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Need for Technological Innovation in Dietary Assessment

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In 2007, the National Institutes of Health developed the Genes, Environment and Health Initiative (GEI) (www.gei.nih.gov) to promote research to better understand the genetic and environmental contributions to health and disease. GEI funded technology-driven methodology to improve measures of diet, physical activity, chemical exposures, psychosocial measures, and biological response indicators for use in future large-scale population studies. Similarly, since 2004, the National Cancer Institute (NCI) has internally funded the development of another technology advance in dietary assessment: an automated self-administered 24-hour dietary recall (ASA). The purpose of this paper is to briefly overview issues related to the uses of technology in dietary assessment, as a backdrop for advances in the field.

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DIETARY ASSESSMENT METHODS: OVERVIEW

Dietary assessment methods have been extensively described and discussed in a recent publication (1) (also available at www.riskfactor.cancer.gov). All self-report methods are challenging. People do not commonly attend to the foods they have eaten; do not remember everything; do not know the contents of the foods eaten; and cannot estimate portion sizes accurately (2). Further, factors such as gender and weight status can bias reports of diet (3–5). Three principle types of diet assessment instruments are widely used: the food frequency questionnaire (FFQ), food record (or diary) and 24 hour dietary recall (24HR). Each has strengths and weaknesses (1). Biological indicators of intake do not suffer from errors in self-reporting, but have other limitations, including that they often reflect status rather than intake, short term rather than long term intakes, are highly specific, and are generally expensive and invasive (6).

Food Frequency Questionnaire (FFQ)

The FFQ asks about usual intake over a long period of time, e.g. last year (1). Most currently used FFQs ask both frequency of intake and usual portion size for a list of foods (1). Because the FFQ is usually self-administered and responses are entered through optical scanning or electronically in web-based versions, it is economical for researchers and presents minimal burden to respondents. However, it relies on the ability of the respondent to form and report a generic central tendency of frequency and portion size over a long time interval, typically the past month or year. This generic memory is distinctive from episodic memory, in which a specific memory is evoked (7). Summarizing intake in this requested time frame can be problematic if diet was not stable. For example, individuals sometimes intentionally changed their diets, or are undergoing changes, due to pregnancy, illness or economic uncertainties. Foods eaten at different times throughout the year, because of availability or price, also pose problems. A common understanding of the meaning of a particular food category between the researcher and the respondents is a major requirement (8).

The FFQ employs close-ended responses on a number of foods. While the U.S. Department of Agriculture (USDA) maintains food composition data for over 7,000 different foods (9), the FFQ is usually limited to about 100 food categories. Each food category contains similar foods, but responding to the entire food category precludes capturing the variability of intake (and nutrient composition) of the foods in the category. Since most FFQs ask about intake independent of meal occasion, details regarding which foods are consumed with each other at specific meals, time intervals between meals, and so on, are not assessed.

Food Record

The food record asks respondents to record the foods and beverages and the amounts of each consumed over one or more days. The food record can minimize error from incomplete attention and memory. If foods are also weighed, error in portion size estimation can be reduced. Incomplete knowledge of the food, especially mixtures, remains a problem. Generally, food records have relied on recording by paper and pencil, and thus have required a high level of literacy and motivation. A severe limitation of the food record is its potential for bias. The demands of frequent recording may discourage many respondents from participating and cause others to drop out. Research has shown dramatic dropouts after three consecutive days of recording (10). In addition, respondents may change their diet as a result of the recording itself, termed reactivity (11); for example, they may eat simple foods to avoid the burden of recording a complex mixture or they might eat less. Reactivity due to social desirability and other reporting biases are also problems.

24 hour Dietary Recall (24HR)

The 24HR asks respondents to remember and report all the foods and beverages consumed in the preceding 24 hours or the preceding day (1). In its purest form, a recall is administered without prior notice, thus eliminating the issue of reactivity. Interviewer administration minimizes literacy barriers. The main challenges to accuracy with the 24HR are attention and memory. Many respondents are challenged with distinguishing between what they usually eat and what they ate yesterday, opening the possibility for omissions and intrusions (foods reported, but not actually eaten) (12). Actual memory of distinct events decays with time (7, 13), which has been documented to start within an hour of the meal (14). Portion size estimation is also challenging as the amount consumed has to be both remembered and accurately estimated (1).

