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Comparison of digital photography to weighed and visual estimation of portion sizes

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ABSTRACT

Objective The primary goal was to test the validity of digital photography for measuring food portion sizes compared with weighed foods and with direct visual estimation.
Samples A total of 60 test meals consisting of 10 different portion sizes from six different university cafeteria menus were prepared and weighed.
Design Food selections and plate waste, as estimated by digital photography and direct visual estimation, were compared with weighed foods. For each method, three observers independently estimated portion sizes of each food. Observers expressed the portion sizes as a percentage of a standard serving. These percentages were multiplied by the weight of the standard portion to yield estimated weights.
Statistical analyses To test validity, the estimates of food weights derived from both methods were compared with weighed foods using correlations and were compared with each other using Bland-Altman regression analysis.
Results For the digital photography and direct visual estimation methods, estimates of the portion sizes for food selections, plate waste, and food intake were highly correlated with weighed foods. Both methods tended to yield small overestimates or underestimates. Bland-Altman regression found the two estimation methods to yield comparable results (bias less than 1.5 g).
Applications/conclusions These findings support the validity of the digital photography method for measuring portion sizes. Digital photography may be most useful for measuring food intake in settings that allow for the direct observation of food selections and plate waste but require minimum disruption of the eating environment, and allow unhurried estimates of portion sizes. *J Am Diet Assoc. 2003;103:1139-1145.*

A variety of methods have been used to obtain dietary intake data, including weighing foods, direct observation of eating, food records, food frequency questionnaires, and dietary recalls. Collecting and analyzing dietary intake data from large samples can be time consuming and expensive (1). Most self-report methods rely on the individual's ability to keep accurate records or recall food consumed. Self-report methods for dietary intake assessment have been criticized with respect to accuracy (2,3). In particular, dietary intake reports from obese people, white women, and individuals from lower socioeconomic groups have been found to underestimate food intake (3-10).

The most accurate method for measuring food intake is weighing foods before and after eating (11). Disadvantages of this method, called "weighed inventory," are that it is time consuming, costly, and disruptive (11). Because of the problems associated with self-report and weighing methods, researchers have developed procedures that involve direct observation that is relatively unobtrusive (11). Observation of dietary intake by direct visual estimation is a nonintrusive method of estimating dietary intake. This method is well suited to cafeteria settings or other public eating situations (11-13). The method involves having trained observers directly observe food trays (plates) before and after eating. The observers clas-

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sify foods and estimate portion sizes for each food in reference to standard portions that have been weighed for each food. This method has been used extensively in studies of nutrient intake and eating behaviors in institutional settings (14-17). Direct visual estimation of intake, either in natural or cafeteria settings, has been cited as a good method for validating other intake assessment methods (17-20). The validity of the direct visual estimation method for measuring food intake has been tested in a few controlled research studies (12,21,22). In addition, Shankar and colleagues (23) validated direct visual estimates of intake against weighed foods in field tests.

Recent technological advances are now being used to improve dietary assessment. Kubena (24) described how personal computers could be connected to a food scale so that subjects could scan a bar code for the food in a codebook, resulting in automatic, accurate recording of food and weight. She acknowledged that logistics, cost, and portability are barriers to the widespread use of this method. She suggested that more creative methods that use technology are needed. Recently, an alternative method for measuring food intake that uses new technology was introduced (25). This approach, called the digital photography method, uses procedures similar to the direct visual estimation method, but instead of having observers in the eating environment, food selections and plate waste are recorded using a digital video camera. Photographic images are viewed on a computer screen by trained observers. They estimate portion sizes using the photographs of foods (in an unhurried laboratory environment). This digital photography approach has several advantages: rapid acquisition of data in the eating environment, convenience for participants and researchers, and relatively unhurried evaluation of foods that are studied in photographs, as opposed to in the immediate eating environment. The agreement of different expert observers for estimation of portion sizes was found to be very high when using digital photography, but this initial study did not test for validity of the estimates of portion sizes against known amounts of food (25). Also, this initial study did not compare the new digital photography method with a well-established method such as direct visual estimation. The primary goals of this study were to test the validity/accuracy of the digital photography method in comparison with weighed foods and to compare estimates of portion sizes using the digital photography estimation method with estimates from the direct visual estimation method, which can be viewed as an intermethod study. A secondary goal was to test the agreement of portion size estimates by different observers using the two estimation methods.

