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Validity of energy intake estimated by digital photography + recall in overweight and obese young adults

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Abstract

Background—Recent reports have questioned the adequacy of self-report measures of dietary intake as the basis for scientific conclusions regarding the associations of dietary intake and health, and reports have recommended the development and evaluation of better methods for the assessment of dietary intake in free-living individuals. We developed a procedure that utilized pre-

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and post-meal digital photographs in combination with dietary recalls (DP+R) to assess energy intake during *ad libitum* eating in a cafeteria setting.

Objective—To compare mean daily energy intake of overweight and obese young adults assessed by a DP+R method with mean total daily energy expenditure assessed by doubly labelled water (TDEE_{DLW}).

Methods—Energy intake was assessed using the DP+R method in 91 overweight and obese young adults (age = 22.9±3.2 yrs., BMI=31.2 ± 5.6 kg·m², female = 49%) over 7-days of *ad libitum* eating in a University cafeteria. Foods consumed outside the cafeteria (i.e., snacks, non-cafeteria meals) were assessed using multiple-pass recall procedures using food models and standardized, neutral probing questions. TDEE_{DLW} was assessed in all participants over the 14-day period.

Results—The mean energy intakes estimated by DP+R and TDEE_{DLW} were not significantly different (DP+R = 2912 ± 661 kcal/d; TDEE_{DLW} = 2849 ± 748 kcal/d, *p* = 0.42). The DP+R method overestimated TDEE_{DLW} by 63 ± 750 kcal/d (6.8 ± 28%).

Conclusion—Results suggest that the DP+R method provides estimates of energy intake comparable to those obtained by TDEE_{DLW}.

Keywords

Digital Photography; Diet Intake; Food Records; Doubly Labeled Water; Energy Balance

INTRODUCTION

Improved methods for the assessment of dietary intake are needed to advance our understanding of the association between energy and macronutrient intake and the risk for chronic diseases including cancer, heart disease, diabetes, and obesity.^{1–3} Dietary intake in health-related research is typically assessed using self-report measures including food frequency questionnaires, diet records, and recalls.^{4–6} However, self-report measures have been shown to underestimate energy intake by approximately 20% when compared with objectively measured energy expenditure (doubly labeled water),^{7–9} with greater underestimations in overweight and obese individuals compared with normal weight individuals.^{9–11} Although relatively inexpensive and convenient, several recent reports have questioned the adequacy of self-report measures of dietary intake as the basis for scientific conclusions regarding the associations of dietary intake and health.^{3,12,13} They also suggested that investigators should work to improve and apply newer methods of energy intake assessment suitable for use in free-living individuals, such as remote sensing devices^{14,15} or digital photography,¹⁶ rather than continuing to rely on self-report.

Digital food photography, in which images of food selections and any food remaining after the meal are used to estimate dietary intake, may provide a quick, unobtrusive method for the assessment of dietary intake in relatively large samples of individuals in naturalistic settings. The digital approach eliminates reliance on participant estimations of portion size, which have been shown to be a major source of error with self-report measures of energy

intake.¹¹ Participant training has been shown to improve portion size estimation only moderately.¹⁷

Digital photographic assessments have been employed in studies on dietary intake in military recruits during basic training¹⁸ and in both pre-school¹⁹ and elementary school children;²⁰ however, evidence for the validity of these methods is limited. With the exception of the Remote Food Photography method described by Martin et al,²¹ which uses a smartphone to capture food images and plate waste, validity for the other digital photographic approaches has been established by comparing estimates of food weight by digital photography vs. measured food weight of test meals in a laboratory setting^{18,19} or against weighed food records over 1 to 7 days²² rather than against a biomarker of energy expenditure, such as doubly labelled water in free-living individuals.

