Precision and Bias of Food Frequency-based Measures of Fruit and Vegetable Intakes[1]

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Abstract

Accurate assessment of fruit and vegetable intakes is critical for cancer control research and public health surveillance. This report examines the bias and precision of two commonly used food frequency questionnaire methods to assess fruit and vegetable intakes: (*a*) the 5 A Day method, based on seven items; and (*b*) the summation method, based on adding total servings of all fruit and vegetable items on a comprehensive (100+ item) food frequency questionnaire. Data are from three studies in which 24-h dietary recalls, food records, or serum carotenoid concentrations could be used as criterion measures ($n = 260$, 1031, and 342). Studies differed markedly in distributions of participants' age, race/ethnicity, sex, and socioeconomic status. Mean intakes of total fruit and vegetables based on the 5 A Day method were consistently lower than those from either the summation method (3.11 *versus* 4.06), 24-h recalls (3.32 *versus* 4.07), or food records (3.11 *versus* 3.46; all $P < 0.01$), and this was due primarily to underestimates of vegetable intake. Correlations of the 5 A Day and summation measures with all criterion measures were similar and were consistently higher for fruit (range, 0.33–0.57) than for vegetables (range, 0.24–0.32). These results, which were consistent across diverse participant samples, suggest that the 5 A Day method yields both biased and imprecise measures of vegetable intake and that research to improve this measure is needed.

Introduction

There is growing scientific consensus that diets high in fruit and vegetables reduce the risks of cardiovascular disease (1) and several cancers (2, 3). In the United States, this is reflected both in dietary guidelines, which include recommendations to eat diets rich in fruit and vegetables (4, 5), and by the 5 A Day for Better Health Program, which promotes increased fruit and vegetable intakes through mass media nutrition education campaigns, grants to state health departments, and research grants to develop and evaluate effective dietary change interventions (6, 7). Both the epidemiological research linking fruit and vegetables to reduced disease risks and the public health research to develop and evaluate nutrition intervention programs require valid measures of fruit and vegetable intakes. Surprisingly, there are very few studies that have carefully examined the measurement characteristics of generally accepted standard measures of fruit and vegetable consumption.

The majority of studies measuring fruit and vegetables have used some type of food frequency approach. One approach, commonly called the 5 A Day method, uses two summary questions to capture consumption of most fruits and vegetables ["How often did you eat a serving of fruit (not including juices)?" and "How often did you eat a serving of vegetables (not including salad and potatoes)"], to which usual consumption of juice, salad, and potatoes are added (8). These questions are usually asked alone, as a very short FFQ,[3] or can be extracted from items included in a longer, more comprehensive FFQ. This method is well suited for population-level surveillance and intervention evaluation because it is simple to administer and analyze. Another food frequency approach, which we call the summation method, is to add the frequencies of fruit and vegetable consumption from a list of relevant items in a comprehensive FFQ. This method is often used in epidemiological studies of diet and disease, for which long dietary questionnaires are more feasible. Lastly, instead of a food frequency approach, one can calculate servings of fruit and vegetables from 24-h dietary recalls or food records (9–13). This requires either complex computer algorithms or hand coding of fruits and vegetables to extract the desired information. The computer expertise, costs, and high participant burden make this approach suitable only for small clinical studies or validation studies.

This report examines the bias and precision of the two commonly used FFQ-based approaches to measuring fruit and vegetable intakes: (*a*) the 5 A Day method; and (*b*) the summation method. We examine total fruit and vegetable consumption, as well as the consumption of components (*e.g.,* fruit juice and salads) that comprise the total fruit and vegetable measure. Bias and precision are presented from three large studies that collected a FFQ-based measure and at least one independent criterion measure such as food records, dietary recalls, or serum carotenoids.

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[3] The abbreviation used is: FFQ, food frequency questionnaire.

