Original Article

Validity and practicability of smartphone-based photographic food records for estimating energy and nutrient intake

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Background and Objectives: Image-assisted dietary assessment methods are frequently used to record individual eating habits. This study tested the validity of a smartphone-based photographic food recording approach by comparing the results obtained with those of a weighed food record. We also assessed the practicality of the method by using it to measure the energy and nutrient intake of college students. **Methods and Study Design:** The experiment was implemented in two phases, each lasting 2 weeks. In the first phase, a labelled menu and a photograph database were constructed. The energy and nutrient content of 31 randomly selected dishes in three different portion sizes were then estimated by the photograph-based method and compared with a weighed food record. In the second phase, we combined the smartphone-based photographic method with the WeChat smartphone application and applied this to 120 randomly selected participants to record their energy and nutrient intake. **Results:** The Pearson correlation coefficients for energy, protein, fat, and carbohydrate content between the weighed and the photographic food record were 0.997, 0.936, 0.996, and 0.999, respectively. Bland-Altman plots showed good agreement between the two methods. The estimated protein, fat, and carbohydrate intake by participants was in accordance with values in the Chinese Residents' Nutrition and Chronic Disease report (2015). Participants expressed satisfaction with the new approach and the compliance rate was 97.5%. **Conclusions:** The smartphone-based photographic dietary assessment method combined with the WeChat instant messaging application was effective and practical for use by young people.

Key Words: energy intake, nutrient intake, dietary assessment, weighed food record, menu labelling

INTRODUCTION

Traditional approaches to dietary assessment, including weighing food, direct observation of eating, food diaries, food frequency questionnaires, and so on, have been widely used to measure the risk of both nutrient shortages and excesses, as well as to monitor and estimate the impacts of a nutritional intervention. However, achieving accuracy and precision when assessing dietary intake is a challenge. When choosing a dietary assessment method, researchers usually consider the participants' burden, staffing requirements, ease of use, need for special equipment, instrument costs, accuracy, and reliability.[1] However, most existing assessment approaches do not address all of these considerations. For example, weighing food, considered the 'gold standard' method for individual-level dietary assessment, is difficult to apply widely at a population level because it is time-consuming, costly, and disruptive.[2] Direct observation of eating requires trained observers to directly observe food trays before and after eating in a cafeteria setting, making this a costly and labour-intensive approach.[3-6] Food diaries and dietary recall surveys depend largely on the participants' memory and ability to estimate portion size,[7] and are unsuitable for children or those with intellectual and developmental disabilities.

Given the limitations of traditional dietary assessment approaches, the use of digital photographic food records has received more and more attention.[8-10] This approach uses a digital camera to record food selection and plate waste. Trained observers review the photographs on a computer screen and estimate portion sizes to calculate nutrient intake in an unhurried laboratory environment.

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The photographic approach has several advantages: 1) rapid acquisition of data in the eating environment; 2) convenience for participants and researchers; and, 3) relatively unhurried evaluation of the food captured in photographs.[3] The emergence of smartphones with cameras and wireless transmission capabilities greatly increases the attractiveness of photographs as a research tool. Several studies have shown that photographing food is a useful and feasible method to record dietary choices.[8,11,12] However, several studies report that this method can over- or underestimate actual nutrient consumption.[13-16] Therefore, we improved the two-dimensional (2D) food image approach based on previous digital photographic assessments. Given the popularity of smartphones with a built-in camera, we asked participants to take photos of the food before and after eating with their smartphones. The photos were then sent to the researchers using the WeChat instant messaging application.

MATERIAS AND METHODS

Study design

The study took place at Shanghai Jiao Tong University of Medicine (Huangpu District), and was divided into two phases, each lasting 2 weeks.

Phase 1

The first phase was implemented from October 13, 2014, to October 26, 2014. During this phase, the manager of the school cafeteria was asked to provide a consistent and unchanging menu. The staff in the school cafeteria was blinded to the experimental protocol. With advice from the researchers, the staff defined portion sizes to correspond with what they would provide college students in daily life. These were then weighed. Finally, a menu comprising 39 breakfast items and 88 lunch and dinner items was constructed. All food items were plated and photographed at a 90° angle and at a height that ensured all margins of the full food tray were included. Photographs of all menu items (before eating) were then consolidated in a database.

