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Validity of the Remote Food Photography Method against Doubly Labeled Water among Minority Preschoolers

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Abstract

Objective—To determine the validity of energy intake (EI) estimations made using the Remote Food Photography Method (RFPM) compared to the doubly-labeled water (DLW) method in minority preschool children in a free-living environment.

Methods—Seven days of food intake and spot urine samples excluding first void collections for DLW analysis were obtained on 39 3-to-5 year old Hispanic and African American children. Using an iPhone, caregivers captured before and after pictures of the child's intake and pictures were wirelessly transmitted to trained raters who estimated portion size using existing visual estimation procedures and energy and macronutrients were calculated. Paired t-test, mean differences and Bland-Altman limits of agreement were performed.

Results—The mean EI using the RFPM was 1,191 ± 256 kcal/d and 1,412 ± 220 kcal/d by the DLW method, resulting in a mean underestimate of 222 kcal/d (−15.6%) (p<0.0001) that was consistent regardless of intake. The RFPM underestimated EI by −28.5% in 34 children and overestimated EI by 15.6% in 5 children.

Conclusions—The RFPM underestimated total EI when compared to the DLW method among preschoolers. Further refinement of the RFPM is needed for assessing EI of young children.

Keywords

digital photography; dietary assessment; preschoolers; validation

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DISCLOSURE: This manuscript was collaboratively drafted by all authors who provided edits and corrections and agreed to the final submitted version. Pennington Biomedical Research Center / the Louisiana State University System has an interest in the intellectual property surrounding the SmartIntake® app and Corby Martin is listed as an inventor of the approach.

Introduction

In a systematic review of 15 studies on dietary assessment methods in children, the authors found one study from the United Kingdom that concluded that weighed food records for children aged 0.5 to 4 years, provided accurate estimates of energy intake (EI) compared to doubly labeled water (DLW).[1] However, the method entailed high participant response burden and was impractical for young children who have multiple caregivers and eating occasions in different settings outside of home (*e.g.* daycare centers, preschool) where parents are not the primary informants. Therefore, proxy estimates of young children's dietary intake provided by parents may be inaccurate.[2, 3] Progress in information and communication technology has prompted the research field to find new and innovative ways to enhance dietary assessments for increased accuracy.[4, 5] Smart phones equipped with high resolution digital cameras, high memory capacity, network capacity and faster processors make them a good tool for collecting dietary information and images of the food consumed.[6–9] Image-based approaches aimed at capturing all eating occasions with images as the primary record of dietary intake minimizes errors from memory recall and portion size estimations.[10] The image-assisted records showed significantly higher estimates (p=0.001) of total EI per eating occasion compared with proxy-assisted records;[11, 12] thus, reports from other studies[13–15] indicate reduction in under-reporting using the smart phone. The amenability and acceptability of a mobile food record (mFR) were examined among young children 3–10 years of age attending summer camps. Given instructions with demonstration and practice, children were able to use the mFR to record their dietary intake.[16] Children and specifically adolescents prefer technology-based approaches over traditional ones.[17] Reviews and evaluations of innovative technologies for measuring food intake in children identified the following as strengths: faster, almost real-time data collection, reduced memory bias, good respondent acceptance, and suitable for low-literacy subjects. For parent-assisted dietary assessment in children, the method possibly provides higher quality control because of reduced time delay and is not dependent on assessment from memory. However, the smart phone method requires training, expensive technical development, security infrastructure for digital data transfer, and accuracy of portion size estimations using trained researchers.[18]

The remote food photography method (RFPM),[19, 20] which relies on the validated digital photography method,[21, 22] has been developed to remotely measure food intake with real-time transfer of data.[19] The method has been tested with adults in free-living conditions[19, 20] but not with preschool children.

