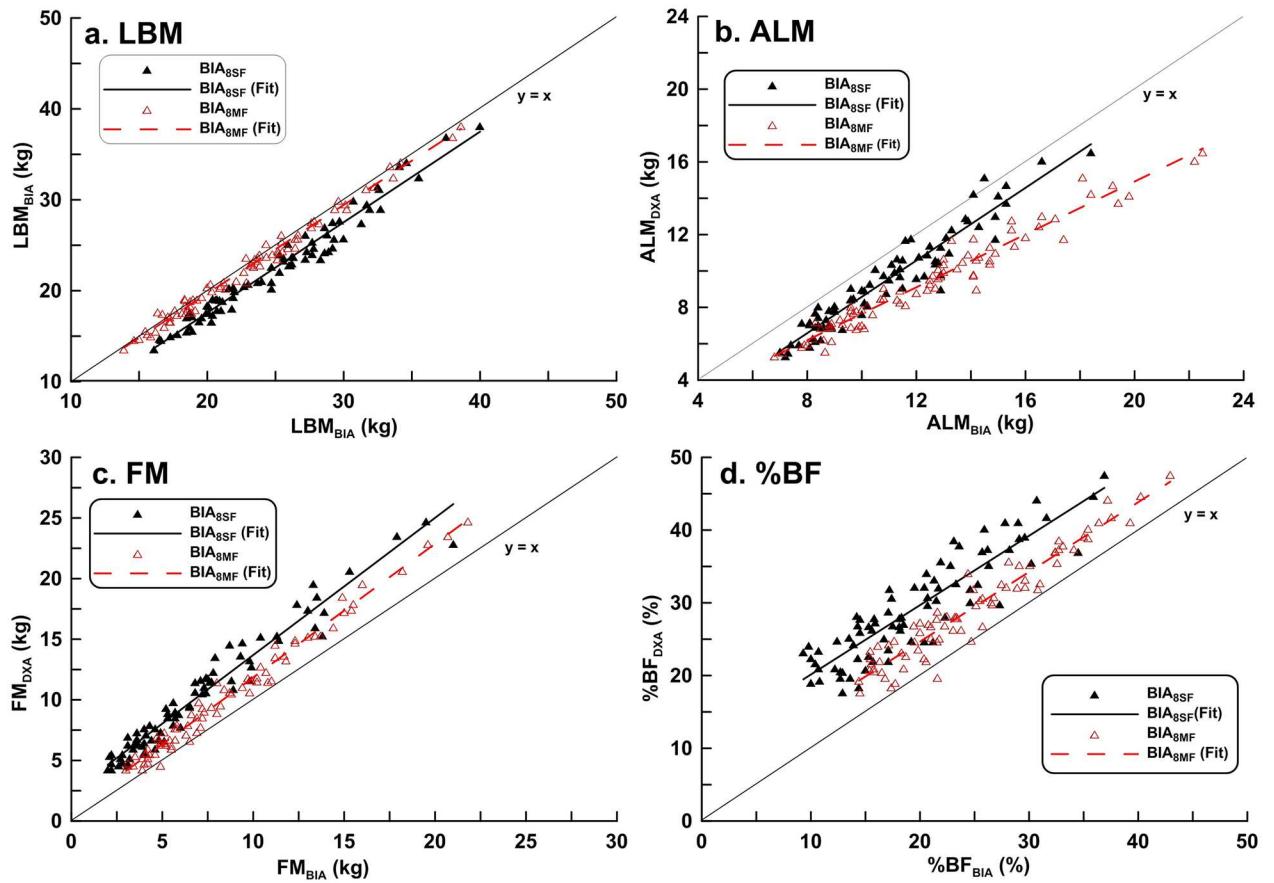
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and 4.48% in girls (Figs 3d and 4d). The LOAs in %BF estimation between BIA<sub>8MF</sub> and DXA were clinically important. Even worse, there were larger LOAs in %BF estimation by BIA<sub>8SF</sub> and DXA (-17.46 to -0.19% in boys and -15.99 to -3.45% in girls, Table 3).