The net food weights were recorded. Owing to the nature of Chinese foods, the cooked ingredients of some dishes were separately weighed and recorded. For instance, the researcher weighed the dish 'braised potatoes with chicken' by weighing the cooked potatoes and the chicken separately. Each item was weighed twice and the average adopted. After photographing and weighing, all food items were sent to the Instrumental Analysis Centre of Shanghai Jiao Tong University to measure their energy and nutrient content. These measurements were then used to construct a labelled menu that provided 'core information' about each dish (energy, protein, fat, and carbohydrate content and nutrient reference values).

Using a random number table, researcher A randomly selected 31 food items from the labelled menu. Researcher A weighed three different portion sizes of each food item with tableware to simulate real-life (Figure 1), and then calculated the energy, protein, fat, and carbohydrate content by referring to the labelled menu. At the same time, the researcher photographed the food in the manner described above with a smartphone and sent 93 photographs (one photo per portion size) to Researcher B. Researcher B estimated the energy, protein, fat, and carbohydrate content from the photographs by referring to the photograph database and the labelled menu. Finally, we compared the weighed and photographed food records to assess the validity of the smartphone-based photographic food record.

Phase 2

The second phase lasted from October 27, 2014, to November 9, 2014. Researchers assigned students a number

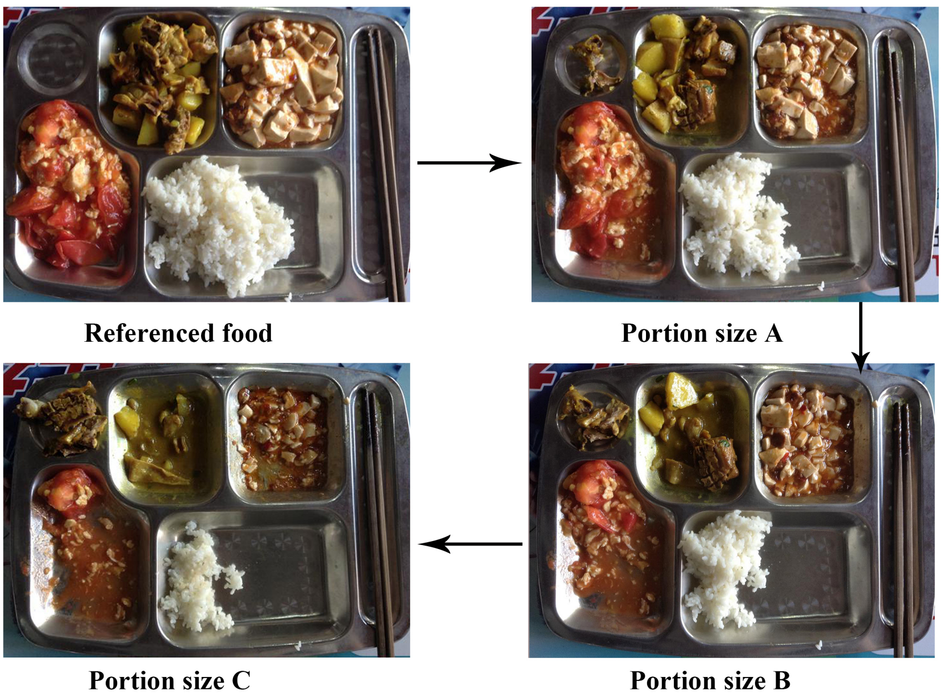

Figure 1. Photographs of foods included in the study. Photographs were taken of all foods at three different portion sizes, simulating real-life eating situations.

based on their identification number and a random number table was then used to select 120 participants, consisting of 40 undergraduate students who began their studies in 2012, 40 undergraduate students who began their studies in 2013, and 40 graduate students who began their studies in 2013.

