Measuring diet cost at the individual level: a comparison of three methods

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BACKGROUND/OBJECTIVES: Household-level food spending data are not suitable for population-based studies of the economics of nutrition. This study compared three methods of deriving diet cost at the individual level.

SUBJECTS/METHODS: Adult men and women (n = 164) completed 4-day diet diaries and a food frequency questionnaire (FFQ). Food expenditures over 4 weeks and supermarket prices for 384 foods were obtained. Diet costs (US$/day) were estimated using: (1) diet diaries and expenditures; (2) diet diaries and supermarket prices; and (3) FFQs and supermarket prices. Agreement between the three methods was assessed on the basis of Pearson correlations and limits of agreement. Income-related differences in diet costs were estimated using general linear models.

RESULTS: Diet diaries yielded mean (s.d.) diet costs of $10.04 (4.27) based on Method 1 and $8.28 (2.32) based on Method 2. FFQs yielded mean diet costs of $7.66 (2.72) based on Method 3. Correlations between energy intakes and costs were highest for Method 3 (r² = 0.66), lower for Method 2 (r² = 0.24) and lowest for Method 1 (r² = 0.06). Cost estimates were significantly associated with household incomes.

CONCLUSION: The weak association between food expenditures and food intake using Method 1 makes it least suitable for diet and health research. However, merging supermarket food prices with standard dietary assessment tools can provide estimates of individual diet cost that are more closely associated with food consumed. The derivation of individual diet cost can provide insights into some of the economic determinants of food choice, diet quality and health.

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INTRODUCTION

The cost of a nutritious diet is an important and complex issue for public health.1–3 Real or perceived inability to afford healthful foods can be a barrier to dietary change.4–6 Lower-cost foods tend to be energy-dense but nutrient-poor.7,8 Such foods are often consumed by groups of lower socioeconomic status (SES) who are more likely to be obese.9,10

Epidemiologic analyses have drawn a direct link between measures of diet quality and estimated diet cost.11–14 However, studies on nutrition economics have been hampered by the lack of appropriate methods and tools.15 Studies on food purchases have typically dealt with food expenditures at the household level11,16 and could not provide individual estimates of food consumed. Although such data can be used to impute individual food expenditures, by dividing by the number of household members, they may be problematic if applied to individual level studies on diets and health. By contrast, most studies on diet and chronic diseases, always conducted at the individual level, provided no data on the cost of foods consumed.

Individual-level diet costs have been estimated by linking dietary intake data from 24-h recalls or diet diaries to national or local food prices.17–19 More typically, diet costs are estimated by linking prices to diet history or food frequency questionnaires (FFQs). Following this approach, studies conducted in Europe,12,14,20 the USA11,21,22 and Japan13,23,24 have produced diet cost estimates based on fixed tables of food prices containing 57–384 foods. However, costs estimated from FFQs might not be directly comparable to those obtained with diet diaries. Furthermore, costs estimated using prevailing supermarket price data might not reflect the individual’s own food expenditures.

This study compared three different methods of estimating individual-level diet costs that were derived from: (1) 4-day diet diaries and individual food expenditures; (2) diet diaries and supermarket prices; and (3) FFQ data and supermarket prices. The three diet cost data sets were compared to each other, to estimated energy intakes and to self-reported household incomes.

MATERIALS AND METHODS

Study sample

The study was based on a stratified sample of faculty and staff of a large public university in Washington state, USA.22 Eligible respondents were aged 25–65 years and had the primary or shared responsibility for food purchasing and preparation and not on a medically prescribed diet. Data were collected between June 2005 and September 2006. All study procedures were reviewed and approved by the university’s institutional review board.
Recruitment and study procedures
As described previously,22 a total of 3000 recruitment letters were sent to potential participants by campus mail. Because the 3000 invitations mailed out were based solely on salary strata from the university payroll office, an unknown fraction of the 3000 invitations were sent to individuals who may not have been eligible because of our three inclusion criteria. Out of 350 who responded positively to the letter, 91 were ineligible on account of at least one of the inclusion criteria. The 259 eligible respondents enrolled and 185 completed the 4-week study.