The aim of this study was to test the validity of the RFPM as a method for collecting 24-hour EI of minority preschool children (ages 3–5 years) under free-living conditions against the reference DLW method during a period of relative energy balance where total energy expenditure (TEE) is equal to EI.[23, 24]

Methods

The study was approved by the Baylor College of Medicine and the Pennington Biomedical Research Center Institutional Review Boards and, by the Head Start (HS) administration in Houston, TX. A total of 83 caregivers signed up with a contact phone number. Phone calls were conducted to explain the study and to screen the participants. Forty-three dyads (caregiver/child) were recruited. All caregivers provided written informed consent for their child's participation and the child gave his/her own verbal assent. Due to issues with urine sampling and/or picture capturing, four dyads were excluded from the analysis. Participants were healthy minority children with low socioeconomic status, 19 were African American (11 males and 8 females) and 20 Hispanics (11 males and 9 females). The children provided a baseline urine sample and agreed to drink the individualized DLW dose. The primary caregiver met with a study coordinator, received the required training for collecting urine and on how to use the SmartIntake® application (SI), and instructions on how to return all materials at the end of the study. Caregivers took pictures of the child's food/beverage and the corresponding plate waste using the iPhone with the SI® application. They also collected, aliquoted, and froze spot urine samples from the child daily for seven consecutive days. Due to the commitment required from caregivers, families with more than three children in the household were excluded. Caregivers who could not understand, speak or write in English were also ineligible.

Anthropometry

Height and weight were collected on all children and were measured twice; once at baseline and another after the seven days of observation to monitor growth. Height was measured to the nearest 0.1 cm using the Seca 213 stadiometer (Seca & Co, Hammer Steindamm 9–25. Hamburg, Germany) and weight to the nearest 0.1 kg using a Health-O-meter (manufacturer's model 751 KLS, Sunbeam Products Inc. Boca Raton, Fl). The child's initial weight was used to calculate the DLW dosage.

Training Caretakers to Take Photographs Using the SmartIntake (SI) Application

Both caregivers and teachers received training and practiced using the SI application to capture and transmit images of foods/beverages consumed by the child. Training of the caregivers and teachers was conducted using a standardized protocol used in other studies.[25, 26] In a private area of the HS center, coordinators met the caregivers and teachers and provided them iPhones uploaded with the SI application. One iPhone was shared between the caregiver at home and the teacher in HS. The training provided detailed instructions on how the photographs were to be taken, which included proper lighting, a 45-degree angle, an arm's-length distance between the camera and each child's plate, and presence of a 2-by-2 inch card (fiduciary marker) in the image. The fiduciary card provided perspective to the food images and also allowed for color correction. A total of 2,674 pictures of foods/beverages were taken by the caregivers and teachers (Table S1).

Training Caretakers to Collect and Store Urine Samples

Following study coordinators' directions, caregivers successfully collected the baseline urine samples from their child in a sterilized specimen container using an individually wrapped plastic pipette, and transferred approximately 2 mL of urine into two pre-labeled cryovials. Day, time and date of the collection were documented. Caregivers were provided the seven day supply of urine collection materials. At home, caregivers collected the post dose urine sample 6–8 h after dose administration. Thereafter, for seven consecutive days caregivers collected spot urine samples from the child while excluding the first void in the morning. Urine samples transferred to the o-ring cryovials (VWR, Sugar Land, TX) and were kept frozen in the home freezer until the collection was finished. After all samples were collected, they were delivered to a Gas-Isotope Ratio Mass Spectrometry Laboratory.

Preparing and Administering the DLW Dosage

Each child drank 1.5 g/kg body weight of a cocktail containing 0.086 g of $^{2}H_2O$ at 99.98 atom % ^{2}H and 1.38 g of 10% ^{18}O.[27–29] The DLW dosage was designed to minimize potential errors introduced by the anticipated fluctuation in the natural abundances of the two isotopes during the study, to reduce the effect of analytical errors on the precision of the DLW method, and to ensure there were sufficient isotopes at the end of the seven day DLW study period for accurate and precise isotope ratio measurements. The DLW dose was measured using a calibrated electronic scale (Sartorius Corporation, 140 Wilbur PI, Bohemia, NY 11716) accurate to 0.01 g. The mixture was diluted with bottled spring water and the child was asked to drink the mixture while seated using a drinking straw. The dose bottle was rinsed twice with ~10–20 mL of bottled spring water and the child was asked to drink each rinse using the same straw.