The participants were asked to record their daily food choices in the school cafeteria by taking photographs with a smartphone camera. The participants were required to take two photos of their food with tableware: one of the food they selected (before eating) and one of any leftovers (after finishing). A set of chopsticks or a tablespoon was placed beside each food item when the photographs were taken. The smartphones were to be positioned at the above-mentioned angle and height. Participants were instructed to capture images of all the food in their three meals, including any extra food portions, starters, desserts, and beverages. A photograph and data transfer platform was set up using the smartphone application WeChat, which is used by most college students in their daily life. At the end of the second phase, the participants were asked to complete a questionnaire requesting information on their snack and fruit intake, general dietary habits, degree of satisfaction with the improved photographic food record.

Two trained nutritionists analysed the photographs (Figure 2) and estimated portion size with reference to photographs in the database established in the first phase. They then calculated each participant's energy, protein, fat, and carbohydrate intake after each meal according to the labelled menu. The averages of estimated energy and nutrient intake were then calculated.

Ethics

The study was approved by the Xinhua Hospital Ethics Committee, which is affiliated with the Shanghai Jiao Tong University School of Medicine. The procedures employed did not require specific informed consent.

Statistical analysis

The differences between estimates made with the weighing method and photograph-based method were tested with a Wilcoxon signed rank test (for non-normally distributed data) or a paired t-test (for normally distributed data). Pearson's correlation coefficient was calculated to assess the relationship between the weighing and photograph-based methods. The modified Bland-Altman analysis for repeated measurements[17] was used to evaluate the agreement between the two methods. Mean differences between the two methods were plotted against the average energy or nutrient content value and the 95% limits of agreement were marked. This plot shows the magnitude of disagreement, highlights outliers, and facilitates identification of trends. Perfect agreement between the two methods would result in a difference of zero.[18] A one-sample *t*-test was used to compare actual consumption with recommended values. All statistics were performed using a two-tailed test and a *p*-value <0.05 was considered statistically significant. All analyses were implemented using the Statistical Analysis System (SAS) computer software, version 6.1. The Bland-Altman plots were performed with MedCalc Software.

RESULTS

Validity of the photographic food record

The average energy, protein, fat, and carbohydrate contents of the 31 randomly selected dishes estimated by a photograph-based method, were compared with those of the same 31 randomly selected dishes estimated by the weighing method (Table 1). The Pearson correlation coefficients for energy, protein, fat and carbohydrate content between the weighing and the photograph-based methods

