Validity of the Remote Food Photography Method Against Doubly Labeled Water Among Minority Preschoolers

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Objective: The aim of this study was 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 thirty-nine 3- to 5-year-old Hispanic and African American children. Using an iPhone, caregivers captured before and after pictures of each child’s intake, pictures were wirelessly transmitted to trained raters who estimated portion size using existing visual estimation procedures, and energy and macronutrients were calculated. Paired t tests, mean differences, and Bland-Altman limits of agreement were performed.

Results: The mean EI was 1,191 ± 256 kcal/d using the RFPM and 1,412 ± 220 kcal/d using 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 the EI of young children.

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 more accurate estimates of energy intake (EI) than the doubly labeled water (DLW) method (1). However, the method entailed a high participant response burden and was impractical for young children who have multiple caregivers and eating occasions in different settings outside of the 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). Smartphones are equipped with high-resolution digital cameras, high memory capacity, network capacity, and faster processors, making 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 minimize errors from memory recall and portion size estimations (10). The image-assisted records have shown significantly higher estimates (P = 0.001) of total EI per eating occasion than proxy-assisted records (11,12); thus, reports from other studies (13-15) have indicated a reduction in underreporting when smartphones were used to record data. The amenability and acceptability of a mobile food record were examined among young children 3 to 10 years of age attending summer camps. Given instructions with demonstration and practice, children were able to use the mobile food record to document 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 have identified the following as strengths: faster, almost real-time data collection, reduced memory bias, good respondent acceptance, and suitability 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 smartphone 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 a 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 the 24-hour EI of minority preschool children (aged 3-5 years) under free-living conditions against the reference DLW method during a period of relative energy balance in which total energy expenditure was equal to EI (23,24).

**Methods**

The study was approved by the Baylor College of Medicine Review Board, the Pennington Biomedical Research Center Institutional Review Board, and the Head Start (HS) administration in Houston, Texas. 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. Because of 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 were Hispanic (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 using the SmartIntake (SI) application, and received instructions on how to return all materials at the end of the study. Caregivers took pictures of each 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 each child daily for seven consecutive days. Due to the commitment required from caregivers, families allowed for color correction. A total of 2,674 pictures of foods/beverages were taken by the caregivers and teachers (Supporting Information Table S1).

**Training caretakers to take photographs using the SI application**

Both caregivers and teachers received training and practiced using the SI application to capture and transmit images of foods/beverages consumed by each child. Training of the caregivers and teachers was conducted using a standardized protocol that has been used in other studies (25,26). In a private area of the HS center, coordinators met the caregivers and teachers and provided them with iPhones loaded 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 the 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 (Supporting Information Table S1).

**Training caretakers to collect and store urine samples**

Following study coordinators’ directions, caregivers successfully collected the baseline urine samples from each child in a sterilized specimen container. Using an individually wrapped plastic pipette, caregivers transferred approximately 2 mL of urine into two prelabeled cryogenic vials. The day, time, and date of the collection were documented. Caregivers were provided the 7-day supply of urine collection materials. At home, caregivers collected the postdose urine sample 6 to 8 hours after dose administration. Thereafter, for 7 consecutive days, caregivers collected spot urine samples from each child while excluding the first void in the morning. Urine samples were transferred to the o-ring cryogenic vials (VWR International, Sugar Land, Texas) 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$_2$O at 99.98 atom % $^2$H and 1.38 g of 10% $^{18}$O (17-29). 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 7-day DLW study period for accurate and precise isotope ratio measurements. The DLW dose was measured using a calibrated electronic scale (Sartorius Corp., Bohemia, New York) 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 to 20 mL of bottled spring water and the child was asked to drink each rinse using the same straw.

**Anthropometry**

Height and weight were collected for all children and were measured twice, once at baseline and another time after the 7 days of observation to monitor growth. Height was measured to the nearest 0.1 cm using the Seca 213 stadiometer (Seca & Co., Hamburg, Germany) and weight to the nearest 0.1 kg using a Health-O-meter 751 KLS scale (Sunbeam Products Inc., Boca Raton, Florida). Each child’s initial weight was used to calculate the DLW dosage.

**Measuring EI**

Caregivers used the iPhone for 7 consecutive days for taking before and after pictures of all foods and beverages consumed by each child and of 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 or meat consumed, 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 application. Pictures and the composed descriptions 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 the Pennington Biomedical Research Center, where human raters performed the diet estimations.

Training of human raters

Digital diet estimations. The human raters had 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” photographs or situations were presented, and the raters were provided with 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 photograph library was created that consisted of an archive of more than 15,000 photographs of different foods, each with different portion sizes of the same food. Raters individually estimated the portion size of each food item on the subject’s plate in the “before” photograph as a percentage of the portion size displayed in a selected standard photograph of the food item. The “before” photograph was matched to a proper food code in the United States Department of Agriculture 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” photograph. 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. 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 attended a weekly meeting in which 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 application. When raters’ estimates of the same food differed by ≥30% or when 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 each rater’s data set. Conflicts in rater estimates were discussed as a group to arrive at a consensus.