The  $\rho_c$  value for ALM estimated by BIA<sub>8SF</sub> was 0.770 in boys and 0.828 in girls, and the  $\rho_c$  value for ALM estimated by BIA<sub>8MF</sub> was 0.671 in boys and 0.635 in girls, all of which were considered poor agreement (Table 3). In agreement with CCC, Bland-Altman analysis showed a poor agreement with clinically importance between ALM estimations by BIA and DXA in both genders (Table 3).

## Discussion

This study compared the estimates of body composition obtained from multi-segment BIA<sub>8SF</sub> and BIA<sub>8MF</sub> with DXA measurements in primary school children from Taiwan. Pearson product moment correlation was used to test the linear association whereas ICC, CCC and Bland-Altman Plot were used to test agreement between BIA and DXA results. So far, there is still a debate about which method is the best for assessing agreement between two instruments. The ICC and CCC are scaled agreement indices depending on the measurement range, and therefore they are easy to summarize but hard to interpret [19]. In contrast, bias and LOAs (Bland-Altman plot) are unscaled indices based on the original unit and interpretation of the



**Fig 2. Correlation between dual-energy X-ray absorptiometry results and estimates of body composition in girls obtained with BIA<sub>8SF</sub> or BIA<sub>8MF</sub>.** (a) LBM: BIA<sub>8SF</sub>:  $r^2 = 0.964$ , BIA<sub>8MF</sub>:  $r^2 = 0.987$  (b) ALM: BIA<sub>8SF</sub>:  $r^2 = 0.915$ , BIA<sub>8MF</sub>:  $r^2 = 0.951$  (c) FM: BIA<sub>8SF</sub>:  $r^2 = 0.953$ , BIA<sub>8MF</sub>:  $r^2 = 0.981$  (d) %BF: BIA<sub>8SF</sub>:  $r^2 = 0.802$ , BIA<sub>8MF</sub>:  $r^2 = 0.964$ .

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agreement requires prior knowledge of the measurement variables [20]. Since these methods all have some disadvantages, we have used more than one statistical method to assess agreement between two instruments in this study.

The LBM estimates by BIA<sub>8MF</sub> and DXA were in high agreement for both genders using all statistical methods in this study. Therefore, BIA<sub>8MF</sub> and DXA were interchangeable test methods for the measurement of LBM in children. However, the FM estimates showed fair to substantial agreement between BIA<sub>8MF</sub> and DXA by CCC but clinically important differences by Bland-Altman plots. One possible explanation for the discrepancy in the degree of agreement may be due to the fact that CCC was scaled relative to the between-subject variability and the large FM range in our subjects produced a relatively high  $\rho_c$  value. In contrast, Bland-Altman analysis was not dependent on between-subject variability such that it was easier to identify the error between the two methods.

Except for LBM estimates, the remainder of the BIA measurements showed strong linear correlation (but with clinically significant errors) with the gold standard method, DXA. Talma et al. [21] reported similar findings in a review article. Most previous BIA validation studies reported high precision using the BIA models but did not use a reference method to measure the accuracy of BIA estimates [22]. In addition to linear regression and ICC, we also performed Bland-Altman analysis and determined CCC to rigorously assess the statistical