Our group has an interest in studying energy balance in the context of clinical weight management trials; therefore, we have developed and/or evaluated methods for the assessment of energy intake in overweight and obese individuals.^{23,24} An earlier trial assessed energy intake over 14-day periods of ad libitum eating in a university cafeteria. Research staff weighed all foods and beverages before and again after completing the meal. Any food/snacks or beverages consumed outside the cafeteria were captured by dietary recalls conducted prior to each meal. Baseline data indicated this method provided estimates of mean energy intake within ~3% of total energy expenditure assessed by doubly labeled water.²⁴ However, the burden for both participants and investigators of this time and labor-intensive procedure make its use impractical for most applications. To reduce participant and investigator burden, a procedure was developed which utilized pre- and post-meal digital photographs in combination with dietary recalls (DP+R) to assess energy intake during ad libitum eating in a cafeteria setting for use in a recently completed 10-month Midwest Exercise Trial-2 (MET-2). In the analysis presented herein, baseline data from MET-2 was used to compare mean daily energy intake assessed by the DP+R procedure with mean total daily energy expenditure assessed by doubly labelled water (TDEE_{DLW}).

SUBJECTS AND METHODS

Background

The primary aim of MET-2 was to evaluate the role of aerobic exercise training without energy restriction on weight and body composition. A detailed description of the design and methods for MET-2,²⁵ results for the primary outcomes,²⁶ and changes in non-exercise energy expenditure and physical activity²⁷ and energy and macronutrient intake²⁸ have been published. Briefly, MET-2 randomized young adults age 18–30 years with BMI 25–40 kg/m² to a 10-month, 5 d/wk. supervised exercise intervention at 2 levels of exercise energy expenditure (400 or 600 kcal/session) or non-exercise control.

Participant eligibility

Potential participants were excluded for the following reasons: age outside the range 18–30 years, BMI outside the range 25–40 kg/m², a history of chronic disease (e.g., diabetes, heart disease, etc.), elevated blood pressure (>140/90 mm/Hg), fasting lipids (cholesterol >

259 mg/dl; triglycerides > 495 mg/dl), fasting glucose (> 140 mg/dl),²⁹ use of tobacco products, taking medications that would affect physical performance (e.g., beta blockers) or metabolism (e.g., thyroid, steroids), inability to perform laboratory tests or to participate in moderate-to-vigorous intensity exercise, and currently engaged in planned physical activity greater than 500 kcal/wk. as assessed by recall.³⁰

Recruitment

Potential participants were obtained from a variety of sources including advertisements in the local and campus newspapers and radio stations, flyers in campus buildings, and postings on our laboratory website. All forms of advertisement included our dedicated study phone number as well as our laboratory web site and study e-mail address. Potential participants completed a web-based initial eligibility screener regarding height and weight to determine BMI, use of medications, smoking and drinking habits, and current levels of physical activity. Those without web access completed the initial screen by hard copy or telephone interview. Participants who appeared eligible based on the initial eligibility questionnaire met with the project coordinator who described the study, answered questions, obtained written informed consent, and assessed height and weight to determine final eligibility. A total of 2,338 individuals completed the initial eligibility questionnaire. One hundred and forty-one individuals were determined to be eligible and were randomized to one of the 3 study groups. Of the 141 participants randomized, the 91 participants (46 men, 45 women) who completed the 9-month study and completed all assessments of energy intake by DP+R and TDEE_{DLW} were included in this analysis.²⁶ Approval for this study was obtained from the Human Subjects Committee at the University of Kansas-Lawrence. Participants were financially compensated for participation.

Digital photography+diet recall (DP+R)

The study protocol required participants to eat a minimum of 2 meals/d on weekdays and 1 meal/d on weekends over the 7-day period in a university cafeteria. The cost of food was incurred by the study. The cafeteria featured a food court where different stations offered specialized items, such as stir-fry, pasta, salads, sandwiches, pizza, and grilled foods. Participants typically had a choice between 8 to 10 entrees at each meal. The cafeteria was open for a total of 9.5 hours on weekdays and 5.5 hours on weekends (brunch and dinner). After obtaining their food, participants reported to the research station located in a corner of the cafeteria and placed their tray in a docking station to standardize distance and the camera angle for digital photographs. Two digital still photographs were taken by a digital camera (Canon Power Shot, Melville, NY) approximately 30 inches above the tray. One photograph was taken from directly above the tray (90° angle) and another was taken at a 45° angle to maximize depth perception and improve identification of specific food and beverage items (Figure 1). Notes were placed on the tray to identify types of beverages (e.g. diet vs. regular soft-drink, skim vs. whole milk, etc.) and any other food items that would be difficult to identify from the photo. Condiments were served in individual bowls to assess portion size. Additionally, standard measures for both liquids and solids were included in the photo to guide the assessment of portion size (Figure 2). After completing their meal, participants returned to the research station where the identical photographic procedure was repeated to

verify the quantity of food consumed. If second helpings were obtained, the photographic procedure was repeated with the second round of food and beverage items.