Both the food record and the 24HR collect detailed information about a single day. Since day-to-day variability in diet is high (15), the information from a single day cannot accurately reflect the usual diet of an individual (16). Multiple days of information are collected and statistical techniques employed to address this problem (17,18). Collecting information on non-consecutive days is preferred, since consecutive days suffer from the error in one day being correlated with the error in the next day, and thus are not independent assessments. Use of automated systems increases reliability by standardizing probes about foods consumed, but the costs are high, since software must be purchased; interviewers require extensive training; and the actual collection of the data require substantial staff time (and costs) for interviewing, coding, processing, and quality control (19). The expense of the interviewer-administered 24HR has limited its use in large scale diet studies.

Nutritional Biomarkers

Biological indicators measure status or change in biochemical processes, structures, or functions (6). Nutritional biomarkers reflect different aspects of nutritional status or intake. Some, for example, toenail selenium and tissue fatty acid composition, reflect long-term nutritional status; others, such as urinary sodium and serum folate, reflect recent consumption (20). However, there is seldom a direct relationship between intake and biomarker value. In addition, nutrient concentrations can vary by individual characteristics, both genetic and environmental, such as smoking and body weight. Some nutritional indicators are homeostatically controlled, so there is little relationship between intake and biomarker value. Given that most nutritional biomarkers require the collection of blood, urine, or other biological tissues or products, they can be burdensome and costly to collect and analyze. Finally, biomarkers are specific to particular nutrients, and thus none can reflect the multiple dimensions of dietary intake. Because of this, biomarkers are generally too expensive for too little dietary information, and are not often used as a primary measurement in dietary intake studies.

INCOROPORATION OF TECHNOLOGY IN DIETARY ASSESSMENT INSTRUMENTS

Adaptations of technology have led to extensive changes in how dietary assessment is performed. The most common objective has been to reduce the costs of both the collection and processing of dietary intake information due to the amounts and complexity of data usually involved.

The early Framingham and Tecumseh community studies were the first to establish cohorts for the express purpose of examining diet and disease relationships, but their tools were interviewer administered, and the data processed manually. The advent of optical scanning (i.e. the bubble forms) led to collecting dietary information from large numbers of respondents, and thus to huge cohort studies using scannable FFQs. This approach has been used in nearly all large cohort studies. Later technological advances allowed administering FFQs on computers (21,22), thereby reducing printing and mailing costs and enhancing completeness of responses. More recently web-based FFQs and audio questions with touch screen picture responses have been incorporated for use in low literacy groups (23), and are becoming more popular.

Technology also facilitated reporting for the food record. Instead of writing down entries, alternative approaches included audio recording reports and capturing images of foods to be eaten (24). An electronic diary (ED) used a two-level food reporting and coding system with 15 broad food categories at the first level and up to 18 sublevel specific foods for each food category (25). The Food Recording Electronic Device (FRED) replaced a paper record by linking a kitchen scale directly to a computer allowing the participant to identify the food within categories, and immediately record the weight (22). The Nutrition Evaluation Scale System (NESSy) further simplified records by combining a food bar code reader (with a bar coded food identification catalogue) with an electronic balance and a computer that had a built-in modem to transmit data by telephone (26). The “food-meter” combined a bar code reader with a booklet of bar codes representing 187 different food items, and type of meal, and amount eaten (27).

There have been major technological advances in processing dietary data. Early work compared nutrient estimates from dietary analysis software with those from manual processing, and found reasonable concordance (28). Computer processing of responses is now standard. However, the choice of the nutrient database and software requires consideration: estimates of intake can vary by the nutrient composition database that is used to process the data (29,30). The large array of nutrient databases and software described in the 2008 International Nutrient Databank Directory (31) reflects the substantial development in this area. Data analysis systems that process 24HR are available on personal digital assistants, making this technology feasible in a wide range of environments including developing countries.