**Table 3.** Agreement between bioelectrical impedance analysis and dual-energy X-ray absorptiometry.

Method	Bland-Altman Plot				CCC ( $p_c$ )	ICC ( $r_1$ )
	Bias	Limit of agreement	Function	p		
Boys (n = 72)						
LBM <sub>8SF</sub>	2.12	-0.65 to 4.90	y = 0.082 x + 4.208	0.005	0.900	0.887
LBM <sub>8MF</sub>	-0.15	-1.82 to 1.52	y = -0.002 x - 0.096	0.902	0.989	0.943
FM <sub>8SF</sub>	-3.05	-5.63 to -0.47	y = 0.012 x - 3.156	0.571	0.911	0.973
FM <sub>8MF</sub>	-1.35	-3.21 to 0.55	y = -0.055 x - 0.763	< 0.0001	0.975	0.977
%BF <sub>8SF</sub>	-8.82%	-17.46 to -0.19%	y = 0.205 x - 13.526	< 0.0001	0.717	0.992
%BF <sub>8MF</sub>	-3.00%	-7.54 to 1.55%	y = 0.013 x - 3.335	0.620	0.936	0.986
ALM <sub>8SF</sub>	1.87	-0.97 to 4.71	y = 0.216 x - 0.585	< 0.0001	0.770	0.989
ALM <sub>8MF</sub>	2.93	0.69 to 5.17	y = 0.248 x + 0.016	< 0.0001	0.671	0.972
Girls (n = 78)						
LBM <sub>8SF</sub>	2.44	0.37 to 4.52	y = -0.015 x + 2.790	0.500	0.890	0.990
LBM <sub>8MF</sub>	0.37	-0.88 to 1.63	y = 0.018 x - 0.076	0.126	0.991	0.994
FM <sub>8SF</sub>	-3.29	-5.68 to -0.90	y = -0.150 x - 2.008	< 0.0001	0.763	0.992
FM <sub>8MF</sub>	-1.70	-3.30 to -0.10	y = -0.107 x - 0.691	< 0.0001	0.923	0.970
%BF <sub>8SF</sub>	-9.72%	-15.99 to -3.45%	y = -0.065 x - 8.149	0.229	0.445	0.989
%BF <sub>8MF</sub>	-4.48%	-8.50 to -0.46%	y = -0.001 x - 4.512	0.969	0.798	0.979
ALM <sub>8SF</sub>	1.42	-0.14 to 2.97	y = -0.045 x + 1.877	0.192	0.828	0.981
ALM <sub>8MF</sub>	3.01	0.74 to 5.28	y = 0.295 x - 0.208	< 0.0001	0.635	0.953

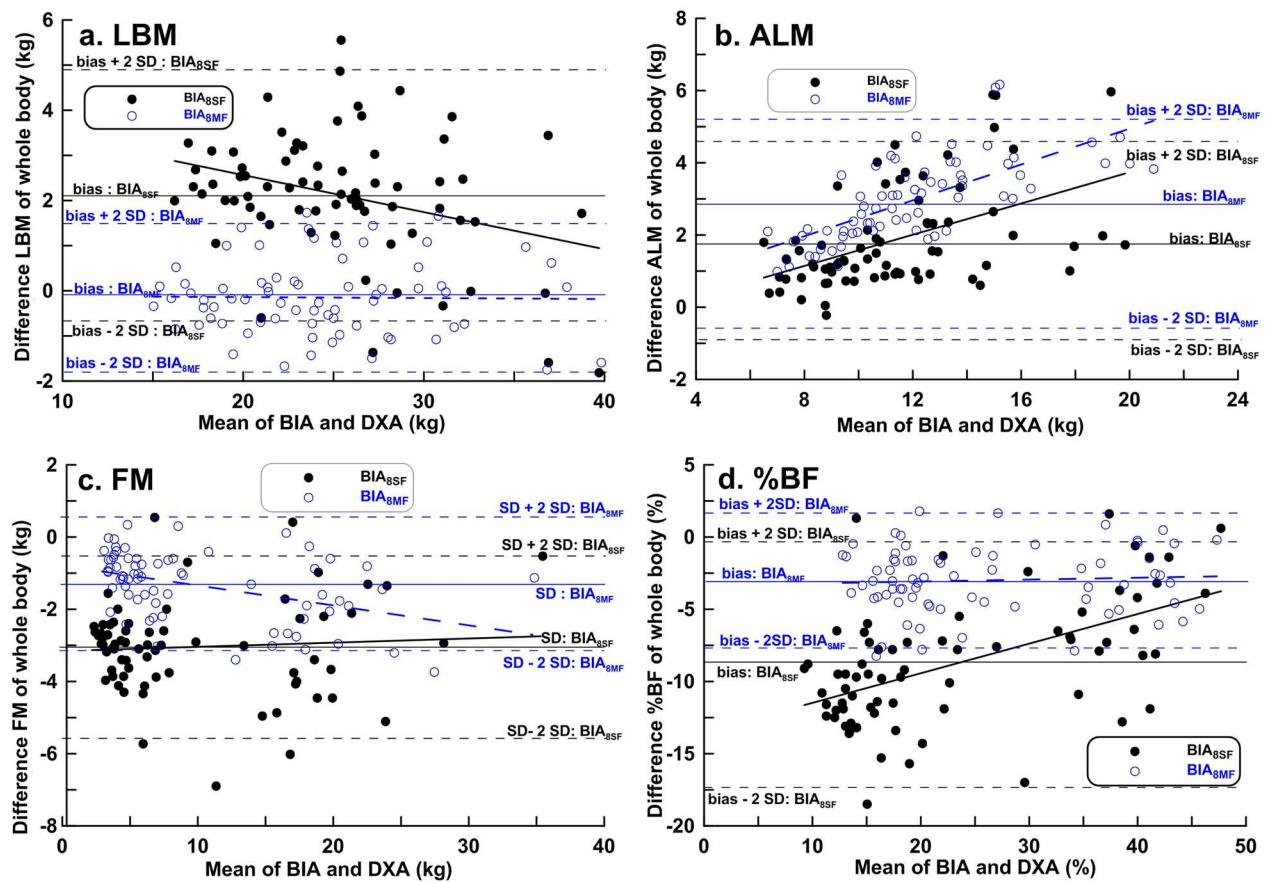
Abbreviation: CCC, Lin's concordance correlation coefficient;  $p_c$ , CCC coefficient; ICC, intra-class correlation;  $r_1$ , ICC coefficient