During the initial visit, participants completed the FFQ and were instructed in the keeping of diet diaries and recording food spending. Participants recorded food expenditures and kept receipts for all foods purchased for home consumption in grocery stores during all 4 weeks. During weeks 3 and 4, receipts for ‘away-from-home’ foods, including foods from restaurants, take-out and delivery were also saved. Diet diaries and food expenditures were reviewed by a registered dietitian upon study completion and participants were compensated for their participation.

Dietary intake assessment

4-Day diet diaries. Diet diaries were completed on 4 nonconsecutive days (including one weekend day) during week 4. For each food item consumed, participants indicated place purchased, details (including brand name, cooking methods, package size or quantity) and amount consumed. Diet diaries were entered, coded and analyzed for energy and nutrient values using Food Processor 8.1 (ESHA Research, Salem, OR, USA).

Food frequency questionnaire. All participants completed a semi-quantitative 152-item FFQ developed by the Fred Hutchinson Cancer Research Center (FHCRC) and used in prior studies on diet and health.25,26 The reference period for reporting was the previous 12 months. Completed and reviewed FFQs were analyzed using the FHCRC Nutrition Assessment Shared Resource using the Minnesota database.26

Assessing diet costs

The mean daily diet cost (USD) was derived for each participant using the three methods described below.

Method 1: diet diaries and food expenditures. All foods and beverages reported in each participant’s coded 4-day diet diary were linked to corresponding items in the participant’s receipts, collected during weeks 1–4 of the study. To compute the expenditure for each food portion of food or beverage consumed, the gram weight consumed was multiplied by the ratio of the purchase price over total grams purchased, correcting for edible portion (EP):

\[
\text{Cost per portion} = \frac{\text{Cost consumed} \times \text{EP}}{\text{grams purchased} \times \text{EP}}
\]

For example, the expenditure associated with a 1 cup portion (109 g) of fresh apple that was purchased for $1.49/pound (454 g) was 109 g \times $1.49/(454 g \times 0.90) = $0.531. Overall, approximately 80% of all foods and beverages consumed were accounted for in the participants’ receipts. For missing receipt data, expenditures were imputed using food prices collected by study staff. The posted price was recorded for the product and matched for details provided by the participant. The key details were product brand, type, package size and the retail outlet from which it was purchased. When product or retail outlet information was not available, the closest match was identified from among three major supermarket chains (Safeway, Albertson’s and Quality Food Centers (a subsidiary of Kroger)), which were selected because of their large market share in the region. Prices were obtained during in-store visits and from supermarket home shopping websites (Safeway and Albertton’s), which reported the same prices as those available to in-store customers. When no exact match from the 384 products was available, the closest match from among the broader food categories was used. As in Method 1, daily totals were computed and 4-day means were derived.

Method 3: FFQ data and supermarket prices. The same database of supermarket prices used in Method 2 was used to derive diet cost from the FFQ, using methods described previously.21,22

Analytic approach

All analyses of dietary energy, nutrients and monetary cost included all reported foods and beverages, except drinking water. We used parametric statistics throughout as all diet cost estimates appeared to follow standard log-normal distributions. The Pearson product–moment correlation was used to test the agreement between estimates of nutrient intake in Methods 1 and 3 and between all three diet cost estimates. Nutrient and diet cost variables were natural log transformed before conducting Pearson correlations. Energy adjustments were based on the method of residuals.11,28 The association between energy intakes and estimates of diet cost was based on linear least squares regression. The agreement among all three crude (not transformed or energy-adjusted) diet cost estimates was assessed using the limits of agreement. This method provided a mean difference between values from any two methods and the range of difference values within which 95% of all differences between methods will be expected to fall.22 Estimates of diet cost across income groups were based on a general linear model to adjust for energy intake, age, sex and number of adults and children in the household. Analyses of variance were used to test for differences across groups. Four income groups were defined to keep numbers of respondents similar. All analyses were conducted using SPSS 18.0 for Mac (IBM, Chicago, IL, USA).