Another major technological advance was software that automated the 24hr interview questions. Two widely used interviewing systems are the University of Minnesota’s Nutrition Data System for Research (NDSR) (32) and the USDA’s Automated Multi-Pass Method (AMPM) (33). These systems enhanced consistency of interviewing, since the probes which query details of foods and portions consumed are standardized. In addition, the NDSR and to some extent the AMPM systems support automated coding of the responses.

Computers have also facilitated the blending of methods. An interviewer-administered diet history combined elements of an FFQ with 24HR (34). DietAdvice was a web application that combined a multiple pass approach with FFQ and 24HR procedures by starting with meals, querying food intake within broad food categories for which further details, portion size and frequency of usual intake were assessed (21).

The first self-administered computerized 24HR quantified primarily fruit and vegetable intake among fourth grade children using artist renderings of 300 foods to prompt recall and enhance portion size estimation (35). Called the Food Intake Recording Software System (FIRSSt), version 2, FIRSSt2 revealed a substantial intrusion rate, which is a common frailty in memory-based systems (7). Accuracy could be enhanced if recalls were conducted several times during the day, soon after food consumption, thereby minimizing the intrusion rate, creating a record-like approach. The internet Data Logger (iDL) did just this using a web based food record analysis system (36). Cell phones with camera capability could further reduce self report error by taking and storing food images before and after consumption in a data base which could be assessed by dietitians (37,38). Cell phones using a voice recognition system linking reported foods to a food-nutrient database enhanced ease and lowered error (39).

Thus, there has been a long history of technological innovation in the design and development of diet assessment systems. The National Cancer Institute is developing the Automated Self Administered 24 hour recall (ASA24) (40,41) which seeks to adapt USDA's AMPM interview to an electronic self-administered format for adults. In addition, four recently funded GEI projects are advancing technology for dietary assessment. The FIRSSt (version 4) (42–46) will adapt the ASA24 for use by children. The Mobile Phone Food Record (mpFR) project (47, 48) will integrate the currently available technology in mobile phones with image processing, visualization, and a nutrient database and custom software for the purpose of allowing a participant to "record" foods eaten in real time. The Food Intake Visual and Voice Recognizer (FIVR) (49) will capture a photographic record of food intake, similar to the mpFR project, and will capture additional detailed food information using voice record and recognition data. The goal of the Wearable Device for Diet Assessment project (50) is to develop an electronic device, that can be worn unobtrusively, to record images of food intakes; these images would be processed later to extract relevant information. Successful development of these projects will further enhance the accuracy, reduce cost, and minimize respondent burden of existing diet assessment systems.

CONCLUSIONS

There has been a long history of using technology to enhance the accuracy and speed and minimize the costs and inconvenience of assessing diets. GEI is advancing these efforts by funding state of the art technology based approaches. The products of these projects will offer investigators innovative new methods to enhance dietary assessment.

