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CHAPTER

1

Dietary Assessment Methodology

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I INTRODUCTION

This chapter is a revision of the similarly named chapter in the 2008 [1] and 2001 [2] editions of this book, which itself was based on the "Dietary Assessment Resource Manual" [3] by Frances E. Thompson and Tim Byers, adapted with permission from the *Journal of Nutrition*. Dietary assessment encompasses food supply and production at the national level, food purchases at the household level, and food consumption at the individual level. This review focuses only on individual-level food intake assessment. It is intended to serve as a resource for those who wish to assess diet in a research study, for example, to describe the intakes of a population, using individual measurements for group-level analysis. This chapter does not cover clinical assessment of individuals for individual counseling. The first section reviews major dietary assessment methods, their advantages and disadvantages, and validity. The next sections describe which dietary assessment methods are most appropriate for different types of studies and for various types of populations. Finally, specific issues that relate to all methods are discussed. The intent of this chapter is to contribute to an understanding of various dietary assessment methods so that the most appropriate method for a particular need is chosen.

II DIETARY ASSESSMENT METHODS

A Dietary Records

In the dietary record approach, the respondent records the foods and beverages and the amounts of each consumed over one or more days. Ideally, the recording is done at the time of the eating occasion in order to avoid reliance on memory. The amounts consumed may be measured, using a scale or household measures (e.g., cups or tablespoons), or estimated, using models, pictures, or no aid. If multiple days are recorded, they are usually consecutive, and no more than 7 days are included. Recording periods of more than 4 consecutive days are usually unsatisfactory, as reported intakes decrease [4] due to respondent fatigue, and individuals who do comply may differ systematically from those who do not. Because the foods and amounts consumed on consecutive days of reporting may be related (e.g., leftovers and eating more one day and less the next day), it may be advantageous to collect nonconsecutive single-day records in order to increase representativeness of the individual's diet.

To complete a dietary record, each respondent must be trained in the level of detail required to adequately describe the foods and amounts consumed, including the name of the food (brand name, if possible), preparation methods, recipes for food mixtures, and portion sizes. In some studies, this is enhanced if the investigator contacts the respondent and reviews the report after 1 day of recording. At the end of the recording period, a trained interviewer should review the records with the respondent to clarify entries and to probe for forgotten foods. Dietary records also can be recorded by someone other than the subject, such as parents reporting for their children.

The dietary record method has the potential for providing quantitatively accurate information on food consumed during the recording period [5]. By recording foods as they are consumed, the problem of omission may be lessened and the foods more fully described. Furthermore, the measurement of amounts of food consumed at each occasion should provide more accurate portion sizes than if the respondents were recalling portion sizes of foods previously eaten.

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Although intake data using dietary records are typically collected in an open-ended form, close-ended forms have also been developed [6-12]. These forms consist of listings of food groups; the respondent indicates whether that food group has been consumed. In format, these "checklist" forms resemble food frequency questionnaires (FFQs) (see Section II.C). Unlike FFQs, which generally query about intake over a specified time period such as the past year or month, checklists are intended to be filled out concurrently, with actual intake or at the end of a day for that day's intake. A checklist can be developed to assess particular "core foods" that contribute substantially to intakes of some nutrients [13], and it also has been used to track food contaminants [14]. Portion size can also be asked, either in an open-ended manner or in categories.

A potential disadvantage of the dietary record method is that it is subject to bias both in the selection of the sample and in the sample's completion of the number of days recorded. Dietary record keeping requires that respondents or respondent proxies be both motivated and literate (if done on paper), which can potentially limit the method's use in some population groups (e.g., low literacy, recent immigrants, children, and some elderly groups). The requirements for cooperation in keeping records can limit who will respond, compromising the generalizability of the findings from the dietary records to the broader population from which the study sample was drawn. Research indicates that incomplete records increase significantly as more days of records are kept, and the validity of the collected information decreases in the later days of a 7-day recording period, in contrast to collected information in the earlier days [4]. Part of this decrease may occur because many respondents develop the practice of filling out the record retrospectively rather than concurrently. When respondents record only once per day, the record method becomes similar to the 24-hour dietary recall in terms of relying on memory rather than concurrent recording.

An important disadvantage of this method is that recording foods as they are being eaten can affect both the types of food chosen and the quantities consumed [15-17]. The knowledge that foods and amounts must be recorded and the demanding task of doing it may alter the dietary behaviors the tool is intended to measure [18]. This effect is a weakness when the aim is to measure typical dietary behaviors. However, when the aim is to enhance awareness of dietary behaviors and change them, as in some intervention studies, this effect can be seen as an advantage [19]. Recording, by itself, is an effective weight loss technique [20,21]. Recent interest in "real-time" assessment [22] has led to the development and testing of a dietary intake self-monitoring system delivered through a mobile phone that enables concurrent recording and immediate, automated feedback. A pilot study testing this approach found improved self-monitoring and adherence to dietary goals [19]. A later study found more frequent weight loss in those using electronic self-monitoring than in those using traditional paper-and-pencil dietary records [23].

A third disadvantage is that unless dietary records are collected electronically, the data can be burdensome to code and can lead to high personnel costs. Dietary assessment software that allows for easier data entry using common spellings of foods can save considerable time in data coding. Even with high-quality data entry, maintaining overall quality control for dietary records can be difficult because information often is not recorded consistently from respondent to respondent, nor are different coders consistent in their coding decisions. This highlights the need for training of both the respondents and the coders.