Measuring Energy Intake

Caregivers used the iPhone for seven consecutive days for taking before and after pictures of all foods and beverages consumed by the child, and any additional servings the child had with the exception of water. In addition to the pictures, caregivers also scripted additional descriptions of the meals consumed such as the type of milk consumed, the type of meat, the preparation method, or the type of fat used. The information provided was used to customize food selections and better represent mixed dishes. Twenty four caregivers used the backup food record form that was initially provided to them to document some of their children's intake that was not captured with the SI. Pictures and the composed description were sent *via* email and transmitted in real-time to the server containing the automated data management utility then transferred to the main program, the Food Photography Application© (FP application©), which was used to identify and quantify type of food and portion size from the digital images submitted by the SI application. The FP application© was on a server at Pennington Biomedical Research Center (PBRC) with human raters who perform the diet estimations.

Training of Human Raters

Digital Diet Estimations

The human raters had an educational training in nutrition and each attended at least 15 hours of training by the designated master rater. The raters learned how to use the FP application© software by observing the master rater. Photographs from previous studies were used for the training. Specific examples of "problem" photos or situations were presented, and the raters were provided guidelines on how to address each issue. Each rater then practiced digital photography estimation of foods using the software and sample photographs. An open discussion was held among all raters to address questionable estimations. Each rater's estimations had to fall within 20% of the master rater's estimations to be considered acceptable.

Procedure for Estimating Food Selection and Plate Waste

Digital diet photographs were estimated by trained raters using the FP application©. To maximize reliability among raters, a decision tree was developed and implemented to address specific issues that could occur. From previous studies a food photo library was created consisting of an archive of over 15,000 photographs of different foods, each with different portion sizes of the same food. Raters individually estimated a percentage of each food item on the subject's plate in the "before" photo compared to a selected standard photo of the food item. The "before" photo was matched to a proper food code in the USDA Food and Nutrient Database for Dietary Studies 2011–2012.[30] This estimate reflected the food selection. To estimate plate waste, the same procedure was followed using the "after" photo. Rater estimates were entered into the data entry grid in the computer software. The FP application© software calculated grams of food intake by subtracting the plate waste estimate from the food selection estimate.

Quality Assurance

Reliability and Accuracy

Within the FP application© software, 25% of the foods from the present study were oversampled and were assigned to all raters. The raters' food selection, plate waste, and food intake estimations were compared using Intraclass Correlation Coefficients (ICCs). A correlation of 0.85 or higher indicated good reliability among raters. To help promote accurate ratings over time and across raters, the raters consulted with each other regarding foods that were difficult to rate and they also attended a weekly meeting where foods that were difficult to rate could be discussed and the rating process was reviewed to foster adherence to the rating protocol.

Data Extraction

Data were locked and extracted from the FP app©. When raters' estimates of the same food differed by ≥30%; or there was missing or duplicated data an error message alerted raters of the discrepancy found, and the software was unlocked for correcting the flagged entries on his or her dataset. Conflict in rater estimates were discussed as a group to arrive at a consensus.

Doubly Labeled Water (DLW) Method

For stable hydrogen isotope ratio measurements, the hydrogen gas-water equilibration method was used.[31] Briefly, 200 μL of urine was transferred into a 12-mL Exetainer (Labco International Inc, Ceredigion, UK) that contained ~5 mg of activated charcoal (Fisher Scientific, Sugar Land, TX, USA) and ~200 mg of copper powder (Fisher Scientific, Sugar

Land, TX, USA) and a platinum catalytic rod (Thermo Scientific, Madison, WI, USA). After recapping the Exetainer, the content was flushed with 2% H_2 in helium (Air Liquide USA, Houston, TX) at 483 kPa for seven minutes. The sample was then allowed to equilibrate with the H_2 at room temperature for at least three hours. At the end of the equilibration, an aliquot of the H_2 in the Exetainer was injected into a Thermo Delta V Advantage mass spectrometer system (Thermo Electron North America, West Palm Beach, FL, USA) for stable hydrogen isotope ratio measurement. The same sample was analyzed for ^{18}O content after a 22 hours of equilibration with CO_2 of known ^{18}O content again using the Thermo Delta V Advantage mass spectrometer system.[32] The ^2H assays using the equilibration method was determined to be accurate within 2.8 ‰ and reproducible to within 4.0 ‰. For ^{18}O assays using the continuous-flow mass spectrometry, the accuracy was determined to be 0.18±2.61 ‰. The isotopic results were normalized against two international water standards: Vienna-Standard Mean Ocean Water and Standard Light Antarctic Precipitation.[33] The isotope dilution spaces for ^2H (N_H) and ^{18}O (N_O) were calculated as follows:

$$N_H \text{ or } N_O \ (\text{mol}) = \frac{d\ x\ A\ x\ E_\alpha}{\alpha\ x\ E_d\ x\ 18.02}$$

where “d” is the dose of ^2H_2O or $H_2{}^{18}O$ in grams, “A” is the amount of laboratory water in grams used in the dose dilution, “α” is the amount of ^2H_2O or $H_2{}^{18}O$ in grams added to the laboratory water in the dose dilution, “E_α“ is the rise in ^2H or ^{18}O abundance in the laboratory water after the addition of the isotopic water, and “E_d“ is the rise in ^2H or ^{18}O abundance in the urine samples at time zero obtained from the zero-time intercepts of the ^2H and ^{18}O decay curves in the urine samples. The use of dose dilution in the calculation of isotope dilution spaces to assure accuracy of the isotope dilution calculations.[34] Carbon dioxide production rate $\left(\dot{V}CO_2\right)$ was calculated from the fractional turnover rates of ^2H (k_H) and ^{18}O (k_O) as follows:[35]

$$\dot{V}CO_2(\text{mol/d}) = 0.4812 \times [(\text{k}_\text{O} \times \text{N}_\text{O}) - (\text{k}_\text{H} \times \text{N}_\text{H})] - 0.0246 \times \text{r}_\text{g}$$

where r_g is the fractionated water loss which was calculated as 1.05 × ($N_O \times k_O - N_H \times k_H$). The $\dot{V}CO_2$ was converted to energy expenditure based on an energy equivalent of a liter of CO_2 to be 3.815/FQ + 1.2321[36] where FQ was the food quotient calculated from food intake.[37]

Statistical Analysis

All analyses were performed in SAS version 9.4 (SAS Institute Inc., Cary, NC, 2012). A p-value of 0.05 was considered the significance level. Means and standard deviations were calculated for EI estimated by the RFPM and the DLW method. To quantify measurement error, the mean percent error (MPE) or relative difference and the root means square error (RMSE) were calculated.

Paired student's t-tests were conducted to compare the RFPM with the DLW method. The null hypothesis was "no difference". Differences between methods were considered statistically significant if zero was not included in the 95 percent confidence interval.

Bland-Altman agreement approach was used to evaluate the level of agreement between the two methods for EI. Differences or bias between the two methods on the Y-axis was plotted against the mean of the two methods on the X-axis. Zero bias line, 95% upper or lower confidence limits (mean difference ± 2 SD of the differences), and the regression trend line were also overlaid on the same plot.

Results

The 39 participating children comprised of 22 boys and 17 girls, 51% Hispanic and 49% African American with a mean age of 5.4 ± 0.6 y (3.7–5.7 years). The children had a mean weight of 18.8 ± 3.9 kg, height of 105.7 ± 7.0 cm, and a BMI of 16.7 ± 1.9 kg/m^2. Thirty-nine percent of the children were overweight or obese (Table 1).

Inter-rater reliability among the raters was excellent (intra-class correlation coefficients ≥. 95). The mean percent of EI from protein was 15.8 % ± 2.7, 53.8 % ± 5.7 for carbohydrates, and 31.7 % ± 4.5 for fat using the RFPM (Table 2). The mean daily EI from the RFPM was 1,191 ± 256 kcal compared to 1,412 ± 220 kcal by the DLW method thus resulting in an underestimation of EI using the RFPM of −222 ± 274 kcal ($p < 0.0001$) (group mean error = −15.6%).

The mean percent error (−28.5% ± 27.5) for the 34 participants whose intake was underestimated by RFPM is illustrated in Figure 1. The mean percent error (15.6% ± 5.34) for the 5 participants whose intake was overestimated by RFPM is also provided in Figure 1. Overall it represented a 15.65% underestimation.

The Bland-Altman limit of agreement plots (Figure 2) for EI showed that there was a slight positive trend of the differences (RFPM-DLW) as the mean EI ((RFPM+DLW)/2) of the two methods increased from 1000 to 1800 kcal/d, but the regression indicated that this bias was not statistically significant ($p = 0.33$). The mean difference was −222 kcal/d, the 95% confidence limits were −759 and 316 kcal/d, and 34 out of the 39 comparisons (87%) fell below the zero line.