Table 1 FFQ items used to calculate servings of fruits and vegetables

Fruit & vegetable assessment method	FFQ		
	7-item FFQ[a]	100-item FFQ[b]	122-item FFQ[c]
5 A Day method			
Summary Questions	Fruit, not including juices Vegetables, not including salad and potatoes	Fruit, not including juices Vegetables, not including salad and potatoes	Fruit, not including juices Vegetables, not including salad and potatoes
Juice	Orange and grapefruit juice Other 100% fruit juices	Orange and grapefruit juice Other fruit juices	Orange and grapefruit juice Other fruit juices
Salad	Green salad	Green salad, including spinach salad	Lettuce and plain lettuce salad Mixed lettuce or spinach salad with vegetables, such as carrots or tomatoes
Fried potatoes	Fried potatoes	Fried potatoes, such as French fries and hash browns Fried plantains	Fried potatoes, such as French fries and hash browns Fried plantains
Other potatoes	Other potatoes	Other potatoes, cassava, yucca (boiled, baked, mashed) Sweet potatoes, yams	Other potatoes, cassava, yucca (boiled, baked, mashed) Sweet potatoes, yams
Total	7 items	9 items	10 items
Summation			
Fruit		10 items	11 items
Juice		2 items	2 items
Vegetables		13 items	16 items
Salad		1 item	2 items
Fried Potato		2 items	2 items
Other Potato		2 items	2 items
Total		30 items	35 items

[a] Seattle 5 A Day Worksite Project (7).
[b] Women's Health Trial: Feasibility Study in Minority Populations (16).
[c] Olestra Post-Marketing Surveillance Study (17).

Materials and Methods

Data Sources

The first data source was the Seattle 5 A Day Worksite Project, a randomized, controlled trial of a worksite-based intervention to promote fruit and vegetable consumption (14). At baseline, participants at 33 worksites completed a mailed questionnaire, which included a seven-item fruit and vegetable FFQ that asked about intakes over the past month. Response rates to the survey averaged 79%. A sample of eight participants per site, selected at random from those who completed the baseline survey, completed three telephone-administered, 24-h dietary recalls. The participation rate for the 24-h recalls is not known. Data for this analysis are from baseline and include 260 participants who completed all 24-h recalls. Participants were well educated (10% had completed $\leq$ 12 years of education, 55% had completed 16 or more years of education), 57% were female, 89% were white, and their mean age was 42 years (range, 20–67 years).

The second data source was the Women's Health Trial Feasibility Study in Minority Populations, a randomized trial to test the effectiveness of a low-fat dietary intervention program in minority and low socioeconomic status women. Details of the study design and participant characteristics (15) and dietary assessments (16) have been published. Dietary data are from baseline assessments, when participants completed both a 100-item FFQ that asked about diet over the past 3 months and a 4-day food record. Data from this analysis are from 1031 women with acceptable FFQs and analyzed food records (see Ref. 16 for details). Participants were of diverse race (28% black, 16% Hispanic, and 56% white) and mixed educational background (12% completed less than 12 years of education, 20% completed 12 years of education, and 37% completed 16 or more years of education), with a mean age of 60 years (range, 50–79 years).

The third data source was the Olestra Post-Marketing Surveillance Study, a population-based observational study of dietary patterns and serum concentrations of fat-soluble vitamins and carotenoids. Details on the design and participant characteristics of this study have been published (17). Participants were recruited for a telephone interview using random-digit dialing (efficacy rate, 61.9%) and then invited into a clinic for further assessments (participation rate, 56.9%). Data for this analysis are from 342 adults from the sentinel site in Marion County (Indianapolis, IN). Participants completed four 24-h dietary recalls (three dietary recalls were administered by telephone, and one dietary recall was conducted in person) over a 1-year period. The last recall was administered at a clinic visit during which participants gave a fasting blood sample and completed a comprehensive 122-item FFQ that asked about diet over the past year. Participants were of diverse race (19% black, 77% white, and 4% other) and educational background (40% completed 12 or fewer years of education, 30% completed 13–15 years of education, and 30% completed 16 or more years of education), and 62% were female, with a mean age of 41 years (range, 18–84 years).

Measures

FFQs. Table 1 gives details on how each FFQ was used to calculate servings of fruit and vegetables. All FFQs used fixed categorized frequency responses. On the 100- and 122-item FFQs, all food items included information on portion size, categorized as small, medium, or large compared with a stated medium portion size. Portion sizes matched those used in the 5 A Day program (*e.g.,* ½ cup cooked vegetable) and were used when calculating total servings.