Several approaches using a variety of technological advances have been used to allow easier data capture. These include programs for recording food intake, delivered on the Internet [24], a CD-ROM [25], a personal digital assistant [9,26,27], which have now been replaced by mobile phones with cameras [28,29]. A computer-administered instrument illustrates the potential benefits of technology, particularly for low-literacy groups. With this approach, the respondent selects the food consumed and the appropriate portion size through food photographs on the computer screen [25,30]; this can be done using touch-screen technology [31]. A smart phone can be coupled with a camera that photographs foods selected [32]; this approach requires before and after pictures of a consumption event and training of the participant in how to consistently take pictures, using a standard reference object and a specific angle. Wearable cameras have been developed, which can continuously take pictures or videos, lessening the burden on the respondent and potentially allaying some reactivity (i.e., changes in the respondent's behavior that are caused by the instrument) [33,34].

Processing of the image information for all these methods is not yet fully developed. The images that illustrate the beginning of the consumption event and its completion must be selected, the food has to be identified, and the mathematical properties of the food image need to be quantified in order to develop an accurate estimate of the food's volume. However, if the foods and volumes can be accurately derived, they can be linked to appropriate databases (see Section V.E), dramatically reducing the burden of coding.

Respondent burden and reactivity bias may be less pronounced for the hybrid method of the "checklist" [35] because checking off a food item is easier than recording a complete description of the food [36], and the costs of data processing can be minimal, especially if the form is machine scannable. Checklists are often developed to assess particular foods that contribute substantially to intakes of some nutrients. However, as the comprehensiveness of the nutrients to be assessed increases, the length of the form also increases, and it becomes more burdensome to complete at each eating occasion. The checklist method may be most appropriate in settings with limited diets, such as institutional settings or in impoverished households, or for assessment of a limited set of foods or nutrients.

Many studies in selected small samples of adults indicate that reported energy and protein intakes on dietary records are underestimated in the range of 4–37% compared to energy expenditure as measured by doubly labeled water or protein intake as measured by urinary nitrogen [20,37–50]. Because of these findings, the dietary record is considered an imperfect gold standard. Underreporting on dietary records is probably a result of the combined effects of incomplete recording and the impact of the recording process on dietary choices leading to undereating, and thus not typical of usual intake [20,46,51,52]. The highest levels of underreporting on dietary records have been found among individuals with high body mass index (BMI) [39,41,42,53–55], particularly women [39,41,42,50,56–58]. This effect, however, may be due, in part, to the fact that overweight individuals are more likely to be dieting on any given individual day [59]. These relationships between underreporting and BMI and sex have also been found among elderly individuals [60]. Other research shows that demographic or psychological indices such as education, employment, social desirability, body image, or dietary restraint also may be important factors related to underreporting on diet records [39,46,57,58,61–63]. The research evidence for the psychosocial factors related to energy misreporting is reviewed in Mauer *et al.* [52]. A few studies suggest that underreporters compared to others have reported intakes that are lower in absolute intake of most nutrients [54], higher in percentage of energy from protein [54,58], and lower in percentage of energy as carbohydrate [54,58,64,65] and in percentage of energy from fat [65]. Correspondingly, underrepor-ters may report lower intakes of desserts, sweet baked goods, butter, and alcoholic beverages [54,65] but more grains, meats, salads, and vegetables [54]. Some research has examined the validity of food checklists relative to accelerometry [66] or, more commonly, complete dietary records [10,11,36], 24-hour dietary recalls [13], dietary history [67], and biological markers [67]. An evaluation study of the 7-day precoded food diary used in the Danish National Survey of Dietary Habits and Physical Activity 2000–2002 reported that energy intake was underestimated by 12% compared to accelerometer [66].

Some approaches have been suggested to overcome underreporting in the dietary record approach. These include enhanced training of respondents and incorporating psychosocial questions known to be related to underreporting in order to estimate the level of underreporting [52]. Another approach is to calibrate dietary records to doubly labeled water or urinary nitrogen, biological indicators of energy expenditure and protein intake, respectively, including covariates of sex, weight, and height, to more accurately predict individuals' energy and protein intake [68]. This approach was applied to a subcohort of the Women's Health Initiative. Calibration equations that included BMI, age, and ethnicity explained much more of the variation in the energy and protein biomarkers than did simple calibration, for example, 45% vs. 8% for energy [55]. Further research is needed to test this approach and to develop and test other ideas.

B 24-Hour Dietary Recall

In the 24-hour dietary recall, the respondent is asked to remember and report all the foods and beverages consumed in the preceding 24 hours or in the preceding day. The recall typically is conducted by interview, in person or by telephone [69,70], either computer-assisted [71] or using a paper-and-pencil form, although self-administered electronic administration has recently become available [72–76]. When interviewer-administered, well-trained interviewers are crucial because much of the dietary information is collected by asking probing questions. Ideally, interviewers would be dietitians with education in foods and nutrition; however, non-nutritionists who have been trained in the use of a standardized instrument can be effective. All interviewers should be knowledgeable about foods available in the marketplace and about preparation practices, including prevalent regional or ethnic foods.

The interview is often structured, usually with specific probes, to help the respondent remember all foods consumed throughout the day. An early study found that respondents with interviewer probing reported 25% higher dietary intakes than did respondents without interviewer probing [77]. Probing is especially useful in collecting necessary details, such as how foods were prepared. It is also useful in recovering many items not originally reported, such as common additions to foods (e.g., butter on toast) and eating occasions not originally reported (e.g., snacks and beverage breaks). However, interviewers should be provided with standardized neutral probing questions so as to avoid leading the respondent to specific answers when the respondent really does not know or remember.