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consistency of body composition estimates from BIA relative to DXA. Our results indicated clinically important errors in FM and %BF estimated by both BIA devices which may limit their applicability to body composition measurements at an individual level in children, even though the  $r$  and  $r_1$  values were high between both BIA methods and DXA. It is worth noting that although ICC is a popular test to compare the results between two methods, there is still a debate about the use of ICC in assessment agreement [23, 24].

We also compared both BIA<sub>8SF</sub> and BIA<sub>8MF</sub> models in children with a wide range of body fat composition, using DXA as the gold standard. Although the estimates from both BIA devices and DXA showed strong linear correlations, the correlation coefficients and agreements were higher for BIA<sub>8MF</sub> compared with BIA<sub>8SF</sub>. In general, the BIA devices (especially the BIA<sub>8SF</sub>) overestimated LBM and underestimated FM. In addition, the LOAs were larger and the biases were greater for BIA<sub>8SF</sub> measurements compared with BIA<sub>8MF</sub> measurements, except for ALM in girls. The CCC analysis also indicated better agreements in measurements of LBM, FM, and %BF for the BIA<sub>8MF</sub> in both sexes. These results confirm the findings of Kriemler et al. [25] that BIA<sub>8MF</sub> is superior to BIA<sub>8SF</sub> in pediatric body composition analysis.

In our study, both BIA<sub>8SF</sub> and BIA<sub>8MF</sub> underestimated FM and %BF in children who had large or small amounts of body fat. Additionally, BIA<sub>8SF</sub> had a fixed bias or proportional bias in all components of body composition. Talma et al. [21], in their systematic review, indicated that BIA provided inconsistent results, depending on the reference method used. A literature review of validation studies for the Tanita BC-418 system in children also showed inconsistent results similar to our findings, whereas other studies had results which contradicted our findings. For example, Pietrobelli et al. [26] showed a perfect linear correlation between body composition parameters measured by the Tanita BC-418 system and DXA in subjects aged 6–64 years. However, they did not perform agreement analysis, and had a small sample size and