METHODS

Preparation of Test Meals

Food items were prepared to represent typical meals in a university cafeteria, before and after eating. Sixty meals consisting of 10 different portion sizes of foods from six different menus were prepared as test meals. The meals included an entree (beef, chicken, or casserole), accompanied by starches, vegetables, fruits, desserts, condiments, and beverages. Reference foods in typical portion sizes were prepared and weighed for comparison with the foods in the test meals when the observers made estimates of portion sizes. The same standard reference foods were used for both the direct visual estimation and digital photography methods. The food items of each meal were weighed before either estimation method was conducted. Test meal portions ranged from 0% to 235% of reference portions. Some proportion of each food item from each test meal was discarded to simulate plate waste that would result from eating foods in each test meal. Plate waste food portions ranged from 0% to 93% of the reference portion size.

Trained Observers

Six research associates participated in the validation study. Before the study, three research associates were trained to use the direct visual estimation technique and three were trained to estimate food portions using digital photography. Estimations were made independently. Observers who provided direct visual estimates did not provide estimates using digital photography, and vice versa.

Direct Visual Estimation of Test Meals

Three trained research associates used the direct visual estimation method to estimate the portion sizes of all food items for each meal. The estimates were recorded as a percentage, in units of 10%, eg, 90%, 100%, or 110%, of the prepared reference portion of each food. The food items were estimated again using the test meals for plate waste. This direct visual estimation of plate waste was performed using the same methods used to estimate food selections, and they were compared against the same reference portion.

Digital Photography of Test Meals

The same reference portions, food selections, and plate waste for all meals were used for the digital photography method. The foods were photographed using a digital video camera (Sony Digital Handy Cam DCR-VX1000; Sony Corporation of America, New York, NY) mounted on a tripod with the lens 0.62 m (24.5 in) above the meal tray with a camera angle of approximately 45°. A place mat with marked regions for placement of the meal tray was fixed to the table supporting the camera tripod to ensure optimal visibility of the meal in the digital photographs. The digital camera was connected to a computer equipped with a video capture board. Digital photographs of the reference portion, food selection, and plate waste for test meals were captured and incorporated into a computer application designed for estimation of food portions in digital photographs. The test meals and reference portions were photographed with the exact same camera angle and distance from foods so that the apparent size of all foods remained constant across photographs. Three research associates used the software to view simultaneously photographs of the food selection and plate waste test meals along with photographs of the reference portion of each food. The observers independently estimated the percent of the reference portion of each food in the photographs in units of 10%, and these estimates were entered into a data entry grid in the computer software application.

Statistical Analyses

Gram weights of each food estimated by direct visual estimation and digital photography were calculated by multiplying the estimated percent of the reference portion by the weight of the reference portion of each food. The computer software program used for statistical analyses was SAS (version 8.2, 2002, SAS Institute, Cary, NC). For the digital photography and direct visual estimation methods, the reliabil-

Table 1
Correlations of estimates of food weights by digital photography and direct visual estimation compared with known weights of food

Food type	Number of items	Food selection		Plate waste		Food intake	
		Direct visual	Digital	Direct visual	Digital	Direct visual	Digital
Overall	453	0.97[a]	0.94[b]	0.95[a]	0.89[b]	0.96[a]	0.92[b]
Entree	60	0.98[a]	0.87[b]	0.89	0.91	0.96[a]	0.85[b]
Starch	117	0.98[a]	0.94[b]	0.95	0.94	0.97[a]	0.93[b]
Fruit/vegetable	106	0.96[a]	0.93[b]	0.96[a]	0.89[b]	0.95[a]	0.90[b]
Dessert	60	0.93	0.90	0.92[a]	0.86[b]	0.94[a]	0.82[b]
Beverage	50	0.93	0.92	0.94	0.96	0.93	0.94
Condiments	60	0.83[a]	0.63[b]	0.74[a]	0.52[b]	0.81[a]	0.60[b]

Note. All correlations were significantly different from 0.00 ($P<.0001$). Different superscripts indicate that the correlations of digital with weighed foods were significantly smaller than the correlations of direct visual with weighed foods ($P<.01$). Note that there were 10 soups that were a part of the overall number of food items that were analyzed. Soups were not analyzed separately because of the small number of observations. "Overall" refers to the average (grams) across all food types.