RESULTS

The final analytic sample of 164 (103 women and 61 men) provided complete FFQ and diet diary data, all questionnaires and shopping and restaurant receipts over 4 weeks.

Sample characteristics

Mean age was 42.2 years for women and 38.0 years for men (range 25–65 years). Most men (92%) and most women (85%) had completed a bachelor’s degree or higher. A majority of women (60%) and half the men (51%) had annual household incomes of $55 000 and above. Most men (85%) and women (82%) identified themselves as white, with the rest being Asian or Pacific Islander and African American. Demographic and SES data are summarized in Table 1.

Estimates of energy and nutrient intakes

On the basis of diet diaries, mean (s.d.) intakes overall were 2134 (508) kcal/day (8.93 MJ), with a range of 1192–3796 kcal/day (5.0–15.9 MJ). Men consumed 2426 kcal/day (10.2 MJ) and women 1960 kcal/day (8.2 MJ). The FFQ showed a lower overall mean but more variance than the diet diary estimates. Average daily energy intake for the whole sample was 1894 (641) kcal/day (7.9 MJ) and intakes ranged from 689 to 4110 kcal/day (2.9–17.2 MJ). Men reported energy intakes of 2088 kcal/day (8.7 MJ) and women 1779 kcal/day (7.4 MJ).

Crude nutrient intakes from the two instruments are summarized in Table 2. As with energy intake, macronutrient intakes from 4-day diet diaries were generally higher than the estimates produced by the FFQ. However, for crude micronutrient intakes, estimates from diet diaries tended to be lower than those from the FFQ. Among both macronutrients and micronutrients, the magnitude of differences in estimated mean nutrient intake between the diet diaries and FFQs varied from as low as 2% for fiber (diet diary estimate higher) to 46% for magnesium (diet diary estimate lower). Pearson correlations for energy-adjusted nutrient intake estimates from the two instruments ranged from 0.27 (vitamin B1) to 0.7 (fiber).
Estimates of crude and energy-adjusted diet costs

Mean (s.d.) diet costs based on 4-day diet diaries and food expenditures (Method 1) were $10.04 (4.27)/day (range $2.09–24.90/day). Despite the difference in estimated energy intake between the two sexes, men and women spent a similar amount of money on food per day: $9.97/day versus $10.08/day, respectively. However, on a per-2000 kcal (8.38 MJ) basis expenditures were $8.37 for men and $10.47 for women. The overall energy-adjusted diet cost was $9.70 (4.06).

The top panel in Figure 1 shows the association between diet costs estimated using Method 1 and estimates of dietary energy for all 164 participants. Diet costs based on food expenditures showed much greater inter-subject variability than did energy intakes. Although food expenditures varied by more than 10-fold, energy varied only by a factor of four. Diet cost was only weakly associated with food intake, with dietary energy accounting for 6% of the variation in food expenditure.

Mean (s.d.) diet costs based on 4-day diet diaries and supermarket prices (Method 2) were estimated at $8.28 (2.32)/day. Relative to Method 1, the range was greatly reduced at supermarket prices (Method 2) were estimated at $8.05–14.74/day. The estimated diet cost was higher for men ($8.59/day) than for women ($8.09/day) before adjusting for energy. Diet cost per 2000 kcal was $7.21 for men and $8.37 for women with an overall mean of $7.94 (2.19). Relative to Method 1, the association between diet cost and energy was stronger ($r^2 = 0.24; Figure 1, middle panel).

Mean (s.d.) diet costs based on FFQ data and standard supermarket prices (Method 3) were $7.66 (2.72) per day, ranging from $2.03 to $18.11/day. Diet cost was $8.12/day for men and 7.39/day for women. Diet cost per 2000 kcal was $7.73 for men and $8.44 for women with an overall mean of $8.19 (1.68). Figure 1 bottom panel shows that the association between diet cost and energy was robust ($r^2 = 0.66).