The current state-of-the-art 24-hour dietary recall instrument is the U.S. Department of Agriculture's (USDA) Automated Multiple-Pass Method (AMPM) [78,79], which is used in the U.S. National Health and Nutrition Examination Survey (NHANES), this country's only nationally representative dietary survey. In the AMPM, intake is reviewed more than once in an effort to retrieve forgotten eating occasions and foods. It consists of (1) an initial "quick list," in which the respondent reports all the foods and beverages consumed, without interruption from the interviewer; (2) a forgotten foods list of nine food categories commonly omitted in 24-hour recall reporting; (3) time and occasion, in which the time each eating occasion began and what the respondent would call it are reported; (4) a detail pass, in which probing questions ask for more detailed information about the food and the portion size, in addition to review of the eating occasions and times between the eating occasions; and (5) final review, in which any other item not already reported is asked [78,79]. In addition, research at USDA allowed development of the Food Model Booklet [80], a portion size booklet used in the NHANES in order to facilitate more accurate portion size estimation. A 24-hour recall interview using the multiple-pass approach typically requires between 30 and 45 minutes.

A quality control system to minimize error and increase reliability of interviewing and coding 24-hour recalls is essential. Such a system should include a detailed protocol for administration, training, and retraining sessions for interviewers; duplicate collection and coding of some of the recalls throughout the study period; and the use of a computerized database system for nutrient analysis. One study evaluated the marginal gains in accuracy of the estimates of mean and variance with increasing levels of quality control [81], and the authors recommended that the extent of quality control procedures adopted for a particular study should be carefully considered in light of that study's desired accuracy and precision and its resource constraints.

There are many advantages to the 24-hour recall. When an interviewer administers the tool and records the responses, literacy of the respondent is not required. However, for self-administered versions, literacy can be a constraint. Because of the immediacy of the recall period, respondents are generally able to recall most of their dietary intake. Because there is relatively little burden on the respondents, those who agree to give 24-hour dietary recalls are more likely to be representative of the population than are those who agree to keep food records. Thus, the 24-hour recall method is useful across a wide range of populations. In addition, interviewers can be trained to capture the detail necessary so that new foods reported can be researched later by the coding staff and coded appropriately. Finally, in contrast to record methods, dietary recalls occur after the food has been consumed, so there is less potential for the assessment method to interfere with dietary behavior.

Computerized data collection software systems are currently available in most developed countries, allowing direct coding of most foods reported during the interview. This is highly efficient with respect to processing dietary data, minimizing missing data, and standardizing interviews [82,83]. If direct coding of the interview is done, methods for the interviewer to easily enter those foods not found in the system should be available, and these methods should be reinforced by interviewer training and quality control procedures.

Another technological advance in 24-hour dietary recall methodology is the development of automated self-administered data collection systems [72,74-76,84-88]. These systems vary in the number of foods in their databases, the approach to asking about portion size, and their inclusion of probes regarding details of foods consumed and possible additions. The web-based Automated Self-Administered 24-hour dietary recall (ASA) developed at the National Cancer Institute (NCI) [72,87,88] allows respondents to complete a dietary recall with the aid of multimedia visual cues, prompts, and an animated character versus standard methods that require a trained interviewer. The system uses the most current USDA survey database [89] and includes many elements of the AMPM 24-hour interview developed by USDA [78] and currently used in the NHANES. Portion sizes are asked using digital photographs depicting up to eight sizes [88]. The instrument is freely available for use by researchers, clinicians, and educators. Such web-based tools allow researchers to economically collect high-quality dietary data in large-scale nutrition research. One study indicates that differences between interviewer- and self-administered recalls are minimal among adolescents [76]. Other studies are underway to evaluate differences between interviewer- and web-based self-administered recalls.

The main weakness of the 24-hour recall approach is that individuals may not report their food consumption accurately for various reasons related to knowledge, memory, and the interview situation. These cognitive influences are discussed in more detail in Section V.A.

A potential limitation is that multiple days of recalls may be needed. Whereas a single 24-hour recall can be used to describe the average dietary intake of a population, multiple days of recalls are needed to model estimates of the population's usual intake distributions and their relationships with other factors (see Section V.G).

The validity of the 24-hour dietary recall has been studied by comparing respondents' reports of intake either with intakes unobtrusively recorded/weighed by trained observers or with biological markers. Numerous observational studies of the effectiveness of the 24-hour recall have been conducted with children (see Section IV.B). In some studies with adults, group mean nutrient estimates from 24-hour recalls have been found to be similar to observed intakes [4,90], although respondents with lower observed intakes have tended to overreport and those with higher observed intakes have tended to underreport their intakes [90]. One observational study found energy underreporting during a self-selected eating period in both men and women, similar underreporting during a controlled diet period in men, and accurate reporting during a controlled diet period in women; underestimates of portion sizes accounted for much of the underreporting [91]. Studies with biological markers such as doubly labeled water and urinary nitrogen generally have found underreporting using 24-hour dietary recalls for energy in the range of 3–34% [25,40,75,79,92–98], with the largest two studies in adults using a multiple-pass method showing average underreporting to be between 12 and 23% [79,95]. For protein, underreporting tends to be in the range of 11–28% [92,95,96,98–102]. However, underreporting is not always found. Some have found overreporting of energy from 24-hour dietary recalls compared to doubly labeled water in proxy reports for young children and adolescents [103,104]. In addition, it is likely that the commonly reported phenomenon of underreporting in Western countries may not occur in all cultures; for example, Harrison *et al.* [105] reported that 24-hour recalls collected from Egyptian women were well within expected amounts. Finally, in many studies, energy adjustment has been found to reduce error. For example, for protein density (i.e., percentage energy from protein), 24-hour dietary recalls conducted in the large biomarker studies were in close agreement or somewhat higher compared to a biomarker-based measure [55,95,96].