Discussion

The RFPM has been validated to remotely measure food intake of free-living adults[22,20] and with preschool children in a controlled environment.[38] This is the first study to assess 24-hour EI using a mobile phone and comparing it to EI assessed using the reference DLW method in US minority preschool children in a free-living environment. The results showed that EI was underestimated using the RFPM when compared to the DLW method. The limits of agreement in the Bland-Altman plot were wide, indicating low accuracy for RFPM in estimating EI. The mean difference observed between EI by RFPM and the DLW method (−16%) fell within the measurement errors reported in young children (range −6% to 59%) using traditional dietary methods.[1, 2] In one study using a mobile phone-based tool to assess

EI in young Swedish children, a small mean difference in EI of −4% was reported between mobile phone and the DLW method[39] with overestimation observed among children with high EI and underestimation observed among children with low EI based on one day of food intake. This is in contrast with findings from this study, using the RFPM to assess seven days of dietary intake and corresponding urine collections for the DLW method. The RFPM underestimated EI when compared to the DLW method and the magnitude of the bias was consistent regardless of intake.

A comparison was conducted using NHANES 2011–2012[40] data to determine the comparability of the macronutrient intakes of 2-to 5 year old children using the RFPM. The mean intake of total energy, protein, carbohydrate, and fat were higher than what was reported in this study suggesting that the RFPM underestimated all of the macronutrients. There are several possible explanations for the consistent underestimation using the RFPM method to assess EI of young children. There were technical problems with the mobile phones which needed to be replaced by research staff immediately after the problem was reported by the caregivers. Despite using Ecological Momentary Assessment to consistently remind the caregivers to take photographs of the foods and beverages for meals and snacks, it is clear from the assessment of the number of photographs taken that the caregivers fell short of taking photographs of all the foods and beverages consumed by the children. It is not possible to determine what meals and snacks may have not been assessed since the DLW method provided an average of the seven days and was not broken down by time of day or by specific meals and snacks. Another challenge was training of multiple caregivers to use the RFPM. Although training was offered upon screening to all those who would be assisting the child at meal times, not all families disclosed having multiple caregivers which resulted in a few caregivers not receiving the training needed on using the SI application to take and send pictures.

Conclusion

Although traditional dietary methods have inherent limitations, such as memory recall, inaccurate portion size estimations, limited knowledge of foods and food preparation and cognitive abilities, the RFPM presents its own unique challenges as noted above. Although the RFPM has been used successfully with adults and older children in a variety of settings, it underestimated EI when compared to the DLW method among minority preschoolers. Further refinement of the RFPM is needed for assessing EI of young children, particularly those with multiple caregivers.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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STUDY IMPORTANCE

- The Remote Food Photography has been validated to measure food intake of free-living adults in real-time.
- This is the first study to assess energy intake (EI) using mobile phones and compare it to EI assessed using the doubly labeled water method in minority preschool children

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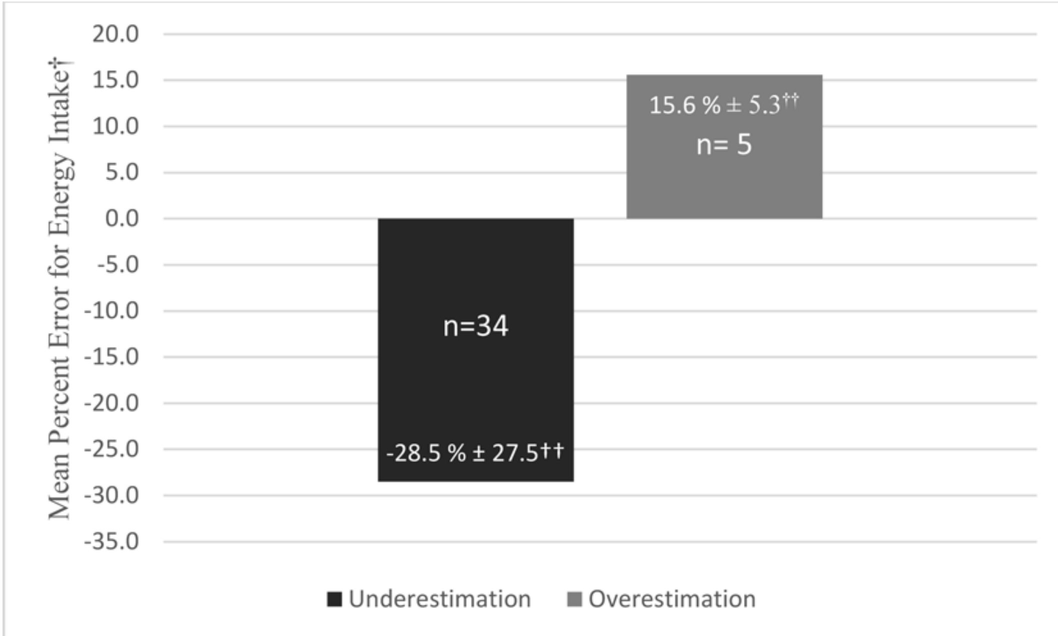