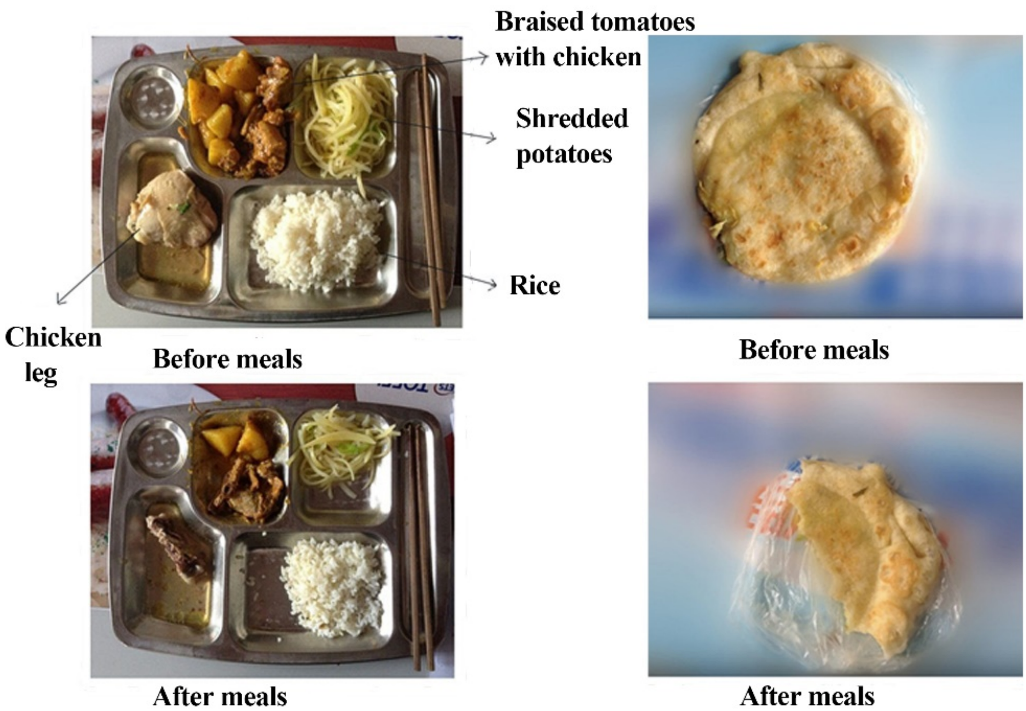

Figure 2. Photographs received from the participants. Photos were taken by study participants before and after eating. These were sent to researchers using the WeChat smartphone application.

were 0.997, 0.936, 0.996, and 0.999, respectively (all *p*-values <0.001). The Bland Altman plots showed that most of the measured differences between weighing and photograph-based methods fell within the limits of agreement (mean±1.96 SD; Figure 3). There were only a few outliers: 2.15% for energy, 2.15% for fat content, 1.08% for protein content, and 10.8% for carbohydrate content. The plots showed that the measurement values were mostly scattered along the difference line and close to the equality line (difference=0; Figure 3). Thus, the plots showed good agreement between the two methods and also indicated that the differences (including the outliers) were random and did not exhibit any systematic bias.

Application of the photographic food record

Participants who sent photographs less than ten times for any meal, participants whose images were in low lighting or had poor clarity, participants who did not complete their questionnaires, and participants who withdrew from the experiment were excluded from the analysis. We included 117 participants after excluding three participants whose dietary records were incomplete; 59% of the participants were female. The mean age of the participants was 21.4 years (SD=2.5), and their mean BMI was 21.1 kg/m^2 (SD=2.6).

Female participants' average energy, protein, fat, and carbohydrate intakes were 1392 kcal/day, 57.7 g/day, 60.8 g/day, and 158 g/day, respectively, compared with male participants' intakes of 1737 kcal/day, 74.4 g/day, 75.2 g/day, and 198 g/day. As the participants all had low-activity lifestyles, their recommend energy intake was 2249 kcal/day for males and 1800 kcal/day for females according to the Chinese Dietary Reference Intakes (2013 Edition).[19] The female participants actual energy consumption was significantly lower than the recommended amount (Statistic=-17.2, p<0.01). The same was true for male participants (Statistic=-12.4, p<0.01). The protein consumption of female participants was equivalent to the recommended intake of 55 g (Statistic=1.67,

Table 1. Energy and nutrient contents of selected dishes estimated by the photograph-based method and the weighing method

Variables	Dietary Assessment Methods		Statistic	*p* value
	Weighing method (mean±SD)	Photograph-based method (mean±SD)		
Calorie (kcal)	78.2±68.2	77.9±68.3	251	0.332
Protein (g)	3.45±3.80	3.60±3.95	47.5	0.852
Fat (g)	3.10±3.19	3.08±3.20	428	0.085
Carbohydrate (g)	9.25±11.4	9.19±11.5	345	0.188