Agreement among estimates of diet cost

The association between diet costs estimated using Method 1 and those estimated using Method 3 was weak. Crude daily food expenditures were an average of 31% higher than diet costs estimated using Method 3. The Pearson correlation coefficient between the two crude measures was 0.21 and limits of agreement analysis indicated a mean difference of $2.37/day (Method 1 higher) with a 95% confidence interval (CI) for the difference of $1.67, $3.08. The weakness of the association was partly attributed to differences in the energy estimates from the two instruments. Adjusting for energy based on residuals yielded a Pearson correlation of 0.30. Adjusting crude diet costs on a per-8.38 MJ (2000 kcal) basis narrowed the difference in estimated diet costs to 18% and yielded a correlation of 0.33 (Table 2).

By contrast, we found higher correlations between diet costs derived using Method 1 and Method 2. Method 1 and Method 2 shared the same instrument of dietary intake assessment, but differed in the use of actual food expenditures versus supermarket prices. The mean (95% CI) difference between the crude estimates was $1.76/day ($1.21, $2.31, Method 1 higher) and the Pearson correlation coefficient for energy-adjusted estimates was 0.49. Diet costs obtained using Methods 2 and 3 were also significantly correlated. Methods 2 and 3 used different methods of dietary intake assessment, but the same price database. The mean (95% CI) difference between the crude estimates was $0.62/day ($–0.16, $1.07, Method 2 higher) and the Pearson correlation coefficient for energy-adjusted estimates was 0.39. The comparison of the resulting three estimates of diet cost and the Pearson correlation of energy-adjusted estimates is illustrated in Figure 2.

| Table 1. Demographic and socioeconomic characteristics of the study sample |
|-----------------|----------------|----------------|
|                 | Men            | Women          | All             |
| Sample size, n  | 61             | 103            | 164             |
| Age, years      | 37.7 (9.7)     | 42 (10.4)      | 40.3 (10.3)     |
| Body weight, kg | 77.7 (10.8)    | 73.9 (18.5)    | 75.4 (16.1)     |
| Body mass index, kg/m² | 25 (2.8) | 26.6 (6.3) | 26 (5.3) |
| Completed 4-year degree or higher, % | 92 | 85 | 89 |
| Household income, number |
| $15,000—$44,999 | 21 | 29 | 50 |
| $45,000—$74,999 | 22 | 35 | 57 |
| $75,000—$104,999 | 10 | 17 | 27 |
| $105,000 and higher | 8 | 22 | 30 |
| Number of individuals residing in the household | 2.1 (1.1) | 2.4 (1.4) | 2.3 (1.3) |

Unless otherwise indicated, values shown are means (s.d.). *Includes adults and children.

| Table 2. Estimated mean energy and nutrient intakes and diet costs based on 4-day diet diaries and food frequency questionnaires |
|-------------------------------|----------------|----------------|----------------|----------------|----------------|
|                               | 4-Day diet diary record | Food frequency questionnaire | Pearson correlation coefficients |
| Energy (kcal/day)² | Mean | s.d. | Mean | s.d. | Crudeᵃ |
| Protein (g/day) | 84 | 23 | 72 | 28 | 0.39 |
| Carbohydrates (g/day) | 266 | 80 | 248 | 90 | 0.47 |
| Fiber (g/day) | 23.2 | 9.6 | 22.8 | 10.1 | 0.62 |
| Total fat (g/day) | 78.4 | 24.6 | 67.5 | 28.3 | 0.45 |
| Saturated fat (g/day) | 24.7 | 9.3 | 21.6 | 9.5 | 0.51 |
| Cholesterol (mg/day) | 249 | 122 | 238 | 175 | 0.53 |
| Vitamin B1 (thiamin, mg) | 1.5 | 0.7 | 1.7 | 0.7 | 0.33 |
| Vitamin C (mg/day) | 111 | 65 | 126 | 64 | 0.45 |
| Calcium (mg/day) | 89 | 338 | 981 | 436 | 0.52 |
| Iron (mg/day) | 16.3 | 7.1 | 15.3 | 6.8 | 0.35 |
| Magnesium (mg/day) | 241 | 89 | 353 | 133 | 0.36 |
| Potassium (mg/day) | 2326 | 792 | 3150 | 1093 | 0.28 |
| Diet cost ($/day) | 10.04 | 4.27ᵇ | 7.66 | 2.72ᵇ | 0.21 |
| Diet cost ($/2000 kcal)² | 9.70 | 4.06ᵇ | 8.19 | 1.68ᵇ | 0.33 |