All digital photographs were downloaded to a secure server for analysis. Dietary recalls, using multiple-pass procedures with food models and standardized neutral probing questions,³¹ were conducted at each cafeteria meal to document any foods or beverages consumed outside the cafeteria. The type and amounts of food and beverages consumed at the cafeteria, and results from recalls were entered into the Nutrition Data System for Research (NDS-R Versions 2011, University of Minnesota, Minneapolis, MN) for the quantification of energy intake.³² Vendor product information, recipes, and cooking methods for all foods and beverages served at the cafeteria were entered into the nutrition database. The daily energy intake for each participant was calculated as the difference between pre- and post-energy content of all meals estimated from digital photographs plus the energy content of foods and beverages consumed outside the cafeteria captured by recall.

Nutrition research staff training

Nutrition research staff, which consisted of undergraduate and graduate college students, attended a 2-hr. training session conducted by the study registered dietitian nutritionist (RDN) where the DP+R procedure was described and demonstrated. Under the supervision of the RDN, participants practiced estimating food items and portion size from sample pre- and post-meal photos previously prepared by the RDN and practiced conducting diet recalls. Prior to collecting data on study participants, nutrition research staff were required to satisfactorily evaluate digital photographs from 10 sample meals and complete ten 24-hr. recalls from non-study participants. The RDN prepared sample meals (breakfast, lunch, dinner) from foods and beverages available at the university cafeteria to serve as a standard for assessing the ability of nutrition staff to identify foods and estimate portion sizes from digital photographs. The portion size of all foods and beverages was measured before and after removing a specified amount to simulate consumption. Energy intake for each of the 10 meals was then calculated using NDS-R. Prior to performing digital photograph analysis on study data, research staff were required to produce energy expenditure estimates from digital photography that were within 5% of actual energy intake for all ten sample meals. Staff failing to meet this standard received additional training from the RDN and were re-evaluated using 10 new meals until the standard was achieved. The RDN also observed research staff as they completed ten 24-hr. recalls on non-study participants. Recalls were evaluated according to a published dietary recall documentation checklist.³³ An error rate of 5% against the recall checklist for all 10 recalls were required prior to data collection on study participants. Additional training and re-evaluation was required for staff failing to meet this standard. Inter-rater reliability coefficients for both digital photograph and 24-hr. recall assessments were 0.95.

Total Daily Energy Expenditure (TDEE_{DLW})

TDEE_{DLW} was assessed over a 14-day period at baseline. Participants reported to our laboratory between 8 and 9 a.m. after an over-night fast. Baseline urine specimens were collected from each participant prior to oral dosing with a mixed solution of ²H₂ ¹⁸O. The isotope was given to each participant based on body weight (0.10g·kg⁻¹ of ²H₂O and

0.15g·kg⁻¹ H₂ ¹⁸O) and was followed with a rinse solution of 100ml of tap water. A weighed 1:400 dilution of each participant's dose was prepared, and a sample of the tap water was stored at -70°C for later analysis. Additional urine samples were collected on days 1 and 14. On these days, 2 urine samples were collected at least 3 hours apart. All urine samples were stored in sealed containers at -70°C prior to analysis. Samples were analyzed in duplicate for ²H₂O and H₂ ¹⁸O by isotope ratio mass spectrometry as previously described by Herd et al.³⁴ Total daily energy expenditure (TDEE) was estimated using the equation of Elia³⁵: Total EE (Mj/d) = (15.48/RQ + 5.55) × rCO₂ (L/d). This approach assumes that the thermic effect of food represents 10% of TDEE.³⁶ Energy intakes by DP+R were assessed during week one of the doubly labelled water period. There were no significant changes in body weight in either men (0.25 ± 1.2 kg) or women (0.29 ± 0.98 kg) over the 14-day doubly labelled water period.