References

1. Thompson, FE.; Subar, AF. Dietary assessment methodology. In: Coulston, AM.; Boushey, CJ., editors. Nutrition in the Prevention and Treatment of Disease. 2. San Diego: Academic Press; 2008.
2. Frobisher C, Maxwell SM. The estimation of food portion sizes: a comparison between using descriptions of portion sizes and a photographic food atlas by children and adults. J Hum Nutr Diet 2003;16:181–188. [PubMed: 12753111]
3. Johnson RK, Soultanakis RP, Matthews DE. Literacy and body fatness are associated with underreporting of energy intake in US low-income women using the multiple-pass 24-hour recall: a doubly labeled water study. J Am Diet Assoc 1998;98:1136–1140. [PubMed: 9787719]
4. Maurer J, Taren DL, Teixeira PJ, Thomson CA, Lohman TG, Going SB, Houtkooper LB. The psychosocial and behavioral characteristics related to energy misreporting. Nutr Rev 2006;64:53–66. [PubMed: 16536182]
5. Black AE, Bingham SA, Johansson G, Coward WA. Validation of dietary intakes of protein and energy against 24 hour urinary N and DLW energy expenditure in middle-aged women, retired men and post-obese subjects: comparisons with validation against presumed energy requirements. Eur J Clin Nutr 1997;51:405–413. [PubMed: 9192200]
6. Lampe, JW.; Rock, CL. Biomarkers and their use in nutrition intervention. In: Coulston, AM.; Boushey, CJ., editors. Nutrition in the Prevention and Treatment of Disease. 2. San Diego: Academic Press; 2008.
7. Smith AF, Jobe JB, Mingay DJ. Question-induced cognitive biases in reports of dietary intake by college men and women. Health Psychol 1991;10:244–251. [PubMed: 1915210]
8. Subar AF. Developing dietary assessment tools. J Am Diet Assoc 2004;104:769–770. [PubMed: 15127062]
9. US Department of Agriculture, Agricultural Research Service. USDA national nutrient database for standard reference, release 21. Nutrient Data Laboratory home page. U.S. Department of Agriculture Web site. [Accessed January 21, 2009.]. http://www.ars.usda.gov/ba/bhnrc/ndlUpdated 2009
10. Gersovitz M, Madden JP, Smiciklas-Wright H. Validity of the 24-hr. dietary recall and seven-day record for group comparisons. J Am Diet Assoc 1978;73:48–55. [PubMed: 659761]

11. Rebro SM, Patterson RE, Kristal AR, Cheney CL. The effect of keeping food records on eating patterns. J Am Diet Assoc 1998;98:1163–1165. [PubMed: 9787724]
12. Guinn CH, Baxter SD, Hardin JW, Royer JA, Smith AF. Intrusions in children's dietary recalls: the roles of BMI, sex, race, interview protocol, and social desirability. Obesity (Silver Spring) 2008;16:2169–2174. [PubMed: 18535542]
13. Baxter SD, Hardin JW, Guinn CH, Royer JA, Mackelprang AJ, Smith AF. Fourth-grade children's dietary recall accuracy is influenced by retention interval (target period and interview time). J Am Diet Assoc 2009;109:846–856. [PubMed: 19394471]
14. Baxter SD, Thompson WO, Davis HC, Johnson MH. Impact of gender, ethnicity, meal component, and time interval between eating and reporting on accuracy of fourth-graders' self-reports of school lunch. J Am Diet Assoc 1997;97:1293–1298. [PubMed: 9366868]