In past national dietary surveys using multiple-pass methods, data suggested that underreporting may have affected up to 15% of all 24-hour recalls [106,107]. Underreporters compared to non-underreporters tended to report fewer numbers of foods, fewer mentions of foods consumed, and smaller portion sizes across a wide range of food groups and tended to report more frequent intakes of low-fat/diet foods and less frequent intakes of fat added to foods [106]. As was found for records, factors such as obesity, gender, social desirability, restrained eating, education, literacy, perceived health status, and race/ethnicity have been shown in various studies to be related to underreporting in recalls [46,55,59,61,79,93,101,106–110].

C Food Frequency

The food frequency approach [111,112] asks respondents to report their usual frequency of consumption of each food from a list of foods for a specific period. Information is collected on frequency, but little detail is collected on other characteristics of the foods as eaten, such as the methods of cooking, or the combinations of foods in meals. Many FFQs also incorporate portion size questions or specify portion sizes as part of each question. Overall nutrient intake estimates are derived by summing, over all foods, the products of the reported frequency of each food by the amount of nutrient in a specified (or assumed) serving of that food to produce an estimated daily intake of nutrients, dietary constituents, and food groups. In most cases, the purpose of an FFQ is to obtain a crude estimate of total intakes over a designated time period.

There are many FFQ instruments, and many continue to be adapted and developed for different populations and purposes. Among those evaluated and commonly used are the Block Questionnaires [113–123], the Fred Hutchinson Cancer Research Center Food Frequency Questionnaire [124,125], the Harvard University Food Frequency Questionnaires or Willett Questionnaires [111,121–123,126–133], and the NCI's Diet History Questionnaire [95,123,134,135], which was designed with an emphasis on cognitive ease for respondents [136–138]. Throughout the years, population-specific FFQs have been developed. Examples include FFQs designed to capture diets of Latinos, Native Americans [139–143], African Americans [144], Hispanics [145,146], native Hawaiians, and Asian ethnic groups living in Hawaii [147,148]. FFQs have been developed throughout the world, such as those for countries participating in the European Prospective Investigation into Cancer and Nutrition (EPIC) [45,149–154] and for Australia [155,156], Belgium [157], France [158], Germany [159], Norway [160], Japan [161,162], Korea [163], and the United Kingdom [164]. An FFQ-like instrument, called the Oxford WebQ, has been developed for large-scale epidemiologic research [165]. Like an FFQ, this instrument includes a comprehensive list of foods and portions, but the participant is asked to report whether the foods listed were consumed the previous day. Such instruments, like 24-hour dietary recalls, are meant to be administered at multiple time points in a study. Evaluation of this tool showed moderate correlations (average $r = 0.6$) with interviewer-administered recalls for the same day [165]—values slightly higher than those generally obtained when full-length FFQs that query intake during the past year are evaluated against interviewer-administered recalls. “Brief” FFQs that assess a limited number of dietary exposures are discussed in the next section. Because of the number of FFQs available, investigators need to carefully consider which best suits their research needs.

The appropriateness of the food list is crucial in the food frequency method [114]. The entire breadth of an individual’s diet, which includes many different foods, brands, and preparation practices, cannot be fully captured with a finite food list. Obtaining accurate reports for foods eaten both as single items and in mixtures is particularly problematic. FFQs can ask the respondent either to report a combined frequency for a particular food eaten both alone and in mixtures or to report separate frequencies for each food use. (For example, one could ask about beans eaten alone and in mixtures, or one could ask separate questions about refried beans, bean soups, beans in burritos, and so on.) The first approach is cognitively complex for the respondent, but the second approach may lead to double counting (e.g., burritos with beans may be reported as both beans and as a Mexican mixture). Often, FFQs will include similar foods in a single question (e.g., beef, pork, or lamb). However, such grouping can create a cognitively complex question (e.g., for someone who often eats beef and occasionally eats pork and lamb). Differences in definitions of the food items asked may also be problematic; for example, rice is judged to be a vegetable by many nonacculturated Hispanics, a judgment not shared in other race/ethnic groups [166]. Finally, when a group of foods is asked as a single question, assumptions about the relative frequencies of intake of the foods constituting the group are made in the assignment of values in the nutrient database. These assumptions are generally based on information from an external study population (such as from a national survey sample) even though true eating patterns may differ considerably across population subgroups and over time.

Each quantitative FFQ must be associated with a database to allow estimation of nutrient intakes for an assumed or reported portion size of each food queried. For example, the FFQ item of macaroni and cheese encompasses a wide variety of different recipes with different nutrient composition, yet the FFQ database must have a single nutrient composition profile. There are several approaches to constructing such a database [111]. One approach uses quantitative dietary intake information from the target population to define the typical nutrient density of a particular food group category. For example, for the food group macaroni and cheese, all reports of the individual food codes reported in a population survey can be collected, and a mean or median nutrient composition (by portion size if necessary) can be estimated. Values can also be calculated by gender and age. Dietary analyses software, specific to each FFQ, is then used to compute nutrient intakes for individual respondents. These analyses are available commercially for the Block, Willett, and Hutchinson FFQs, and they are publicly available for the NCI FFQ.

In pursuit of improving the validity of the FFQ, investigators have addressed a variety of frequency questionnaire design issues, such as length, closed- versus open-ended response categories, portion size, seasonality, and time frame. Frequency instruments designed to assess total diet generally list more than 100 individual line items, many with additional portion size questions, requiring 30-60 minutes to complete. This raises concern about length and its effect on response rates. Although respondent burden is a factor in obtaining reasonable response rates for studies in general, a few studies have shown this not to be a decisive factor for FFQs [137,167-171]. This tension between length and specificity highlights the difficult issue of how to define a closed-ended list of foods for a food frequency instrument. The increasing use of optically scanned or web-based instruments has necessitated the use of closed-ended response categories, forcing a loss in specificity [172].