Statistics

Baseline measures and demographic characteristics were summarized using means and standard deviations for continuous variables, and frequencies and percentages were used for categorical variables. Dependent t-tests were used to evaluate the mean difference between energy intake estimated by DP+R and our criterion measure (TDEE_{DLW}). Differences in energy intake (kcal/d) were computed as DP+R minus TDEE_{DLW}; thus, negative values indicate underestimation and positive values indicate overestimation of energy intake by DP+R. Agreement between energy intake estimated by DP+R and TDEE_{DLW} was evaluated using Bland-Altman plots.³⁷ Specifically, plots of the difference between TDEE_{DLW} and energy intake estimated by DP+R versus the mean of TDEE_{DLW} and DP+R were examined. Limits of agreement between TDEE_{DLW} and energy intake estimated by DP+R were calculated as the mean difference ± 2 standard deviations. All analyses were conducted using SAS 9.3 (SAS Institute, 2002–2010).

RESULTS

The study sample (Table 1) consisted of 91 overweight and obese men (n=46) and women (n=45) with an age range from 18 to 30 yrs., who were primarily non-Hispanic and white (86%).

DP+ R vs. TDEE_{DLW}

There were no significant differences between mean energy intake estimated by DP+R and TDEE_{DLW} in the total sample (DP+R = 2912 ± 661 kcal/d; TDEE_{DLW} = 2849 ± 748 kcal/d, $p = 0.42$) or in men (DP+R = 3267 ± 665 kcal/d; TDEE_{DLW} = 3236 ± 667 kcal/d, $p = 0.80$) or women (DP+R = 2550 ± 423 kcal/d; TDEE_{DLW} = 2453 ± 608 kcal/d, $p = 0.34$). On average, DP+R overestimated energy intake compared to TDEE_{DLW} by 63 ± 750 kcal/d (6.8 ± 28%; limits of agreement: -1437, 1564 kcal/d) in the total sample, 31 ± 818 kcal/d (4.4 ± 28%; limits of agreement: -1266, 1460 kcal/d) in men and 97 ± 682 kcal/d (9.2 ± 29%; limits of agreement: -1606, 1667 kcal/d) in women (Figure 3). The Bland-Altman plot indicates that the proportional bias did not vary as a function of the level of energy intake in the total sample ($R = -0.13$, $p = 0.21$, Figure 3a) or in women ($R = -0.004$, $p = 0.98$, Figure 3b). However, in men the DP+R method tended to underestimate at higher levels of energy

intake ($R = -0.35$, $p = 0.02$, Figure 3c). Energy intake estimated by DP+R was within $\pm 10\%$ of the criterion measure ($TDEE_{DLW}$) in 35% of the total sample, 31% of men and 39% of women, less than 10% of $TDEE_{DLW}$ in 21% of the total sample, 24% of men and 17% of women, and greater than 10% of $TDEE_{DLW}$ in 44% of the total sample 45% of men and 44% of women.

DISCUSSION

The DP+R method provided a valid estimate of energy intake in overweight and obese young adults during ad libitum eating in a cafeteria setting. The magnitude of error was small in the total sample and in both men and women compared with error associated with self-report measures of energy intake observed by others ($\sim 22\%$).³³ Proportional bias did not vary by level of energy intake in the total sample or in women; however, in men, the DP+R method tended to underestimate at higher levels of energy intake. The magnitude of error for the DP+R method is greater than we observed in our previous study, also conducted in overweight and obese young adults in a cafeteria setting, using energy expenditure assessed by DLW as a criterion (6.8% vs. $\sim 3\%$).²⁴ However, in our previous study, energy intake was estimated from investigator measured pre- and post-meal food and beverage weights, plus recalls of foods and beverages consumed outside the cafeteria; procedures that are burdensome for both participants and investigators. Thus, the DP+R method provides reasonable estimates of energy intake, with an acceptable level of burden for both participants and investigators, when compared with weigh and measure methods.