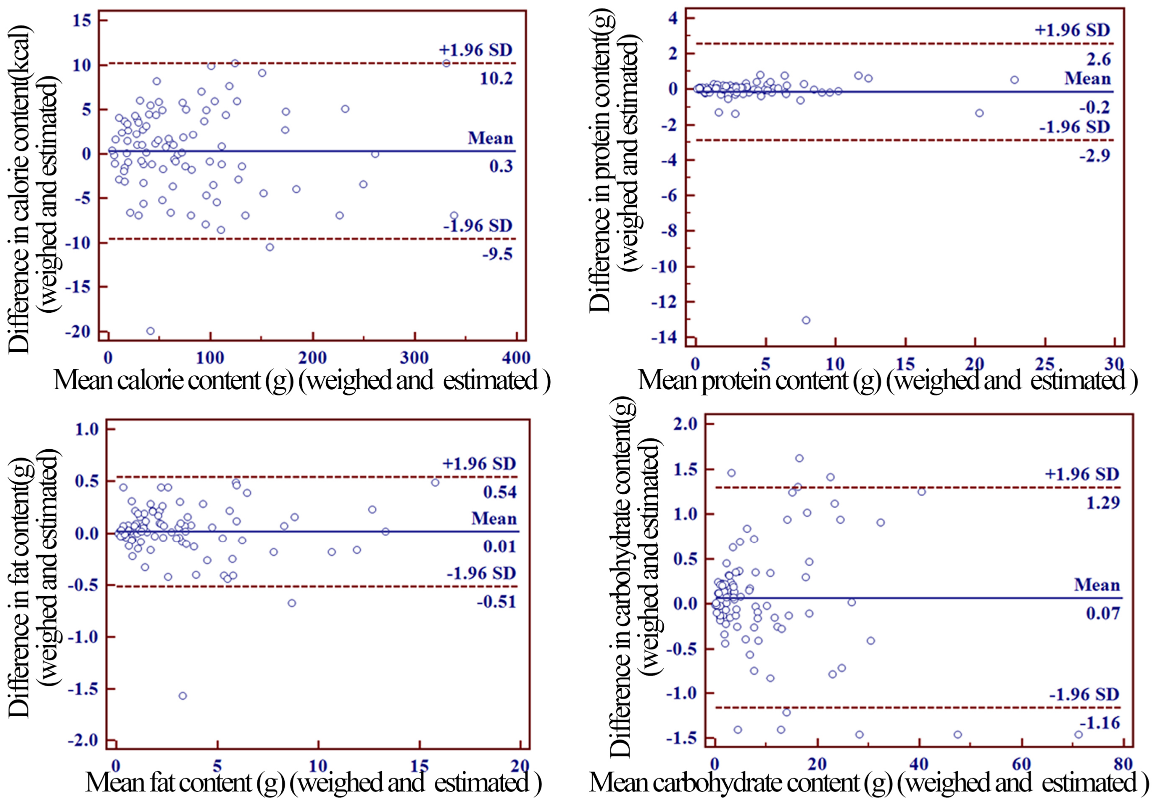

Figure 3. Bland-Altman plots comparing weighing and photograph-based methods. Bland-Altman plots showing the mean bias (solid line) and 95% limits of agreement (top and bottom dotted lines) between the weighing and photograph-based methods for energy and nutrient content; Each point represents a selected food at one of three portion sizes; X-axis: mean energy/nutrient content (weighed and photograph-based method); Y-axis: difference in energy/nutrient content (weighed method - photograph-based method).

p=0.099), while males consumed 9.4 g (SD=13.5 g) more than the recommended 65 g (Statistic=4.86, p<0.01).[19] The percentage of total energy intake due to fat and carbohydrate was 66.7% (SD=14.3%) and 45.4% (SD=7.0%), respectively. According to the Chinese Dietary Reference Intakes (2013 Edition),[19] 97.4% of the participants consumed more fat than recommended while 84.6% of the participants consumed less carbohydrate than recommended. The estimated core nutrient (protein, fat, and carbohydrate) intakes were in accordance with the Chinese Residents' Nutrition and Chronic Disease report (2015).[20] Participants expressed satisfaction with the photographic record approach and they had no difficulties recording their food choices. Only three participants were excluded from the experiment and the compliance rate was as high as 97.5%.

DISCUSSION

It has been reported that young people find that estimating portion sizes and describing foods are burdensome components of dietary assessments.[21] These barriers were addressed here by using smartphone-based photography in combination with the WeChat application to develop a method that fitted into the lifestyle of the young people in this study. Moreover, integrating smartphone use with image analysis, visualization methods, and in-house menu labelling imposed a small burden on participants.