The 5 A Day Method. Servings of fruit and vegetables were calculated as follows: (*a*) total vegetable intake was calculated as "servings of vegetables, not including salad or potatoes" plus servings of salad and potatoes; and (*b*) total fruit intake was calculated as "servings of fruit, not including juices" plus servings of juice. Differences between the 7-, 100- and 122-item FFQs were in the numbers of items used to capture consumption of salads, fried potatoes, and other potatoes.

Summation Method. Servings of fruit and vegetables were calculated as the simple sum of servings of all relevant food items on the FFQ. There were 30 fruit and vegetable items on the 100-item FFQ, and there were 35 fruit and vegetable items on the 122-item FFQ. The summation method does not use questions on either "servings of vegetables, not including salad or potatoes" or "servings of fruit, not including juices."

Four-day Food Records/24-h Dietary Recalls. Recalls were collected using the University of Minnesota Nutrition Coordinating Center's Nutrition Data System (versions 2.9 and 2.91), and food records were entered into the Nutrition Data System for analysis (18). One characteristic of this system is that multiple-component foods (*e.g.,* casseroles) are broken into their component parts (*e.g.,* meat, potatoes, carrots, and onions) for nutrient analysis. We could therefore develop a set of computer algorithms to calculate intake of all fruit and vegetables, both those eaten alone and those eaten as part of multiple-component foods (19). For this analysis, fruits were divided into juice and all other forms of fruit. Vegetables were divided into salads/raw, fried potatoes, and all other vegetables, excluding condiments, legumes, nuts, pickled vegetables, and soybean products. Intake was calculated in servings using definitions that match those commonly consumed (*e.g.,* a single piece of fruit, ¼ cup of dried fruit, and ½ cup of cooked vegetable).

Serum Carotenoids. Bloods were collected after a fast of at least 6 h and protected from light throughout processing. Serum was stored at −70°C until analysis at Quintiles Laboratories (Atlanta, GA). A high-performance liquid chromatography method was used to measure concentrations of α-carotene, β-carotene, lycopene, lutein, zeaxanthin, and β-cryptoxanthin, and an enzymatic method was used to measure serum cholesterol. Details of laboratory methods and assay precision are given elsewhere (20). Both total carotenoids and total carotenoids minus lycopene were used as biological markers of fruit and vegetable intake. Lycopene was removed from the total carotenoid measure because serum lycopene is poorly correlated with other serum carotenoids and fruit and vegetable intake (12, 21).

Statistical Methods

We defined bias as the difference between mean FFQ-based measures of fruit and vegetable intake and a self-reported criterion measure, either multiple 24-h recalls or food records. Tests of significance were based on paired *t* tests. We defined precision as the Pearson correlation between FFQ-based measures and a criterion measure. We examined bias and precision for: (*a*) total fruit and vegetables; (*b*) total fruit and vegetables minus fried vegetables (to match the 5 A Day guidelines); and (*c*) subgroups of fruit and vegetables that could be defined similarly between FFQ- and recall/record-based methods.

To normalize distributions, all values for fruits and vegetables were transformed using a (1+ln) transformation before analysis, and results are given back-transformed for ease of interpretation. Serum carotenoids were adjusted for total serum cholesterol following the residual method described by Willett (22) and log-transformed before analysis.

Table 2 Comparison of dietary recall and 5 A Day method measures of servings per day of fruit and vegetables (n = 260), Seattle 5 A Day Worksite Project (7)

Fruit and vegetable group	Dietary recall[a] ($\bar{X} \pm$ SD)[b]	5 A Day method ($\bar{X} \pm$ SD)[b]	r[c]
Total	4.07 ± 2.07	3.32 ± 1.91[d]	0.50
Total, excluding fried	3.78 ± 2.04	3.15 ± 1.93[d]	0.55
Fruit + Juice	1.41 ± 1.14	1.45 ± 1.19	0.57
Juice	0.37 ± 0.49	0.56 ± 0.64[d]	0.52
Fruit	0.97 ± 0.89	0.84 ± 0.77[e]	0.59
Total vegetable	2.53 ± 1.39	1.80 ± 0.99[d]	0.33
Salad/raw vegetables	0.74 ± 0.70	0.43 ± 0.34[d]	0.39
Cooked, excluding fried vegetables	1.44 ± 0.92	1.37 ± 0.97[d]	0.27
Fried vegetables	0.21 ± 0.36	0.13 ± 0.14[d]	0.30

[a] Mean of three 24-h recalls.
[b] Geometric mean, SD back-transformed into original units.
[c] Pearson correlations, all $P < 0.001$.
[d] *Versus* dietary recall, $P < 0.001$.
[e] *Versus* dietary recall, $P < 0.01$.