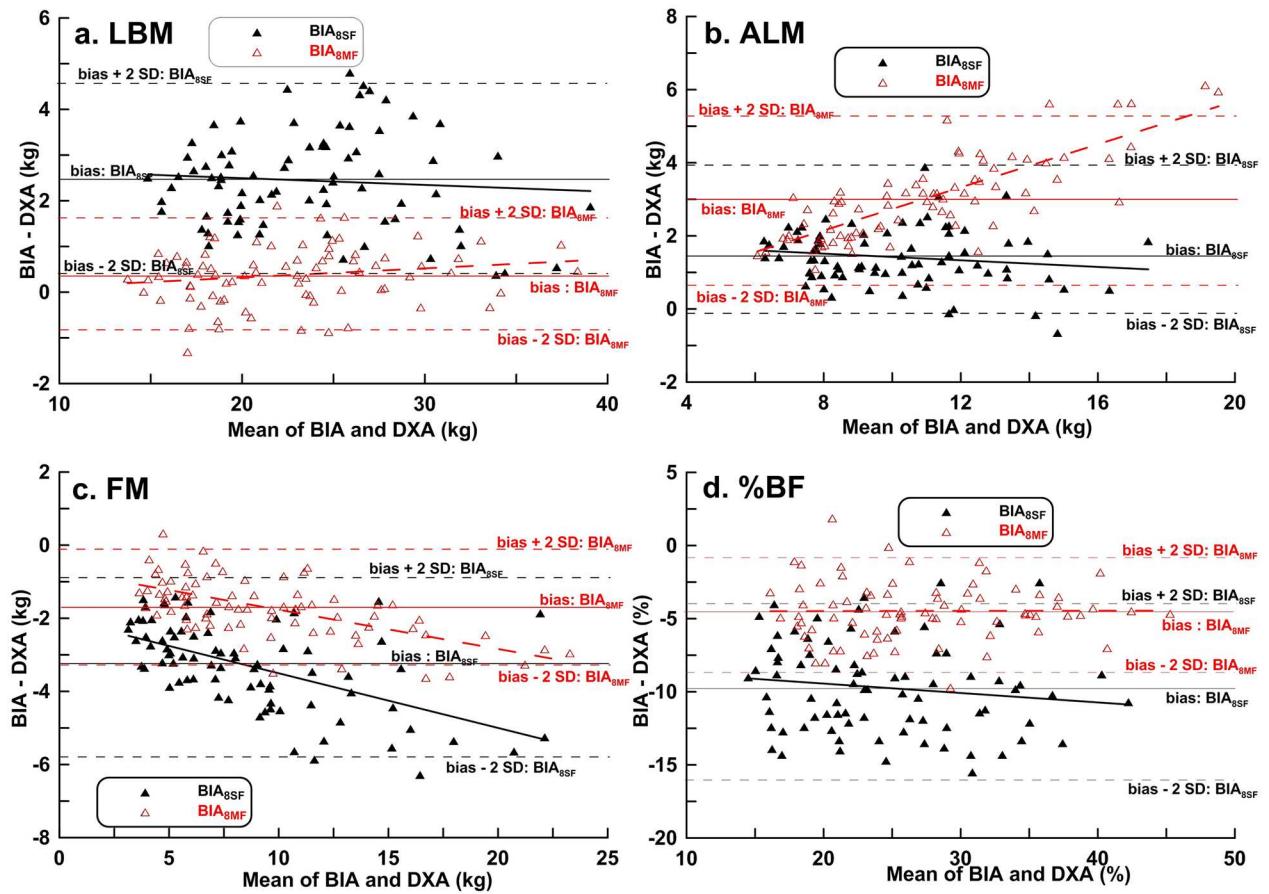


**Fig 3.** Bland-Altman plots with linear regression analysis of dual-energy X-ray absorptiometry results vs.  $BIA_{8SF}$  and  $BIA_{8MF}$  estimates of body composition in boys.