There was no statistical difference between estimates of energy and nutrient content as measured with the weighing or improved photograph-based methods. Bland Altman analysis showed that the discrepancies between the methods were random, did not exhibit any systematic bias, and usually fell within the 95% limits of agreement. Thus, we assert that the improved photograph-based approach is a valid alternative to the food weighing approach for estimating individual energy and nutrient intake. Furthermore, the high compliance and degree of satisfaction we observed affirm the practicability of the improved photographic food record.

Compared with other image-assisted dietary assessment tools, our approach holds a number of advantages. Firstly, we calculated energy and nutrient consumption by referring to a labelled menu developed by researchers, instead of the established Chinese Food Composition Table.[22] Chinese dishes are mostly a mixture of vegetables, meat and other ingredients, which makes it difficult to precisely calculate the energy and nutrient content of a dish by referring to the Chinese Food Composition Table. Moreover, the cooking oil and spices added to a specific dish are nearly impossible to identify. We can thus expect that calculating energy and nutrient consumption from data derived through direct measurement of cooked food would be more precise than using standardized information. The Instrumental Analysis Centre of Shanghai Jiao Tong University where we sent food for testing is nationally accredited, which certifies the reliability of the measurements.

A second advantage of our approach relates to our photographic method. Several studies reported concerns that two-dimensional (2D) images could not be used to precisely calculate portion size because they do not allow estimation of volume.[23] Other studies suggested that 2D images could not used to assess certain types of food, sauces, or cooking oils.[3,14] Three-dimensional (3D) images or the use of multiple images were proposed as alternative methods that could address the weaknesses of 2D food images,[8,14] but these approaches imposed more pressure on participants and led to study fatigue. Because the tableware in our cafeterias was standardized, our researchers knew the depths and areas of the dishes. They were also familiar with the food types. These factors could remedy the limitations of 2D images. Moreover, our researchers calculated the quantity of food consumed by referring to an established photographic database, rather than relying on experience.

Some food intake studies have used image analysis software to automatically identify foods and beverages based on colour, texture, and other visual characteristics. This approach required high quality images and, as a result, imposed a large burden on the participants.[24] In our experiment, we required the participants to simply capture images of their food at a specific angle and distance before and after eating, resulting in a high compliance rate (97.5%). Moreover, instead of using wearable cameras, we captured images with smartphones, which have become ubiquitous among college students. One large-scale investigation involving 28 provinces and 208 universities in China showed that 84.7% of college students used WeChat and 78.4% considered it convenient and easy to use.[25]

Finally, our photograph-based dietary assessment tool combined with WeChat was an improvement on previous digital-assisted recording methods, which had been tested by comparison with traditional dietary record approaches.[18,26] The WeChat software made it easy for participants to send photographs to researchers in a timely manner, which avoided any potential loss of data. Researchers were able to promptly contact participants if they had any questions after receiving photographs. Furthermore, WeChat made it convenient to estimate food intake and plate waste under real-life conditions and without disrupting eating behaviours, which should have minimized the error in our estimates. In summary, our photograph-based dietary assessment tool has many advantages compared with other methods, including reduced participant burden and improved accuracy, efficiency, and cost-effectiveness.

The present study had several limitations. Firstly, although our photograph-based approach decreased the participants' burden, it set rigorous requirements for researchers. Researchers had to be familiar with the tableware in the cafeteria, as well as the portion sizes of all the foods to be able to accurately estimate the participants' energy and nutrient consumption. Secondly, we only required participants to photograph the food during their three meals, but snacks, beverages, fruit, and other food consumption outside of meals were not strictly recorded, which could have led to underestimates of energy and nutrient intake. However, our results for protein, fat and carbohydrate consumption were consistent with the Chinese Residents' Nutrition and Chronic Disease report of 2015,[20] which corroborates the reliability of our approach. If the limitations inherent in food intake estimation were properly acknowledged, our improved smartphone-based photographic food record would be more widely used.

In conclusion, these findings suggest the smartphone-based photographic dietary assessment method combined with the application WeChat is a valid and practicable method for assessing energy and nutrient intake among individuals, and is a useful alternative to other methods for the accurate estimation of calorie and nutrient intake.

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AUTHOR DISCLOSURES

All of the authors declare that they have no conflicts of interest

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