Table 2
Mean differences (total grams) between weighed foods and estimates using digital photography and direct visual estimation

	Type of meal	Weighed foods (g)	Difference score ± SE	
			Direct visual (g)	Digital (g)
Overall	Food selection	111.6±3.73	*5.1±0.71	*5.9±0.87
	Plate waste	20.3±1.42	*1.2±0.35	0.7±0.49
	Food intake	91.3±3.44	*3.9±0.76	*5.2±0.95
Entree	Food selection	142.0±3.78	*14.1±2.65	*18.3±3.94
	Plate waste	15.8±1.0	*5.4±1.12	0.8±1.36
	Food intake	126.2±3.57	*8.7±2.91	*17.5±4.25
Starch	Food selection	85.4±1.65	*3.7±1.00	1.0±1.05
	Plate waste	14.7±0.59	*−0.8±0.39	*2.2±0.62
	Food intake	70.7±1.51	*4.5±1.06	−1.2±1.10
Fruit/vegetables	Food selection	103.5±2.28	*3.6±1.28	*4.8±1.70
	Plate waste	21.5±1.18	−0.64±0.68	0.0±1.06
	Food intake	82.0±1.98	*4.2±1.30	*4.8±1.76
Dessert	Food selection	100.5±2.08	*14.8±2.14	*14.0±2.23
	Plate waste	22.2±19.87	*2.3±0.99	*9.8±1.73
	Food intake	78.3±2.04	*12.5±2.09	4.2±2.64
Beverage	Food selection	220.4±3.12	*−8.7±2.34	−1.5±2.42
	Plate waste	43.4±2.13	*3.3±1.51	*−9.1±1.71
	Food intake	177.0±4.07	*−12.0±2.83	*7.6±3.07
Condiments	Food selection	34.2±0.97	*3.7±1.34	*3.4±1.48
	Plate waste	4.7±0.31	*2.6±0.63	*−1.5±0.54
	Food intake	29.5±1.01	1.1±1.42	*4.9±1.63

*The difference between estimated portions size and known weight for total grams was statistically significant ($P<.05$). Difference scores were defined as: estimated weight − known weight. Therefore, positive difference scores reflect overestimation of portion sizes by the estimation method. "Overall" refers to the average (grams) across all specific types of food.

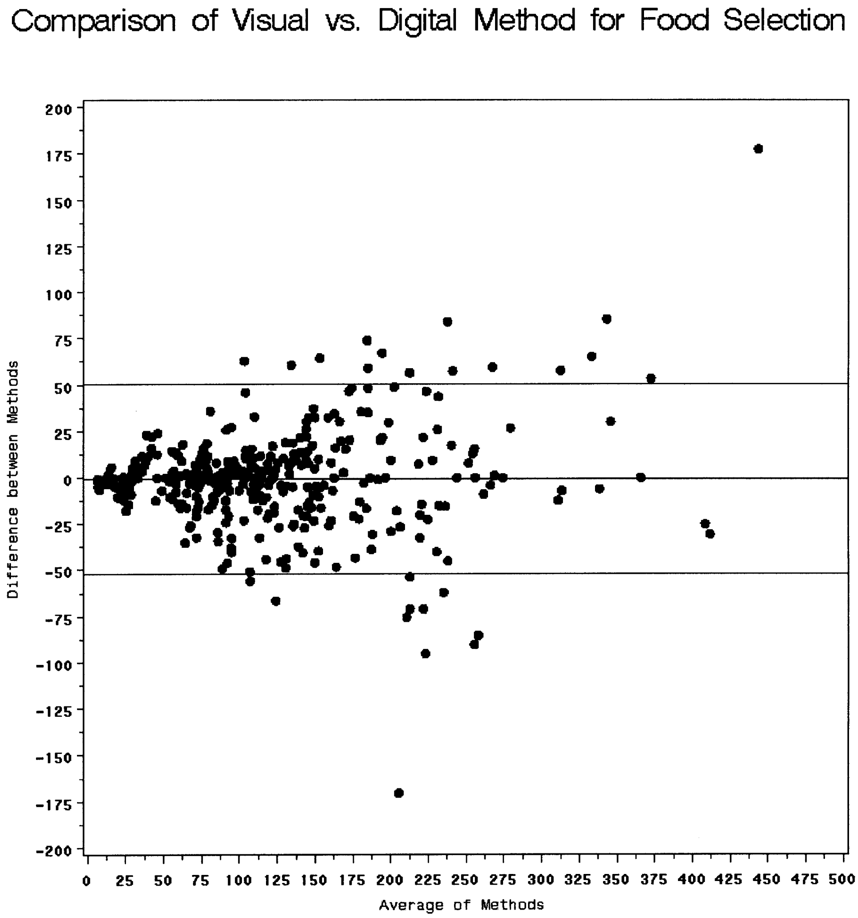

FIG 1. Results of Bland-Altman regression comparing portion size estimates (grams) using digital photography and direct visual estimation of food selection.