Pearson correlation coefficients comparing estimates from the two methods. *After natural log transformation. +Adjusted using the residual method. ²Kilocalorie (2000 kcal = 8.38 MJ). ᵃUsing Method 1. ᵇUsing Method 3.
Although all three estimates of diet cost showed positive associations with household income, an indicator of SES, the strength of the association was different for the three estimates. Figure 3 presents covariate-adjusted means and standard errors for each of the three measures of diet cost across four levels of household income. Diet cost estimates based on Method 1 showed the strongest gradient with income, with the highest income group showing a daily diet cost that was 34% higher than the daily costs for participants in the lowest income group ($2.98/day, \( P = 0.004 \)). Method 2 showed a 16% difference between the highest and the lowest income groups ($1.24/day, \( P = 0.015 \)), whereas Method 3 showed a 15% difference ($1.08/day, \( P = 0.007 \)) between the highest and the lowest income groups.

**DISCUSSION**

Estimates of daily diet costs at the individual level can be obtained by joining dietary intake data with prevailing food price data, from local supermarkets, or individual price data, from each participant’s own food expenditures. The present goal was to test the performance of alternative methods, following the design of previous inter-method reliability and validity studies. Comparisons were therefore conducted both across and within two dietary assessment instruments: diet diaries (Methods 1 and 2) and FFQ (Method 3). In Method 3, FFQ data were combined with area food prices, a widely used approach internationally. Method 2, combining 4-day diet diaries with area food prices, was similar to the approach used in earlier studies.

**Figure 1.** Scatter plots showing estimated diet cost and energy intake ($1 \text{ kcal} = 4.18 \text{ kJ}$) based on three methods, \( n = 164 \). Top panel, Method 1 based on 4-day diet diaries with food expenditures. Middle panel, Method 2 based on 4-day diet diaries linked to a database of supermarket prices. Bottom panel, Method 3 based on FFQ with the same food price database. Energy estimates were based on each corresponding instrument. Least squares regression indicated weakest association between cost and energy for Method 1 and strongest for Method 3.

**Figure 2.** Schematic showing the mean diet cost estimates for the three methods and Pearson correlations for energy-adjusted estimates for each comparison.

**Figure 3.** Estimates of mean and standard errors of diet cost using three methods by income level, \( n = 164 \). Sample sizes in each income level given in Table 1. Means are adjusted for age, gender, energy intake and number of adults and children residing in the household. Method 1 based on 4-day diet diaries with food expenditures. Method 2 based on 4-day diet diaries with a database of supermarket prices. Method 3 based on FFQ with the same price database. Trend tests across income levels were significant for all three diet cost measures. *\( P < 0.05 \); **\( P < 0.01 \); ***\( P < 0.005 \).
studies in Japan\textsuperscript{31} and Sweden\textsuperscript{19} that linked 4-day diaries to national and local food prices. A variation of this approach has been the application of national food prices to 24-h recalls of adults\textsuperscript{18} and children\textsuperscript{17} in the USA.