Although the amounts consumed by individuals are considered an important component in estimating dietary intakes, it is controversial as to whether or not portion size questions should be included on FFQs. Frequency has been found to be a greater contributor than serving size to the variance in intake of most foods [173]; therefore, some prefer to use FFQs without the additional respondent burden of reporting serving sizes [111]. Others cite small improvements in the performance of FFQs that ask the respondents to report a usual serving size for each food [116,118]. Some incorporate portion size and frequency into one question, asking how often a particular portion of the food is consumed [111]. Although some research has been conducted to determine the best ways to ask about portion size on FFQs [136,174,175], the marginal benefit of such information in a particular study may depend on the study objective and population characteristics.

Another design issue is the time frame about which intake is queried. Many instruments inquire about usual intakes during the past year [114,127], but it is possible to ask about the past week or month [176], depending on specific research situations. Even when intake during the past year is asked, some studies have indicated that the season in which the questionnaire is administered has an influence on reporting during the entire year [177,178].

Finally, analytical decisions are required in how food frequency data are processed. In research applications in which there are no automated quality checks to ensure that all questions are asked, decisions about how to handle missing data are needed. In particular, in self-administered situations, there are usually many initial frequency questions that are not answered. One approach is to assign null values because some research indicates that respondents selectively omit answering questions about foods they seldom or never eat [179,180]. Another approach is the imputation of frequency values for those not providing valid answers. Only a few studies have addressed this issue [181,182], and it is currently unclear whether imputation is an advance in FFQ analyses.

Strengths of the FFQ approach are that it is inexpensive to administer and process and it asks about the respondent's usual intake of foods over an extended period of time. Unlike other methods, the FFQ can be used to circumvent recent changes in diet (e.g., changes due to disease) by obtaining information about individuals' diets as recalled about a prior time period. Retrospective reports about diet nearly always use a food frequency approach. Food frequency responses are used to rank individuals according to their usual consumption of nutrients, foods, or groups of foods. Nearly all food frequency instruments are designed to be self-administered, require 30-60 minutes to complete depending on the instrument and the respondent, and most are either optically scanned paper versions or automated to be administered electronically [113,124,139,183-185]. Because the costs of data collection and processing and the respondent burden have traditionally been much lower for FFQs than for multiple diet records or recalls, FFQs have been a common way to estimate usual dietary intake in large epidemiological studies.

The major limitation of the food frequency method is that it contains a substantial amount of measurement error [55,95-98,135]. Many details of dietary intake are not measured, and the quantification of intake is not as accurate as with recalls or records. Inaccuracies result from an incomplete listing of all possible foods and from errors in frequency and usual serving size estimations. The estimation tasks required for a FFQ are complex and difficult [186]. As a result, the scale for nutrient intake estimates from a FFQ may be shifted considerably, yielding inaccurate estimates of the average intake for the group. Research suggests that longer food frequency lists may overestimate, whereas shorter lists may underestimate, intake of fruits and vegetables [187], but it is unclear whether or how this applies to nutrients and other food groups.

Portion size of foods consumed is difficult for respondents to evaluate and is thus problematic for all assessment instruments (see Section V.D). However, the inaccuracies involved in respondents attempting to estimate usual portion size in FFQs may be even greater because a respondent is asked to estimate an average for foods that may have highly variable portion sizes across eating occasions [188].

Because of the error inherent in the food frequency approach, it is generally considered inappropriate to use FFQ data to estimate quantitative parameters, such as the mean and variance, of a population's usual dietary intake [127,189-193]. Although some FFQs seem to produce estimates of population average intakes that are reasonable [155,159,189], different FFQs will perform in often unpredictable ways in different populations, so the levels of nutrient intakes estimated by FFQs should best be regarded as only approximations [190]. FFQ data are usually energy adjusted and then used for ranking subjects according to food or nutrient intake rather than for estimating absolute levels of intake, and they are used widely in case-control or cohort studies to assess the association between dietary intake and disease risk [194-196]. For estimating relative risks, the degree of misclassification of subjects is more important than is the quantitative scale on which the ranking is made [197].

The definitive validity study for a food frequency-based estimate of long-term usual diet would require nonintrusive observation of the respondent's total diet over a long time. Such studies are not possible in free-living populations. One early feeding study, with three defined 6-week feeding cycles (in which all intakes were known), showed some significant differences in known absolute nutrient intakes compared to the Willett FFQ for several fat components, mostly in the direction of underestimation by the FFQ [198]. The most practical approach to examining the concordance of food frequency responses and usual diet is to use multiple food recalls or records over a period as an indicator of usual diet. This approach has been used in many studies examining various FFQs (see [199] for register of such studies). In these studies, the correlations between the methods for most foods and nutrients are in the range of 0.4-0.7. However, recalls and records cannot be considered as accurate reference instruments because they suffer from mistakes that may be correlated with errors in the FFQs, and they may not represent the time period of interest. Biomarkers that do represent usual intake without bias are available for energy (doubly labeled water) [200] and protein (urinary nitrogen) [201]. Validation studies of various FFQs using these biomarkers have found large discrepancies with self-reported absolute energy intake [40,46,49,55,75,92,94-98] and protein intake [44,45,55,92,95,96,98,154,202-205], usually in the direction of underreporting. Correlations of FFQs and the biomarkers have ranged from 0.1 to 0.5 for energy [40,75,92,95,96,98] and from 0.2 to 0.5 for protein [44,45,92,95,96,98,154,202-205]. A few studies show that correlations between a biomarker for protein density constructed from both urinary nitrogen and doubly labeled water and self-reported protein density on an FFQ (kcal of protein as a percentage of total kcal) are higher than correlations between urinary nitrogen and FFQ-reported absolute protein intake [96,98,135], indicating that energy adjustment may alleviate some of the error inherent in food frequency instruments. Various statistical methods employing measurement error models and energy adjustment are used not only to assess the validity of FFQs but also to adjust estimates of relative risks for disease outcomes [55,206-216]. However, analyses indicate that correlations between an FFQ and a reference instrument, such as the 24-hour recall, may be overestimated because of correlated errors [55,96,135]. Furthermore, a few analyses comparing relative risk estimation from FFQs to dietary records [217,218] in prospective cohort studies indicate that observed relationships are severely attenuated, thereby obscuring associations that might exist, but such findings are not consistent [219]. Accordingly, some epidemiologists have suggested that the error in FFQs is a serious enough problem that alternative means (e.g., food records or 24-hour recalls) of collecting dietary data in large-scale prospective studies should be considered [220-222]. It has also been suggested that FFQ data might be combined with recall or record data to improve estimated intakes [222-224].