ity and agreement of estimates of portion sizes by the three observers for each method were tested using intraclass correlations. To test the validity of the two methods for measuring food intake, the estimates of food weights derived from both methods were compared with the weighed foods using Pearson product moment correlations. The same procedure was used for testing the validity of estimating the food weights within specific food categories, ie, entree, starch, fruit/vegetable, dessert, beverage, and condiments. A test of correlated correlations was used to assess the difference in the magnitudes of each pair of correlations (direct visual vs digital). Because there were 42 tests of differences in correlations, a conservative alpha level ($P<.01$) was selected for interpretation of these results. To test whether the two estimation methods significantly overestimated or underestimated portion sizes relative to weighed foods, t tests were used to compare estimates (from the two estimation methods) against weighed foods. Bland-Altman regression was used to compare the results from the two estimation methods. Alpha level for all of these analyses was set at $P<.05$.

RESULTS

Tests of Validity of Estimation Methods in Comparison With Weighed Foods

Estimates of portion sizes related to food selections, plate waste, and food intake were highly correlated with actual weighed foods for both the digital photography and direct visual estimation methods. Correlations shown in Table 1 summarize the overall results (total grams) and tests of the validity of estimates for specific food categories. The pattern of correlations supports the validity of both methods. For total grams, the correlations for both methods were very high (r values between 0.89 and 0.97). The correlations pertaining to direct visual estimation were often significantly higher than those testing the validity of digital photography. Correlations related to specific food categories were also very high (r values between 0.82 and 0.98) for all food categories but condiments (r values between 0.52 and 0.83). Comparisons of the magnitudes of correlations pertaining to the validity of the two estimation methods generally favored the direct visual estimation method (with the exception of beverages).

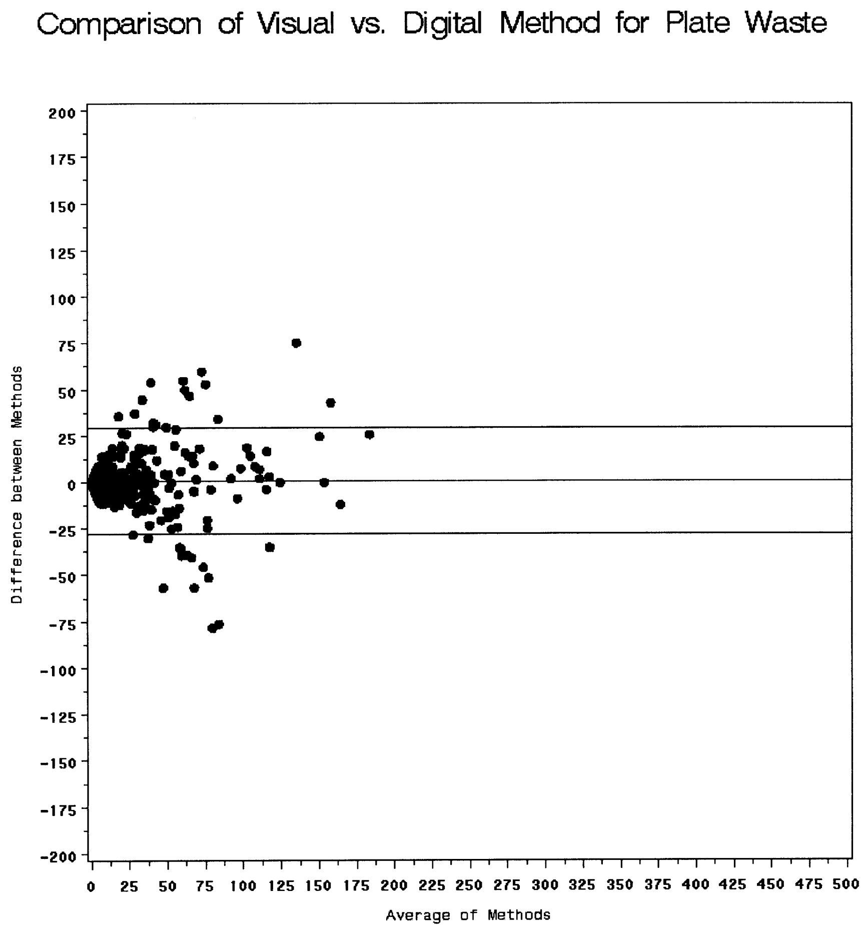

FIG 2. Results of Bland-Altman regression comparing portion size estimates (grams) using digital photography and direct visual estimation of plate waste.