No previous studies were identified that compared estimates of energy intake obtained by either video or still digital photography with energy expenditure assessed by doubly labeled water in free living individuals eating in a cafeteria setting. However, the error associated with our DP+R method is consistent with those reported for a Digital Photography of Foods Method (DPFM) which used a digital video camera in the cafeteria setting to obtain images of foods before and after consumption to estimate energy intake³⁸ when compared with other criterion measures. For example, the validity for the DPFM has been evaluated in both laboratory and cafeteria settings using investigator weighed foods and BMI as a criterion. Williamson et al.¹⁸ reported a significant overestimation of mean measured food intake weight of 5.2 ± 0.95 g (5.7%, $p < 0.05$) compared with intake estimated by the DPFM, and 3.9 ± 0.76 g (4.3%, $p < 0.05$) when food intake weight was estimated by visual observation over 60 test meals prepared to represent typical meals served in a university cafeteria. Nicklas et al.¹⁹ reported food weight estimated by the DPFM was slightly lower (10.6 g, $\sim 4\%$, $p = 0.11$) than directly measured food weight based on 22 lunch meals served to pre-school children in a laboratory setting. There is limited information regarding the validity of other approaches utilizing digital photography to estimate energy intake. For example, Wang et al.³⁹ reported a non-significant overestimation of energy intake ($\sim 6\%$, $p > 0.05$) over 1 day in 20 female undergraduate food and nutrition majors based on energy intake estimated from pre and post consumption pictures obtained with a camera-equipped handheld personal digital assistant (PDA) which were sent to an RDN for analysis, compared with a 1-day weighed diet record. In a subsequent study, Wang et al.⁴⁰ compared energy intake assessed with the camera-equipped PDA system and energy intake assessed by weighed diet record over 1 day, on 2 separate occasions in 28 young females. Results indicated non-significant

($p > 0.05$) underestimation of energy intake for trial 1 (60 kcal/d, 3.8%) and non-significant overestimation for trial 2 (35 kcal/d, 2.3%). However, in a larger sample of free-living adult men and women ($n=75$, age = 48.8 ± 10.2 yrs., BMI = 24.2 ± 2.6 kg/m²) energy intake over 5 days, assessed by the camera-equipped PDA system significantly underestimated energy intake assessed by weighed diet records (259 kcal/d, 13%, $p < 0.001$).

Although the procedures for data acquisition were slightly different, the results from the current study are also consistent with those reported for a remote food photography method (RFPM) designed to assess energy intake in free living individuals developed by Martin et al.⁴¹ The RFPM used a camera-enabled cell phone to take pre and post consumption digital pictures of food which were transmitted to researchers via a cellular network for analysis. Three to 4 prompts per day, customized to be delivered by cell phone around participant's meal times, were used to improve compliance to the protocol. Back-up methods, generally food records, were used when there were technical problems or problems with participants accessing their cell phone. Validity was assessed over 6 days in 13 free-living overweight or obese (33.1 ± 3.4 kg/m²) adults (43.7 ± 12.9 yrs., ~88% women) by comparing energy intake estimated by the RFPM with energy expenditure assessed by doubly labelled water.²¹ Results indicated the RFPM underestimated energy intake (-270 ± 748 kcal/d, $8.8\% \pm 29.8\%$; $p = 0.22$) compared with energy expenditure assessed by DLW with the magnitude of error consistent over levels of energy intake. Energy intake from back-up methods constituted 9.7% of total estimated energy intake. A second study in a larger sample of 42 free-living overweight or obese (31.2 ± 5.1 kg/m²) adults (41.0 ± 12.8 yrs., 88% women), employing the same 6 day protocol as previously described, showed that energy intake using the RFPM was not significantly different from energy intake assessed by DLW (-152 ± 694 kcal/d, $-3.7 \pm 28.7\%$; $p = 0.16$).²¹ Interestingly, the current study demonstrated a non-significant difference between energy intake estimated by the DP+R method and TDEE_{DLW} even though 28.8% of the total estimated energy intake was derived from foods consumed outside the cafeteria setting that was obtained by recall. Thus, the current studies results, and the results of Martin et al.²¹ suggest that the error in estimates of energy intake obtained with digital photography (range -8.8% to 6.8%), even when digital photographs are not available for 100% of foods consumed, still represent a clear improvement over energy intake estimated from self-reports. As illustrated in the current study and the study by Martin et al.,²¹ it is difficult, if not impossible, to observe all foods/beverages consumed in free-living participants. Therefore, implementing techniques such as smartphone photos, which have been shown to improve the quality of diet recalls^{22,23} to improve the accuracy of the DP+R method should be investigated.