D Brief Dietary Assessment Instruments

Many brief dietary assessment instruments, also known as “screeners,” have been developed. These instruments can be useful in situations that do not require either assessment of the total diet or quantitative accuracy in dietary estimates. For example, a brief diet assessment of some specific dietary components may be used to triage large numbers of individuals into groups to allow more focused attention on those at greatest need for intervention or education. Measurement of dietary intake, even if imprecise, can also serve to activate interest in the respondent, which in turn can facilitate nutrition education. These brief instruments may therefore have utility in clinical settings or in situations in which health promotion and health education is the goal. In the intervention setting, brief instruments focused on specific aspects of a dietary intervention also have been used to track changes in diet. However, because of concern that responses to questions of intake that directly evolve from intervention messages may be biased [225] and that these instruments lack sensitivity to detect change [226], this use is not recommended. Brief instruments of specific dietary components such as fruits and vegetables are used for population surveillance at the state or local level, for example, in the Centers for Disease Control and Prevention’s (CDC) Behavioral Risk Factor Surveillance System (BRFSS) [227] and the California Health Interview Survey (CHIS) [228] (see Section III.A). Brief instruments have also been used to examine relationships between some specific aspects of diet and other exposures, such as in the National Health Interview Survey (NHIS) [229]. Finally, some groups suggest the use of short screeners to evaluate the effectiveness of policy initiatives [228,230].

Brief instruments can be simplified or targeted FFQs, questionnaires that focus on specific eating behaviors other than the frequency of intake of specific foods, or daily checklists. Complete FFQs typically contain 100 or more food items to capture the range of foods contributing to the many different nutrients in the diet. If an investigator is interested only in estimating the intake of a single nutrient or food group, however, then far fewer foods need to be assessed. Often, only 15-30 foods might be required to account for most of the intake of a particular nutrient [231,232].

Numerous short questionnaires using a food frequency approach have been developed and compared with multiple days of dietary records, 24-hour recalls, complete FFQs, and/or biological indicators of diet. Single-exposure abbreviated FFQs have been developed and tested for a wide range of nutrients and other dietary components. The NCI has developed a Register of Validated Short Dietary Assessment Instruments [233], which contains descriptive information about short instruments and their validation studies and publications, as well as copies of the instruments when available. To be included, publications were required to be in English language peer-reviewed journals and published in January 1998 or later. Currently, the register includes 103 instruments assessing more than 25 dietary factors. Instruments from 29 different countries have been registered. Instruments in the register may be searched by dietary factors, questionnaire format, and number of questions. Descriptive information about the validation study includes the reference tool, the study population (age, sex, and race/ethnicity), and the geographical location. Much of the focus in brief instrument development has been on fruits and vegetables and on fats.

1 Brief Instruments Assessing Fruit and Vegetable Intake

Food frequency-type instruments to measure fruit and vegetable consumption range from including a single overall question to 45 or more individual questions [234-238]. An early 7-item tool developed by the NCI and private grantees for the NCI's 5 A Day for Better Health Program effort was used widely in the United States [239-241]. This tool was similar to one used in CDC's BRFSS [227,242,243]. Validation studies of the BRFSS and 5 A Day brief instruments, or "screeners," to assess fruit and vegetable intake suggested that without portion size adjustments, they often underestimated actual intake [234,239,243-245]. Using cognitive interviewing findings (see Section V.A), the NCI revised the tool, including adding portion size questions; some studies indicate improved performance [246] and utility in surveillance studies. However, its performance in community interventions was mixed. In six of eight site/sex comparisons, fruit and vegetable consumption was significantly overestimated relative to results from multiple 24-hour recalls [247]. More important, the screener indicated a change in consumption in both men and women when none was seen with the 24-hour recalls [248]. Using cognitive testing and expert guidance, the CDC has developed a new fruit and vegetable screener [249] that assesses intake of all forms of fruit and subgroups of vegetables that are particularly relevant to 2010 Dietary Guidelines for Americans [250]. Portion size, although not asked, will be estimated from external data about portion sizes reported by sex/age groups.

2 Brief Instruments Assessing Fat Intake

A fat screener, originally developed by Block [251] and currently composed of 17 items [113], was designed to account for most of the intake of fat using information about sources of fat intake in the U.S. population. The fat screener was used as an initial screen for high fat intake in the Women's Health Trial [251], and in the BRFSS for nutritional surveillance [252]. However, the screener did not perform well in Hispanic women [252]. A similar fat screener substantially overestimated percentage energy from fat and was only modestly correlated ($r = 0.36$) with multiple 24-hour recalls in a sample of medical students [253]. In samples of men participating in intervention trials, the screener was not as precise [226] or as sensitive [254] as complete FFQs. In addition, the screener did not reflect differences observed from 24-hour recalls among different demographic groups, possibly because the screener did not include all of the high-fat foods that contribute to differences in fat intake [226].