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, United Kingdom) that contained ~5 mg of activated charcoal (Fisher Scientific, Sugar Land, Texas), ~200 mg of copper powder (Fisher Scientific, Sugar Land, Texas), and a platinum catalytic rod (Thermo Scientific, Madison, Wisconsin). After recapping the Exetainer, the content was flushed with 2% H₂ in helium (Air Liquide USA, Houston, Texas) at 483 kPa for 7 minutes. The sample was then allowed to equilibrate with the H₂ at room temperature for at least 3 hours. At the end of the equilibration, an aliquot of the H₂ in the Exetainer was injected into a Thermo Delta V Advantage mass spectrometer system (Thermo Electron North America, West Palm Beach, Florida) for stable hydrogen isotope ratio measurement. The same sample was analyzed for 18O content after 22 hours of equilibration with CO₂ of known 18O content again using the Thermo Delta V Advantage mass spectrometer system (32). The 2H assays using the equilibration method were determined to be accurate within 2.8‰ and reproducible to within 4.0‰. For 18O 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 (N₂H) and 18O (NO) were calculated as follows:

\[ N_{HI} \text{ or } N_{IO} (\text{mol}) = \frac{d \times A \times E_{a}}{z \times E_{a} \times 18.02} \]

In this equation, d is the dose of 2H₂O or H₃¹⁸O in grams, A is the amount of laboratory water in grams used in the dose dilution, z is the amount of 2H₂O or H₃¹⁸O in grams added to the laboratory water in the dose dilution, Eₐ is the rise in 2H or 18O abundance in the laboratory water after the addition of the isotopic water, and Eₙ is the rise in 2H or 18O abundance in the urine samples at time zero obtained from the zero-time intercepts of the 2H and 18O decay curves in the urine samples. Dose dilution in the calculation of isotope dilution spaces was used to assure accuracy of the isotope dilution calculations (34). Carbon dioxide production rate (\( \dot{V} CO₂ \)) was calculated from the fractional turnover rates of 2H (k₄₁) and 18O (k₅₀) as follows (35):

\[ \dot{V} CO₂ (\text{mol/d}) = 0.4812 \times [(k_0 \times N_O) - (k_{HI} \times N_{HI})] - 0.0246 \times r_g \]

In this equation, r₉ is the fractionated water loss that was calculated as 1.05 × N₂H × k₅₀ – N₄H × k₄₁. The \( \dot{V} CO₂ \) was converted to energy expenditure based on an energy equivalent of a liter of CO₂ 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, North Carolina). A P value of 0.05 was considered significant. Means and standard deviations (SD) 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 were calculated.

Paired Student 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% confidence interval.

The 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. The zero bias line, 95% upper or lower confidence limits (mean difference ± 2 SDs of the differences), and the regression trend line were also overlaid on the same plot.

Results
The 39 participating children comprised 22 boys and 17 girls, 51% Hispanic and 49% African American, with a mean age of 5.4 ± 0.6 years (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/m². Thirty-nine percent of the children had overweight or obesity (Table 1).

Interrater reliability among the raters was excellent (intraclass correlation coefficients ≥0.95). 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

### TABLE 1 Demographics of 39 children who participated in the validation of the RFPM

|                | 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) |
| Overweight (≥ 85th and < 95th percentile) | 10 (25.6) |
| Obesity (≥ 95th percentile) | 5 (12.8) |
| Age (y), mean ± SD | 5.4 ± 0.6 |
| Weight kg), mean ± SD | 18.8 ± 3.9 |
| Height (cm), mean ± SD | 105.7 ± 7.0 |
| BMI (kg/m²), mean ± SD | 16.7 ± 1.9 |

### TABLE 2 Mean intake of macronutrients using the RFPM compared to the DLW method

|                | 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|
| EI (kcal/d)    | 1,190.5| 256.1| 1,107.5| 1,273.6|
| Food quotient  | 0.88 | 0.02| 0.88 | 0.89 |
| **DLW method** |      |     |      |      |
| Nh (kg)        | 11.03| 1.90| 10.41| 11.64|
| N0 (kg)        | 10.70| 1.84| 10.10| 11.29|
| Nh/N0          | 1.03 | 0.01| 1.03 | 1.03 |
| k<sub>H</sub> (d<sup>−1</sup>) | −0.12| 0.02| −0.13| −0.11|
| k<sub>0</sub> (d<sup>−1</sup>) | −0.17| 0.02| −0.17| −0.16|
| TEE (kcal/d)<sup>a</sup> | 1,412.4| 220.0| 1,341.1| 1,483.7|
| 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)<sup>a</sup> | −221.9| 274.2| −310.7| −133.0|

k<sub>H</sub>, fractional turnover rate of <sup>2</sup>H; k<sub>0</sub>, fractional turnover rate of <sup>18</sup>O; LCL, lower confidence limit; Nh, isotope dilution space of <sup>2</sup>H; N0, isotope dilution space of <sup>18</sup>O; TEE, total energy expenditure; UCL, upper confidence limit; EI, energy intake; MPE, mean percent error.

<sup>a</sup>P < 0.0001; MPE = −22.82 ± 29.71; root mean square error = 243.68.
Obesity can be viewed at wileyonlinelibrary.com.

MPE 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 MPE (−28.5% ± 27.5%) for the 34 participants whose intake was underestimated by RFPM is illustrated in Figure 1. The MPE (15.6% ± 5.34%) for the five participants whose intake was overestimated by RFPM is also provided in Figure 1. Overall, it represented a 15.6% 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 1,000 to 1,800 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 kcal/d 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 (20,22) and with preschool children in a controlled environment (38). This is the first study to assess 24-hour EI using a mobile phone and compare 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 the mobile phone and DLW methods (39), with overestimation observed among children with high EI and underestimation observed among children with low EI based on 1 day of food intake. This is in contrast with findings from this study, which used the RFPM to assess 7 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 National Health and Nutrition Examination Survey 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 the 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, as the DLW method provided an average of the 7 days and was not broken down by time of day or by specific meals and snacks. Another challenge was the training of multiple caregivers to use the RFPM. Although training was offered upon screening to all those who would be assisting the children 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 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.

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