Method 1, which derived expenditures for food consumed, has to our knowledge not been previously reported and might be described as closest to a ‘true’ indication of diet cost. In fact, the present estimate of $10.04 was similar to the $10.12 per capita food expenditures imputed by the US Department of Agriculture using household food expenditure data for 2006.\textsuperscript{32} However, two factors limit the usefulness of Method 1 for diet and nutrition research. First, for reasons discussed below, this diet cost estimate showed little association with the total amount of food consumed (Figure 1, top panel), which would likely attenuate any association of diet cost with diet composition. Second, estimating individual diet costs by using individual food expenditures is highly labor intensive, requiring 4-8 h to link each coded 4-day diet diary to receipt data and adjust purchased products for edible portion.

Methods 2 and 3, which applied a standard database of supermarket prices, have parallels in nutritional epidemiology, where estimates of energy and nutrient intakes for individuals are derived from common nutrient composition tables. For example, the vitamin C content of fresh, raw apples consumed by participants in the National Health and Nutrition Examination Surveys is set at 4.6 mg per 100 g edible portion;\textsuperscript{33} regardless of the vitamin C content of the apples that were actually consumed. The addition of a price variable was analogous to the inclusion of new nutrient-based variables in the FFQ nutrient database.\textsuperscript{34}

All three estimates of diet cost were positively and mono-
tonically associated with household income, consistent with past studies on incomes and household food expenditures.\textsuperscript{5,10,35} Diet cost estimates based on expenditures (Method 1) were not only the highest but also showed the largest differences across income strata. It is likely that diet costs estimated using a standard prices database (Methods 2 and 3) underestimate the true differences in purchasing power across income groups.

Methodological considerations and sources of bias between estimates

A number of factors may have biased the results of this methodological study. First, analyses were based on a conve-
nience sample of mostly white adults of higher SES, that although small, was similar in size to samples used in previous reliability studies of dietary assessment.\textsuperscript{26,29,30} The socioeconomic profile of the sample was one factor that made the present estimates of diet cost substantially higher than estimates based on a representative sample of adults in the USA: $7.94 per 2000 kcal (Method 2) versus $8.5 per 2000 kcal in NHANES. Samples primarily composed of higher SES persons would have implications for bias in diet cost estimates using either Methods 2 or 3. Our analyses of all three measures of diet cost by household income (Figure 3) indicated that underestimation of food expenditures using either Methods 2 or 3 was greatest for higher-income people. Another consideration is that eligibility required either having primacy or shared responsibility for food purchasing. Finally, following precedent,\textsuperscript{36} Methods 2 and 3 made the assumption that all foods were purchased at retail and prepared at home.

The home preparation assumption was one factor that led to systematically lower estimates in Methods 2 and 3 relative to Method 1, which accounted for away-from-home consumption. The costs of away-from-home foods reflect not only the cost of food and drink but also the cost of services provided.\textsuperscript{37} For instance, in Method 1, the cost of plain brewed coffee depended on whether it was prepared at home ($0.09/100 g) or purchased prepared from a coffee shop ($1.67/100 g). By comparison, our standard database price for prepared coffee (applied to Methods 2 and 3) was $0.04/100 g. The use of standard prices (Methods 2 and 3) also ignored the possibility that different participants may have paid different prices for the same foods, which can vary substantially by brand and by retail outlet.\textsuperscript{38} Furthermore, differences in diet cost estimates also were imposed by the inherent difference between the diet diary and FFQ.

CONCLUSIONS

There is a growing recognition that the quality of individual diets is closely tied to energy-adjusted diet costs. Given the apparent systematic and positive associations between diet cost and diet quality, the higher cost of favorable dietary patterns in nutritional epidemiology\textsuperscript{11-14} may represent a form of confounding that is not entirely addressed through adjustment for indicators of SES.\textsuperscript{23} Estimates of diet cost can enrich nutrition surveillance by providing quantitative insights into a recognized determinant of food choice in the population.\textsuperscript{39} The application of food prices to standard dietary assessment tools is a practical way to derive diet costs in the context of dietary research and public health surveillance.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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