The MEDFICTS (meats, eggs, dairy, fried foods, fat in baked goods, convenience foods, fats added at the table, and snacks) questionnaire, initially developed to assess adherence to low total fat (#30% energy from fat) and saturated fat diets [255], asks about frequency of intake and portion size of 20 individual foods that are major food sources of fat and saturated fat in the U.S. diet. Its initial evaluation showed high correlations with dietary records [255]. In additional cross-sectional studies, the MEDFICTS underestimated percentage calories from fat; it was effective in identifying very high-fat intakes but was not effective in identifying moderately high-fat diets [256] or correctly identifying low-fat diets [257]. The number of mixtures reported on an FFQ (e.g., pizza and macaroni and cheese), which were not specifically included in the MEDFICTS tool, was negatively related to its predictive ability [257]. In a longitudinal setting, positive changes in the MEDFICTS score have been correlated with improvements in serum lipids and waist circumference among cardiac rehabilitation patients [258]. In a large ethnically diverse population, MEDFICTS and the Block Health Habits and History Questionnaire, a food frequency questionnaire, were poorly correlated. Although the accuracy of MEDFICTS differed little among age or race/ethnicity groups, its specificity to correctly identify nonadherence to the prescribed diet was significantly worse for women than for men [259].

Other fat screeners have been developed to preserve the between-person variability of intake [260-262]—that is, to focus on the fat sources that most distinguish differences in fat intake among individuals or groups. A 20-item screener developed and tested at the German site of EPIC correlated with 7-day dietary records ($r = 0.84$) and a complete FFQ ($r = 0.82$) [260,261]. A 16-item percentage energy from fat screener had a correlation of 0.6 with 24-hour recalls in an older U.S. population [262]. However, its performance in intervention studies of adults was variable [263].

Often, dietary fat reduction interventions are designed to target specific food preparation or consumption behaviors rather than frequency of consuming specific foods. Such behaviors might include trimming the fat from red meats, removing the skin from chicken, or choosing low-fat dairy products. Many questionnaires have been developed in various populations to measure these types of dietary behaviors [252,264-271], and many have been found to correlate with fat intake estimated from other more detailed dietary instruments [272,273] or with blood lipids [268,274,275]. In addition, some studies have found that changes in dietary behavior scores have correlated with changes in blood lipids [269,274,276]. The Kristal Food Habits Questionnaire, also called the Eating Behaviors Questionnaire, was originally developed in 1990 [277]. It measures five dimensions of fat-related behavior: avoid fat as a spread or flavoring, substitute low-fat foods, modify meats, replace high-fat foods with fruits and vegetables, and replace high-fat foods with lower fat alternatives. The instrument has been updated and modified for use in different settings and populations [275,278,279]. A modification tested in African American adolescent girls had a relatively low correlation (r = 0.31) with multiple 24-hour recalls [280]. In another modification developed for African American women [281], a subset of 30 items from the SisterTalk Food Habits Questionnaire correlated with change in BMI (r = —0.35) as strongly as did the original 91 items (r = —0.36) [282].

3 Brief Multifactor Instruments

Recognizing the utility of assessing a few dimensions of diet simultaneously, several multifactor short instruments have been developed and evaluated, often combining fruits and vegetables with dietary fiber and/or fat components [16,283-287]. Others assess additional components of the diet. For example, Prime-Screen is composed of 18 FFQ items asking about consumption of fruits and vegetables, whole and low-fat dairy products, whole grains, fish and red meat, and sources of saturated and trans fatty acids; 7 items ask about supplement intake. The average correlation with estimates from a full FFQ over 18 food groups was 0.6 and over 13 nutrients was also 0.6 [288]. The 5-Factor Screener used in the 2005 NHIS Cancer Control Supplement assessed fruits and vegetables, fiber, added sugar, calcium, and dairy servings [289], and the dietary screener used in the 2005 CHIS assessed fruits and vegetables and added sugars [290]. The dietary screener administered in the 2009-2010 NHANES included 28 items addressing consumption of fruits and vegetables, whole grains, added sugars, dairy, fiber, calcium, red meats, and processed meats [291]. This screener was also used in the 2010 NHIS Cancer Control Supplement.

Some multicomponent behavioral questionnaires have also been developed. The Kristal Food Habits Questionnaire was expanded not only to measure the five fat factors described previously but also to measure three factors related to fiber: consumption of cereals and grains, consumption of fruits and vegetables, and substitution of high-fiber for low-fiber foods [292]. This fat- and fiber-related eating behavior questionnaire correlated with food frequency measures of percentage energy from fat (0.53) and fiber (0.50) among participants from a health maintenance organization in Seattle, Washington [292]. Schlundt *et al.* [293] developed a 51-item Eating Behavior Patterns Questionnaire targeted at assessing fat and fiber consumption among African American women. Newly incorporated in this questionnaire were questions to reflect emotional eating and impulsive snacking.

Some instruments combine aspects of food frequency and behavioral questions to assess multiple dietary patterns. For example, the Rapid Eating and Activity Assessment for Patients is composed of 27 items assessing consumption of whole grains, calcium-rich foods, fruits and vegetables, fats, sugary beverages and foods, sodium, and alcohol. When compared to dietary records, correlations were 0.49 with the Healthy Eating Index (HEI) [294], a measure of overall diet quality, and moderately high (range of r = 0.33-0.55) for HEI subscores of fat, saturated fat, cholesterol, fruit, and meats. Correlations for other HEI subscores for sodium, grains, vegetables, and dairy products were low (range of r = 0.03-0.27) [295].