Figure 1.

Mean percent error for the 34 participants whose intake was underestimated by the RFPM when compared to the reference doubly labeled water (DLW) method and mean percent error for the 5 participants whose intake was overestimated by the RFPM when compared to the DLW method.

†Mean percent error= (RFPM-DLW)/DLW

RFPM: Remote Food Photography Method

DLW: Double Labeled Water

††Mean Percent Error ± Standard Deviation

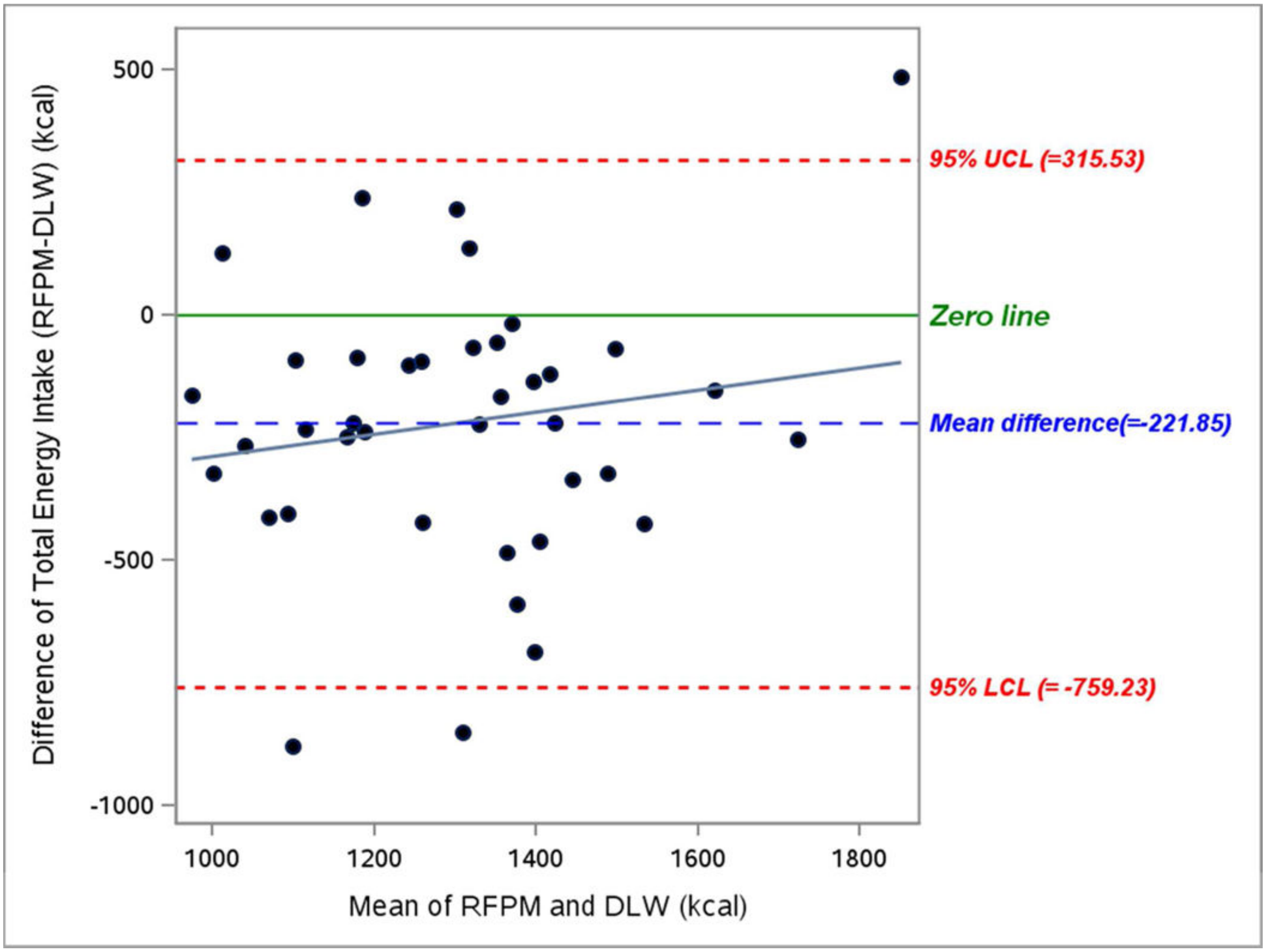

Figure 2.

A Bland-Altman plot comparing energy intake using the Remote Food Photography Method (RFPM) and total energy expenditure (TEE) measured using the double labeled water (DLW) method in 39 preschool children. The mean difference between the methods was −222 kcal/d with limits of agreement (2 SD) of 316 kcal/d. The regression was: Difference in energy intake (RFPM-DLW) = −517.91+ 0.23 × Mean of (RFPM and DLW), R^2= 2.6%, p-value=0.33.

RFPM: Remote Food Photography Method

DLW: Double Labeled Water

UCL: Upper Confidence Limit

LCL: Lower Confidence Limit

Table 1

Descriptive statistics of the demographics of 39 children who participated in the validation of the remote food photography method

	Total
Sample (n)	39
Gender (n (%))	
Male	22 (56.4)
Female	17 (43.6)
Ethnicity/Race (n (%))	
Hispanic	20 (51.3)
African American	19 (48.7)
Weight status, n (%)	
Normal (< 85th percentile)	24 (61.5)
Over weight (≥ 85th and < 95th percentile)	10 (25.6)
Obese (≥ 95th percentile)	5 (12.8)
Age (years) (mean ± SD)	5.4 ± 0.6