Tests of Overestimation and Underestimation

In tests of the overall (average grams across all foods) bias of the two estimation methods against weighed foods, both methods tended to slightly overestimate portion sizes related to food selections, plate waste, and food intake. The top panel of Table 2 summarizes these findings. On average, across all foods, observers yielded small (less than 6 g) but statistically significant overestimations for all test meals except for estimates of plate waste using the digital photography method. The remainder of Table 2 summarizes the findings related to specific types of foods. Similar results were obtained for specific food categories, with the exception that both overestimations and underestimations were found. When estimates were biased, there were small overestimations or underestimations by both methods. The range of bias was −12.0 g to 14.8 g for direct visual estimation. For digital photography, the range of bias was −9.1 g to 18.3 g. For any given food category, the overestimation or underestimation biases were inconsistent, ie, one method may have yielded underestimations and the other method may have yielded overestimations.

Intermethod Study

The estimates of digital and direct visual estimation methods (across all food categories) were compared using Bland-Altman regression. Figure 1 depicts the results of these regression analyses for food selection. Figure 2 presents the findings for plate waste, and Figure 3 depicts the results for food intake. As can be seen in the figures, estimates of bias were small. The two methods for estimating food selections, plate waste, and food intake yielded similar (ie, not significantly different, $P>.30$) estimates of total grams. Mean bias (direct visual estimate−digital estimate) for food selections was −0.75 (±1.21) g, t (446)=−.062, $P>.50$. Mean bias for plate waste was 0.51 (±.67) g, t (446)=0.76, $P>.45$. For food intake, the mean bias was −1.25 (±1.38) g, t (446)=−.91, $P>.35$. Comparisons of variance found that the two methods differed for food selections, t (1)=2.24, $P<.03$, but did not differ for estimates of plate waste, t (1)=1.36, $P>.05$, or food intake, t (1)=0.62, $P>.05$). For food selections, the digital photography method yielded data with less variability than the direct visual estimation method.