The DP+R described herein might be considered an expensive alternative to self-reports. Although a cost analysis was not completed, the expected staff time/cost required to obtain and process photos would not be dissimilar from that required to obtain and process 3 or 7-day food records. In addition, this study, as well as others, have demonstrated that research assistants, who can be hired at reasonable hourly rates, can be trained by an RDN to accurately complete photo analysis with a high level of inter-rater reliability (> 0.90).^{19,41} Until cost comparisons are completed, it is reasonable to assume that any increased costs are

reasonable considering the increased accuracy in energy expenditure estimates associated with methods employing digital photography.

This study has several strengths including evaluation the DP+R method during ad-libitum eating in a relatively large sample of overweight and obese young adults using the gold standard criterion measure of TDEE_{DLW}. However, there are potential limitations. When interpreting these results, it is important to consider that although the DLW technique is the gold standard for quantification of TDEE in free-living individuals, this technique has a coefficient of variation of 5–7% compared with TDEE assessed by whole room calorimetry, which itself has a coefficient of variation of 2–3%.⁴² Although participants in this study were free-living, they were required to eat in a cafeteria setting which provided access to a variety of foods at no cost, which may have altered their energy intake. However, the observation that there was no significant change in weight across the 14-day assessment of TDEE_{DLW} in either this study, or in the previous study using an identical cafeteria protocol,²⁴ argues against this possibility. Another limitation is that the study only looked at overweight and obese young adults. Overweight and obese tend to underestimate their energy intake more than normal weight individuals,^{43, 44} thus, the results of this study may not be generalizable to individuals who are normal weight or underweight. This study also relied vendor product information, recipes, and cooking methods to determine the nutritional information and energy intake for all foods and beverages served at the cafeteria instead of using weighed reference photos of each food and beverage item.

Conclusion

In summary, these results suggest that the DP+R method provides estimates of energy comparable to those obtained by TDEE_{DLW} in overweight and obese young adults. Although 3-DFR are relatively inexpensive and convenient, the level of accuracy of self-report is insufficient for evaluating associations between energy intake and health.^{3,12,13} The continued use of self-report has limited progress in understanding of the impact of behavioral interventions, such as diet and exercise, on energy intake as well as associations between energy intake and health. The DP+R method represents a relatively inexpensive, minimally burdensome approach for use in weight management/energy balance studies where assessment of energy intake is obtained in a cafeteria, or similar settings is feasible.

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Figure 1. Camera positioning for pictures of pre and post consumption meal trays used in the digital photography+diet recall protocol. (A) Photo at 45°; (B) Photo at 90 °

Figure 2.
Sample pre and post consumption photographs. (A) Pre-consumption 90 °; (B) Preconsumption 45 °; (C) Post-consumption 90 °; (D) Post-consumption 45 °.

Figure 3.

Comparison of energy intake assessed by digital photography + diet recall and total daily energy expenditure assessed by doubly labelled water. (A) total sample, n = 91; (B) women, n = 45; (C) men, n = 46.

Table 1

Descriptive characteristics of 91 overweight and obese men and women who completed the study and baseline assessments for doubly labeled water and digital photography+diet recall protocol.

Variable	Total Sample (n=91)	Men (n = 46)	Women (n=45)
Age (yrs.)	22.9 ± 3.2	23.4 ± 3.4	22.4 ± 3.0
Height (cm)	171.7 ± 9.0	177.5 ± 7.6	165.7 ± 6.0
Weight (kg)	90.7 ± 17.6	99.8 ± 14.6	81.4 ± 15.4
BMI (kg/m ²)	30.6 ± 4.6	31.7 ± 4.4	29.5 ± 4.5

^a. Total sample and by sex (mean ± SD)