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wide age range. Some studies showed that the Tanita BC-418 underestimated FM in obese children compared with other reference methods [27, 28]. Shaikh et al. [28] reported a strong linear correlation between FM determined by the Tanita BC-418MA and DXA in obese boys aged  $11.0 \pm 0.53$  years; however, the BIA system underestimated %BF, and the LOA in %BF was -3.8 to 15.4%. Haroun et al. [27] examined obese subjects (between 5–22 years of age) and found that the Tanita BC-418 underestimated FM by 3.5 kg in males and 3.6 kg in females, compared with the isotope dilution method. In contrast, Prins et al. [29] showed the Tanita BC-418MA system overestimated %BF in normal-weight Gambian children aged 5–16 years relative to the isotope dilution method.

We found that LBM estimates between BIA ( $BIA_{8SF}$  and  $BIA_{8MF}$ ) and DXA were in fair to substantial agreement whereas ALM estimates between BIA and DXA showed poor agreement. Few previous studies have used eight-electrode multi-frequency BIA devices (i.e. the Inbody-230) for estimates of body composition in children. Kriemler et al. [25] used a different  $BIA_{8MF}$  device (Inbody 3.0, Biospace, Seoul, Korea) in 6 years-old and found no fixed bias or proportional bias in FFM or ALM relative to measurements from DXA. Jensky-Squires et al. [30] used the Inbody-320 (Biospace, Seoul, Korea) to estimate %BF in children between 10–17 years of age relative to underwater weighing, and found significant differences in girls but not boys. Lim et al. [31] used the Inbody 720 (Biospace, Seoul, Korea) to estimate FFM, FM, and %



**Fig 4.** Bland-Altman plots with linear regression analysis of dual-energy X-ray absorptiometry results vs. BIA<sub>8SF</sub> and BIA<sub>8MF</sub> estimates of body composition in girls.

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BF in healthy children between 6–18 years of age and reported a high precision relative to DXA results. In their study, the LOA in %BF was  $-2.2 \pm 6.1\%$ , which was far less than ours.

BIA is primarily designed to estimate FFM, and the FFM prediction equations were developed using a reference method, such as DXA and/or isotope dilution. Variables in the regression equations may include height, weight, age, sex, race, and other factors [7]. Therefore, the established FFM equations may not applicable to all pediatric populations such as our pediatric populations [32, 33]. Body hydration status can also influence FFM calculation from BIA measurements. Most BIA prediction equations assume that the FFM consists of 73% water. However, although the water content of FFM is about 73% in adults, it is greater in children [22]. Therefore, a BIA prediction equation developed for adults could overestimate FFM in children. Moreover, hydration status changes as a child develops [34]. Therefore, an equation developed for school-aged children may not be accurate for adolescents. These major limitations of the BIA method remain unresolved.

## Conclusion

For all children, LBM measures using the BIA<sub>8MF</sub> were precise and accurate whereas clinically significant errors occurred in both FM and %BF estimates. The BIA<sub>8SF</sub> and BIA<sub>8MF</sub> both underestimated FM and %BF in children. For the estimates of ALM, both BIA devices showed

poor agreement with DXA. Thus, the body composition results obtained using the inbuilt equations of the BIA<sub>8SF</sub> and BIA<sub>8MF</sub> should be interpreted with caution, and high quality validation studies in specific subgroups children are required prior to field research.

## Author contributions

**Conceptualization:** LWL YSL HKL PLH YYC CCC KCH.

**Formal analysis:** LWL KCH.

**Funding acquisition:** LWL CCC.

**Investigation:** LWL YSL PLH.

**Methodology:** LWL YSL.

**Project administration:** LWL CCC.

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**Supervision:** CCC KCH.

**Validation:** LWL YSL HKL PLH YYC CCC KCH.

**Visualization:** LWL KCH.

**Writing – original draft:** LWL KCH.

**Writing – review & editing:** LWL YSL HKL PLH YYC CCC KCH.

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