Results

Table 2 gives comparisons between the 5 A Day method and the mean of three 24-h dietary recalls. Compared with the 5 A Day method, recalls were 23% higher for total fruits and vegetables, 15% higher for fruit, 72% higher for salads, 61% higher for fried vegetables, and 5% higher for cooked vegetables. Recalls were lower than the 5 A Day method only for fruit juice. Correlations between the two measures for total fruit and vegetables were modestly strong, and they were consistently higher for fruit and fruit juices than for vegetables. There was some suggestion that correlations were higher for salads than for cooked or fried vegetables.

Table 3 gives comparisons among the 5 A Day method, the summation method using 30 fruit and vegetable items, and food records. For total fruit and vegetables and for all subgroups of fruits and vegetables where comparisons are possible, intakes were higher for the summation method than for the 5 A Day method. The summation method was 31% higher for total fruit and vegetables, 70% higher for fruit, and 36% higher for cooked vegetables. Intakes calculated from food records were intermediate between the two FFQ-based methods. Correlations with food records were slightly but not significantly higher with the summation method, as compared with the 5 A Day method. For both FFQ-based methods, correlations with food records were higher for fruit and fruit juice than for vegetables. These results did not differ substantially when analyses were stratified by race/ethnicity (black, white, or Hispanic) or by education (≤12 years, 13–15 years, 16+ years; data not shown).

Table 4 gives correlations among the 5 A Day method, the summation method using the sum of 35 fruit and vegetable items, 24-h dietary recalls, and serum carotenoid concentrations. This table focuses on the relative precision of all self-reported measures, using serum carotenoids as an objective, biological measure. For this reason, and because the patterns closely match those previously given, we do not give mean intakes and correlations between recalls and the FFQ-based methods. The correlation between the 24-h recall measure of total fruit and vegetables and serum carotenoids was slightly higher than correlations for either FFQ-based measure. The higher precision for the 24-h recalls is due to stronger correlations for vegetables because correlations for fruit were similar across measures. When the criterion measure was total carotenoids minus lycopene, correlations increased for all measures. Using this criterion measure, correlations are only slightly

Table 3 Comparison of food record and FFQ measures of servings per day of fruit and vegetables ($n = 1031$), Women's Health Trial Feasibility Study in Minority Populations (16)

Fruit and vegetable group	Food record[a] ($\bar{X} \pm SD$)[b]	FFQ: 5 A Day method ($\bar{X} \pm SD$)[b]	FFQ: 5 A Day method r[c]	FFQ: Summation method ($\bar{X} \pm SD$)[b]	FFQ: Summation method r[c]
Total	3.46 ± 1.6	3.11 ± 1.65	0.36	4.06 ± 2.20	0.41
Total, excluding fried	3.38 ± 1.6	2.99 ± 1.63	0.35	3.94 ± 2.17	0.41
Fruit + Juice	1.22 ± 0.92	1.31 ± 0.96	0.45	1.84 ± 1.25	0.47
Juice	0.27 ± 0.33	0.52 ± 0.54	0.53	0.52 ± 0.54	0.53
Fruit	0.90 ± 0.78	0.76 ± 0.65	0.48	1.29 ± 0.94	0.49
Total vegetable	2.14 ± 1.07	1.73 ± 1.01	0.31	2.15 ± 1.28	0.32
Salad/raw vegetables	0.47 ± 0.43	0.40 ± 0.33	0.36	0.40 ± 0.33	0.36
Cooked, excluding fried vegetables	1.55 ± 0.88	1.22 ± 0.81	0.27	1.66 ± 1.03	0.25
Fried vegetables	0.07 ± 0.15	0.10 ± 0.16	0.27	0.10 ± 0.16	0.27

[a] Four-day food record.
[b] Geometric mean, SD *versus* back-transformed into original units. All differences (food records *versus* 5 A Day; food records *versus* summary; 5 A Day *versus* summary) $P < 0.001$.
[c] Pearson correlation with food record, all $P < 0.001$.