15. Hartman AM, Brown CC, Palmgren J, Pietinen P, Verkasalo M, Myer D, Virtamo J. Variability in nutrient and food intakes among older middle-aged men. Implications for design of epidemiologic and validation studies using food recording. Am J Epidemiol 1990;132:999–1012. [PubMed: 2239915]
16. Dodd KW, Guenther PM, Freedman LS, Subar AF, Kipnis V, Midthune D, Tooze JA, Krebs-Smith SM. Statistical methods for estimating usual intake of nutrients and foods: a review of the theory. J Am Diet Assoc 2006;106:1640–1650. [PubMed: 17000197]
17. Tooze JA, Midthune D, Dodd KW, Freedman LS, Krebs-Smith SM, Subar AF, Guenther PM, Carroll RJ, Kipnis V. A new statistical method for estimating the usual intake of episodically consumed foods with application to their distribution. J Am Diet Assoc 2006;106:1575–1587. [PubMed: 17000190]
18. Kipnis V, Midthune D, Buckman DW, Dodd KW, Guenther PM, Krebs-Smith SM, Subar AF, Tooze JA, Carroll RJ, Freedman LS. Modeling data with excess zeros and measurement error: application to evaluating relationships between episodically consumed foods and health outcomes. Biometrics. 2009
19. Cullen KW, Watson K, Himes JH, Baranowski T, Rochon J, Waclawiw M, Sun W, Stevens M, Slawson DL, Matheson D, Robinson TN. Evaluation of quality control procedures for 24-h dietary recalls: results from the Girls Health Enrichment Multisite Studies. Prev Med 2004;38 (Suppl):S14–S23. [PubMed: 15072855]
20. Gibson, RS. Principles of Nutritional Assessment. 2. New York: Oxford University Press; 2005.
21. Probst YC, Tapsell LC. Over- and underreporting of energy intake by patients with metabolic syndrome using an automated dietary assessment website. Nutr Diet 2007;64:280–284.
22. Stockley L, Chapman RI, Holley ML, Jones FA, Prescott EH, Broadhurst AJ. Description of a food recording electronic device for use in dietary surveys. Hum Nutr Appl Nutr 1986;40:13–18. [PubMed: 3957699]
23. Zoellner J, Anderson J, Gould SM. Comparative validation of a bilingual interactive multimedia dietary assessment tool. J Am Diet Assoc 2005;105:1206–1214. [PubMed: 16182635]
24. van Horn LV, Gernhofer N, Moag-Stahlberg A, Farris R, Hartmuller G, Lasser VI, Stumbo P, Craddick S, Ballew C. Dietary assessment in children using electronic methods: telephones and tape recorders. J Am Diet Assoc 1990;90:412–416. [PubMed: 2307817]
25. Kos J, Battig K. Comparison of an electronic food diary with a nonquantitative food frequency questionnaire in male and female smokers and nonsmokers. J Am Diet Assoc 1996;96:283–285. [PubMed: 8613665]
26. Kretsch MJ, Fong AK. Validation of a new computerized technique for quantitating individual dietary intake: the Nutrition Evaluation Scale System (NESSy) vs the weighed food record. Am J Clin Nutr 1990;51:477–484. [PubMed: 2309654]
27. Rivellese AA, Ventura MM, Vespasiani G, Bruni M, Moriconi V, Pacioni D, Sulpini MT, Borrelli R, Giacco A, Cangemi C. Evaluation of new computerized method for recording 7-day food intake in IDDM patients. Diabetes Care 1991;14:602–604. [PubMed: 1914803]
28. Witschi J, Kowaloff H, Bloom S, Slack W. Analysis of dietary data; an interactive computer method for storage and retrieval. J Am Diet Assoc 1981;78:609–613. [PubMed: 7252015]