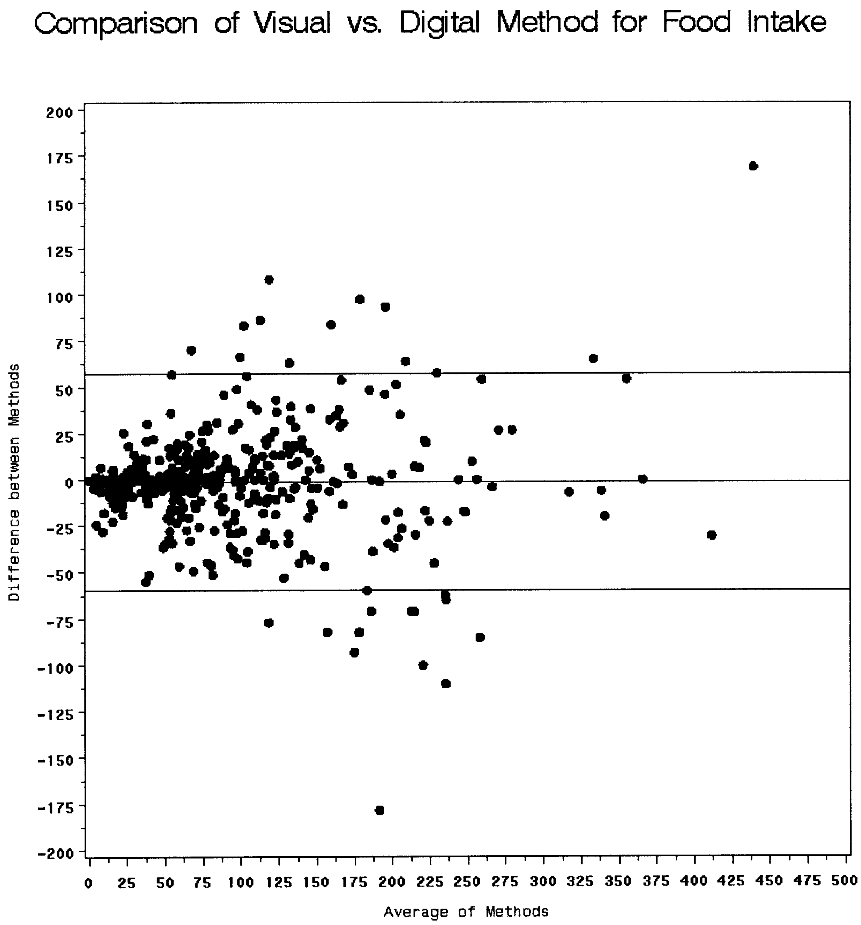

FIG 3. Results of Bland-Altman regression comparing portion size estimates (grams) using digital photography and direct visual estimation of food intake.

Agreement Among Expert Observers

Using intraclass correlations, agreement among the three observers for the weight of each food was very high for both digital photography and direct visual estimation. For the direct visual estimation method, the correlations were 0.94 for estimates of food selections, 0.91 for estimates of plate waste, and 0.92 for estimates of food intake. For the digital photography method, the correlations were 0.94 for estimates of food selections, 0.80 for estimates of plate waste, and 0.92 for estimates of food intake.

DISCUSSION

The results of this study support the validity of the digital photography method for measuring food selections, plate waste, and food intake. Both methods, digital photography and direct visual estimation, were highly correlated with foods that were carefully weighed and measured. Furthermore, the two methods for estimating food selections, plate waste, and food intake yielded similar estimates. For both methods, there was a slight tendency for overestimating overall portion sizes, although the differences from known weights were small, ie, less than 6 g. For specific food categories, both methods yielded underestimates and overestimates of portion sizes, but these biased estimates were generally small. Correlations of portion size estimates from direct visual estimation were generally slightly higher than those based on the digital photography method. This finding suggests that the direct visual estimation method yields the most valid/accurate portion size estimates. Given the very high correlations for portion size estimates from digital photography with weighed foods, the findings strongly support the validity/accuracy of this method as well. The correlations shown in Table 1 are very high for all food categories with the exception of condiments. This limitation may be caused by the small mass of most condiments, which makes accurate estimation by human observers difficult. Condiments generally do not account for much of the total calorie values of most meals. The finding that the direct visual estimation method was highly correlated with weighed foods replicates the findings of earlier studies (11,22,23,26). This was the first study that supported the validity of the digital photography method.

Using Bland-Altman regression, the two estimation methods were found to be comparable, ie, bias was very low. The only difference between the estimates derived from the two methods was that the digital photography method yielded slightly less variance for food selections when compared with the direct visual estimation method. Overall, the findings of the study suggest that both methods are valid for estimating portion sizes, and that they yield very comparable results.

It should be noted that an alternative research design for this study would be the use of a crossover design in which the observers used both estimation methods. The order of method could have been counterbalanced to control for carry-over effects. The findings should be interpreted in the context of this possible limitation.

This study was the first to assess interobserver agreement of the direct visual estimation method, which provides support for the reliability of this method. The results of this study and Williamson and colleagues (25) support the reliability of the digital photography method across observers. The findings indicate that the expert observers for both types of estimation methods reported highly similar estimates of portion sizes across a wide range of foods. In summary, the primary and secondary goals of the study were supported by the results of the study.

The study provides support for the reliability and validity of both methods and for the relative comparability of the new digital photography method with the older direct visual estimation method. Further research is needed to understand how these methods compare in nonlaboratory settings and to understand how they can be used to estimate food intake in the immediate eating environment. For example, it is unknown whether the food intake observed during one or more meals is predictive of 24-hour food intake. There also is a need to establish the number of observations (meals or days of observing total food intake) that is required to validly measure individual and group nutrient intakes that can be generalized to obtain estimates of typical food intake. Examples of this type of research can be found in the research on dietary recall and food intake records (27,28).

APPLICATIONS

Digital photography allows for rapid acquisition of data with very little inconvenience to participants and allows researchers the opportunity to perform unhurried evaluations of portions sizes from photographs. Digital photography can be used most effectively in dining facilities in which the preparation and serving of foods can be measured and would be useful for a variety of purposes:

- To obtain food intake data for nutrient analysis
- To study food consumption patterns at senior nutrition centers, university dining halls, and school lunch or school breakfast programs
- To determine food waste of specific menu items to spot trends in acceptability and other quality control issues
- To check quality control of serving portions for appearance in both commercial and noncommercial food service operations

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