Table 4 Correlations among FFQ and dietary recall measures of servings per day of fruit and vegetables, and serum carotenoid concentrations ($n = 342$), Olestra Post-Marketing Surveillance Study (17)

Fruit and vegetable assessment method		Dietary recall[a,b]	Serum carotenoids[a,c]	Serum carotenoids[a,c] (without lycopene)
5 A Day	Fruit	0.62	0.27	0.33
	Vegetables	0.38	0.15	0.24
	Total	0.58	0.24	0.32
Summation	Fruit	0.65	0.24	0.32
	Vegetables	0.37	0.17	0.26
	Total	0.57	0.23	0.32
Dietary recall[b]	Fruit		0.27	0.35
	Vegetables		0.25	0.27
	Total		0.33	0.38

[a] All correlations $P < 0.001$.
[b] Mean of four 24-h dietary recalls.
[c] Adjusted for total serum cholesterol.

higher for recalls than for the FFQ-based measures. Similar to the findings shown in Tables 2 and 3, there are virtually no differences in precision between the 5 A Day method and the summation method.

Discussion

We used three independent sets of dietary intake data to examine the bias and precision of FFQ-based measures of fruit and vegetable intakes. The primary finding was that the 5 A Day method tends to underestimate total fruit and vegetable intake when compared with methods based on dietary recalls or food records, and this is primarily due to lower estimates of vegetable intake. We also found that there were no differences in the precision of the 5 A Day method and the summation method, and this finding was consistent across all three criterion measures (food records, dietary recalls, and serum carotenoids). Finally, for both FFQ-based methods, the precision of measuring fruit intake was substantially higher than the precision of measuring vegetable intake.

There are very few published reports on the precision and bias of the 5 A Day method using a self-reported criterion measure, and their results are somewhat inconsistent. Field *et al.* (23) examined the validity of FFQ-based measures in 102 high school students, using the mean of three 24-h recalls as the criterion measure; Thompson *et al.* (8) examined the validity of a 10-item FFQ using two 24-h dietary recalls as the criterion measure in 443 adults, and Serdula *et al.* (24) examined the 6-item FFQ used in the Behavioral Risk Factor Surveillance System using a variety of criterion measures in five sites (sample sizes ranged from 51–553 per site). There is consistency in the finding that the 5 A Day method underestimates total fruit and vegetable intakes, and some (23) but not all (24) studies show this to be due to underestimates of vegetable consumption. Several studies have compared the 5 A Day and summation methods (8, 23–26), and almost all show lower intakes from the 5 A Day method. Two studies have compared the precision of the 5 A Day and summation methods, based on an independent criterion measure (8, 23), and both found no substantial differences between the two methods. Finally, there are many studies that have reported on the precision of FFQ-based measures of fruit and vegetables separately (23, 24, 27–32). Most of these studies used the summation method to calculate fruit and vegetable intakes, and most found that correlations with criterion measures were higher for fruit than vegetables.

There is no simple answer regarding whether it is preferable to use the 5 A Day method or the summation method to measure usual fruit and vegetable intakes. This report and other studies (8, 23, 24, 32, 33) clearly show that respondents overestimate fruit and vegetable intakes when they are measured as the sum of long lists of fruit and vegetable items. However, results here and in most other studies show that the 5 A Day method underestimates intake. Because there is no difference in precision between the 5 A Day and summation method, it should make little difference in epidemiological studies of associations between fruit and vegetable intakes and disease risk. However, in research where the objective is to measure absolute rather than relative intake, for example, for comparison with dietary recommendations, these two methods will lead to profoundly different conclusions. Other considerations are that the 5 A Day method is simpler to administer and has a lower respondent burden than the summation method. However, for some purposes, it may be preferable to have detailed information on which fruits and vegetables are consumed, for example, to better design or evaluate the effects of a dietary intervention program.