29. Lee RD, Nieman DC, Rainwater M. Comparison of eight microcomputer dietary analysis programs with the USDA Nutrient Data Base for Standard Reference. J Am Diet Assoc 1995;95:858–867. [PubMed: 7636075]
30. McCullough ML, Karanja NM, Lin PH, Obarzanek E, Phillips KM, Laws RL, Vollmer WM, O'Connor EA, Champagne CM, Windhauser MM. Comparison of 4 nutrient databases with chemical composition data from the Dietary Approaches to Stop Hypertension trial. DASH Collaborative Research Group. J Am Diet Assoc 1999;99:S45–S53. [PubMed: 10450294]
31. Zimmerman, TP.; Stumbo, P.; Chenard, C.; Braithwaite, E.; Selley, B. international nutrient databank directory. National Nutrient Database Conference Web site. 2008 [Accessed May 14, 2009.]. http://www.healthcare.uiowa.edu/gcrc/nndc/survey.htmlUpdated 2008
32. The Nutrition Coordinating Center (NCC). University of Minnesota Web site. [Accessed January 26, 2009.]. http://www.ncc.umn.edu/. Updated 2009
33. Raper N, Perloff B, Ingwersen L, Steinfeldt L, Anand J. An overview of USDA's dietary intake data system. J Food Compost Anal 2004;17:545–555.
34. Slattery ML, Caan BJ, Duncan D, Berry TD, Coates A, Kerber R. A computerized diet history questionnaire for epidemiologic studies. J Am Diet Assoc 1994;94:761–766. [PubMed: 8021418]
35. Baranowski T, Islam N, Baranowski J, Cullen KW, Myres D, Marsh T, de Moor C. The food intake recording software system is valid among fourth-grade children. J Am Diet Assoc 2002;102:380–385. [PubMed: 11902371]
36. Lu C, Pearson M, Renker S, Myerburg S, Farino C. A novel system for collecting longitudinal self-reported dietary consumption information: the internet data logger (iDL). J Expo Sci Environ Epidemiol 2006;16:427–433. [PubMed: 16552428]
37. Wang DH, Kogashiwa M, Ohta S, Kira S. Validity and reliability of a dietary assessment method: the application of a digital camera with a mobile phone card attachment. J Nutr Sci Vitaminol (Tokyo) 2002;48:498–504. [PubMed: 12775117]
38. Wang DH, Kogashiwa M, Kira S. Development of a new instrument for evaluating individuals' dietary intakes. J Am Diet Assoc 2006;106:1588–1593. [PubMed: 17000191]
39. Lacson R, Long W. Natural language processing of spoken diet records (SDRs). AMIA Annu Symp Proc 2006:454–458. [PubMed: 17238382]
40. Subar AF, Thompson FE, Potischman N, Forsyth BH, Buday R, Richards D, McNutt S, Hull SG, Guenther PM, Schatzkin A, Baranowski T. Formative research of a quick list for an automated self-administered 24-hour dietary recall. J Am Diet Assoc 2007;107:1002–1007. [PubMed: 17524721]
41. Subar AF, Crafts J, Zimmerman TP, Wilson M, Mittl B, Islam NG, McNutt S, Potischman N, Buday R, Hull SG, Baranowski T, Guenther PM, Willis G, Tapia R, Thompson FE. Assessment of the accuracy of portion size reports using computer-based food photography aids in the development of an automated self-administered 24-hour recall (ASA24). J Am Diet Assoc. 2009 in press.
42. Beltran A, Knight Sepulveda K, Watson K, Baranowski T, Baranowski J, Islam N, Missaghian M. Diverse food items are similarly categorized by 8- to 13-year-old children. J Nutr Educ Behav 2008;40:149–159. [PubMed: 18457783]
43. Beltran A, Knight Sepulveda K, Watson K, Baranowski T, Baranowski J, Islam N, Missaghian M. Mixed foods are similarly categorized by 8–13 year old children. Appetite 2008;50:316–324. [PubMed: 17936412]
44. Knight Sepulveda K, Beltran A, Watson K, Baranowski T, Baranowski J, Islam N, Missaghian M. Fruit and vegetables are similarly categorised by 8–13-year-old children. Public Health Nutr 2009;12:175–187. [PubMed: 18561864]
45. Beltran A, Knight Sepulveda K, Watson K, Baranowski T, Baranowski J, Islam N, Missaghian M. Grains are similarly categorized by 8- to 13-year-old children. J Am Diet Assoc 2008;108:1921–1926. [PubMed: 18954585]
46. Baranowski T, Beltran A, Martin S, Watson K, Islam N, Robertson S, Berno S, Dadabhoy H, Thompson D, Cullen K, Buday R, Subar AF, Baranowski J. Tests of the accuracy and speed of categorizing foods into child vs. professional categories using two methods of browsing with children. J Am Diet Assoc. 2009 in press.
47. Boushey CJ, Kerr DA, Wright J, Lutes KD, Ebert DS, Delp EJ. Use of technology in children's dietary assessment. Eur J Clin Nutr 2009;63:S50–S57. [PubMed: 19190645]

48. Six BL, Schap TE, Zhu FM, Mariappan A, Bosch M, Delp EJ, Ebert DS, Kerr DA, Boushey CJ. Evidence-based development of a mobile telephone food record. J Am Diet Assoc. 2009 in press.
49. Weiss R, Stumbo PJ, Divakaran A. Automatic food documentation and volume computation using digital imaging and electronic transmission. J Am Diet Assoc. 2009 in press.
50. Yao, N.; Sclabassi, R.; Zhao, R.; Zhang, H.; Sun, M. A laser based depth measurement method for digital imaging of close-up objects. Proceedings of the International Conference on Mechanics in Medicine and Biology; Pittsburgh, PA. July 23–25: 2008;