Weight (kg) (mean ± SD)	18.8 ± 3.9
Height (cm) (mean ± SD)	105.7 ± 7.0
BMI (kg/m^2)	16.7 ± 1.9

SD= standard deviation

BMI= body mass index

Table 2

Mean intake of macronutrients using the Remote Food Photography Method (RFPM) compared to the Doubly Labeled Water (DLW) Method

			Lower 95% CL for Mean	
	Mean	**SD**	**LCL**	**UCL**
RFPM				
Protein (g)	46.50	10.11	43.22	49.78
Carbohydrate (g)	159.29	42.22	145.61	172.98
Fat (g)	42.40	10.83	38.89	45.91
% Calories from Protein	15.84	2.74	14.95	16.72
% Calories from Carbohydrate	53.75	5.70	51.90	55.60
% Calories from Fat	31.65	4.53	30.18	33.12
Energy intake (kcal/d)	1190.5	256.1	1107.5	1273.6
Food Quotient (FQ)	0.88	0.02	0.88	0.89
DLW Method				
N_H(kg)	11.03	1.90	10.41	11.64
N_O(kg)	10.70	1.84	10.10	11.29
N_H/N_O	1.03	0.01	1.03	1.03
K_H (d^{-1})	−0.12	0.02	−0.13	−0.11
k_O (d^{-1})	−0.17	0.02	−0.17	−0.16
TEE (kcal/d) *	1412.4	220.0	1341.1	1483.7
Lean body mass (kg)	13.8	2.4	13.0	14.5
Body fat (kg)	5.1	1.9	4.5	5.7
Body fat (%)	26.6	5.3	24.9	28.3
Energy Difference (RFPM – DLW Method) (kcal/d) *	−221.9	274.2	−310.7	−133.0

* p-value < 0.0001; Mean Percent Error = −22.82 ± 29.71; Root Mean Square Error = 243.68

CL= confidence limit

SD= standard deviation

LCL= lower confidence limit

UCL= upper confidence limit

RFPM= Remote Food Photography Method

DLW= Doubly Labeled Water

N_H = isotope dilution space of ^2H

N_O = isotope dilution space of ^{18}O

k_H = fractional turnover rate of ^2H

k_O = fractional turnover rate of ^{18}O

TEE= total energy expenditure