A related issue concerns using FFQs to calculate intakes of micronutrients concentrated in fruit and vegetables. Comprehensive FFQs typically ask about many different fruits and vegetables, grouped by similarities in nutrient content, to estimate intake of micronutrients (*e.g.,* vitamin C, carotenoids, and folate) and other compounds (*e.g.,* isoflavones). Most algorithms to calculate nutrients from FFQs first adjust the reported intakes of individual fruits and vegetables such that they add up to the answers given to the related summary question (*e.g.,* the sum of the frequencies for all vegetable items would equal the answer to the summary question "How often did you eat a serving of vegetables, not counting salads or potatoes"). This almost always results in a downward adjustment of intake frequencies. Results here suggest that this adjustment procedure will result in estimates of nutrients from fruit and vegetables that are biased to be lower than those based on food records or dietary recalls, whereas calculations made without this adjustment will be higher. The truth appears to lie somewhere between the two approaches.

Differences in precision between components of the total fruit and vegetable measure may be due to both cognitive aspects of dietary recall and to the questions themselves. All self-reported measures were more valid for fruit and juices than for vegetables, and within vegetables, there was better agreement between FFQ-based and recall-based methods for salads than for cooked vegetables. One explanation of this could be that juices and salads tend to be eaten regularly, for example a glass of juice with breakfast and a salad with dinner. Therefore, they may be recalled with greater accuracy than the consumption of foods eaten irregularly. Another explanation is that the word "vegetable" has different interpretations, and vegetables in mixed foods, such as casseroles or sandwiches, may be forgotten and thus underreported (23). One approach to improving the 5 A Day method would be to modify the questions addressing vegetables included in mixed foods, for example, "carrots, onions, or other vegetables including in mixed dishes." Research on ways to better measure vegetables is clearly needed.

These results have implications for all studies of fruit and vegetable consumption using FFQ-based approaches. First, because the precision of measuring usual vegetable intake is poor, it substantially limits study conclusions. Epidemiological studies of diet and disease risk will fail to detect significant associations or report associations that are weaker than true associations. Studies to evaluate intervention programs to increase vegetable intake will underestimate the true intervention effect or may find a significant effect for fruit but not for vegetables. Behavioral research to understand attitudes and other determinants of fruit and vegetable intakes may report that some factors more strongly affect fruit compared to vegetable intakes, when these differences may be due solely to measurement error (33). Second, public health policy may be misguided by weak or negative study results. The generally accepted protective associations of high vegetable intakes with many cancers are likely to be much stronger than previously believed. Third, population-based surveillance studies of fruit and vegetable intakes are probably underestimating vegetable intake, and consumption of fruit and vegetables could be substantially higher than those reported based on programs such as the Behavioral Risk Factor Surveillance System (24, 34).

There are several strengths and limitations to the analyses reported here. Most importantly, we had no truly valid criterion measure of fruit and vegetable intakes. Although we used criterion measures believed superior to FFQ-based measures, it is best to consider our results not as a study of true validity but as a study of convergent validity. Both the FFQ and criterion measures of fruit and vegetable intakes differed across the three studies. This limits our ability to make statements about the actual amount of bias or to compare precision across studies. However, the consistency across studies, which are also based on samples that differed markedly in race/ethnicity and socioeconomic status, do suggest that our conclusions are generalizable. The time periods referenced by dietary assessment instruments used in each study were similar but did not match exactly. The results given here may therefore underestimate the true precision of FFQ-based measures. An important strength of the results of this report is that one study included serum carotenoids as an objective, biological measure of fruit and vegetable intake. Whereas serum carotenoids are only moderately correlated with fruit and vegetable intakes and are affected by many other dietary and lifestyle factors (20, 21), serum carotenoids are still one of the most broadly accepted and useful biomarkers of diet (35, 36).

We conclude that FFQ-based measures of fruit and vegetable intakes have significant limitations, due primarily to their imprecise assessments of vegetable intake. Research on ways to improve these measures is important because they are the only feasible methods for large studies or surveys. Whenever possible, studies should collect additional measures, such dietary recalls or biomarkers of fruit and vegetable intakes, to validate results based on FFQ-based measures alone.

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