Because the cognitive processes for answering food frequency-type questions can be complex, some attempts have been made to reduce the respondent burden by creating brief instruments with questions that require only “yes-no” answers. Kristal *et al.* [296] developed another questionnaire to assess total fat, saturated fat, fiber, and percentage energy from fat that is composed of 44 food items for which respondents are asked whether they eat the items at a specified frequency. A simple index based on the number of “yes” responses was found to correlate well with diet as measured by 4-day dietary records and with FFQs assessing total diet [296]. This same “yes-no” approach to questioning for a food list has also been used as a modification of the 24-hour recall [297]. These “targeted” 24-hour recall instruments aim to assess particular foods, not the whole diet [67,298-300]. They present a precoded close-ended food list and ask whether the respondent ate each food on the previous day; portion size questions may also be asked. For example, a web-administered checklist has been developed to measure the Dietary Approaches to a Stop Hypertension diet. It includes a listing of foods grouped into 11 categories, and it includes serving size information [301].

4 Limitations of Brief Instruments

The brevity of these instruments and their correspondence with dietary intake as estimated by more extensive methods create a seductive option for investigators who would like to measure dietary intake at a low cost. Although brief instruments have many applications, they have several limitations. First, they do not capture information about the entire diet. Most measures are not quantitatively meaningful and, therefore, estimates of dietary intake for the population usually cannot be made. Even when measures aim to provide estimates of total intake, the estimates are not precise and have large measurement error. Finally, the specific dietary behaviors found to correlate with dietary intake in a particular population may not correlate similarly in another population or even in the same population at another time period. For example, behavioral questionnaires developed and tested in middle-class, middle-aged U.S. women [277] were found to perform very differently when applied to Canadian male manual laborers [302], to a low-income, low-education adult Canadian population [303], and to participants in a worksite intervention program in Nevada [304]. Similarly, a screener developed to assess fast-food and beverage consumption in a primarily white, adolescent population [305] was not useful in an overweight Latina adolescent population [306]. Investigators should carefully consider the needs of their study and their own population's dietary patterns before choosing an "off-the-shelf" instrument designed to briefly measure either food frequency or specific dietary behaviors.

E Diet History

The term *diet history* is used in many ways. In the most general sense, a dietary history is any dietary assessment that asks the respondent to report about past diet. Originally, as coined by Burke, the term *dietary history* referred to the collection of information not only about the frequency of intake of various foods but also about the typical makeup of meals [307,308]. Many now imprecisely use the term dietary history to refer to the food frequency method of dietary assessment. However, several investigators have developed diet history instruments that provide information about usual food intake patterns beyond simply food frequency data [309-312]. Some of these instruments characterize foods in much more detail than is allowed in food frequency lists (e.g., preparation methods and foods eaten in combination), and some of these instruments ask about foods consumed at every meal [311,313]. The term diet history is therefore probably best reserved for dietary assessment methods that are designed to ascertain a person's usual food intake in which many details about characteristics of foods as usually consumed are assessed in addition to the frequency and amount of food intake.

The Burke diet history included three elements: a detailed interview about usual pattern of eating, a food list asking for amount and frequency usually eaten, and a 3-day dietary record [307,308]. The detailed interview (which sometimes includes a 24-hour recall) is the central feature of the Burke dietary history, with the food frequency checklist and the 3-day diet record used as cross-checks of the history. The original Burke diet history, which requires administration by an interviewer, has not often been exactly reproduced because of the effort and expertise involved in capturing and coding the information. However, many variations of the Burke method have been developed and used in a variety of settings [309-312,314-318]. These variations attempt to ascertain the usual eating patterns for an extended period of time, including type, frequency, and amount of foods consumed; many include a crosscheck feature [319,320].

Some diet history instruments have been automated and adapted for self-administration, sometimes with audio, thus eliminating the need for an interviewer to ask the questions [31,311,321]. Other diet histories have been automated but still continue to be administered by an interviewer [322,323]. Short-term recalls or records are often used for validation or calibration rather than as a part of the tool.

The major strength of the diet history method is its assessment of meal patterns and details of food intake rather than intakes for a short period of time (as in records or recalls) or only frequency of food consumption. Details of the means of preparation of foods can be helpful in better characterizing nutrient intake (e.g., frying vs. baking), as well as exposure to other factors in foods (e.g., charcoal broiling). When the information is collected separately for each meal, analyses of the joint effects of foods eaten together are possible (e.g., effects on iron absorption of concurrent intake of tea or foods containing vitamin C). Although a meal-based approach often requires more time from the respondent than does a food-based approach, it may provide more cognitive support for the recall process. For example, the respondent may be better able to report total bread consumption by reporting bread as consumed at each meal.

A weakness of the approach is that respondents are asked to make many judgments about both the usual foods consumed and the amounts of those foods eaten. These subjective tasks may be difficult for many respondents. Burke cautioned that nutrient intakes estimated from these data should be interpreted as relative rather than absolute. All of these limitations are also shared with the food frequency method. The meal-based approach is not useful for individuals who have no particular eating pattern and may be of limited use for individuals who "graze" (i.e., eat throughout the day rather than at defined mealtimes). The approach, when conducted by interviewers, requires trained nutrition professionals and is thus costly. Finally, the diet history as a method is not well standardized, and thus methods differ from each other and are difficult to reproduce, making comparisons across studies difficult.

Relative to other assessment approaches, few validation studies of diet history questionnaires using biological markers as a basis of comparison have been conducted. The studies found that reported mean energy intakes using the diet history approach in selected small samples of adults were underestimated in the range of 2-23% compared to energy expenditure as measured by doubly labeled water [324-327]. Generally, underreporting of protein, compared to urinary nitrogen, was less than that for energy and only sometimes significantly different [325,327-329]. These results have also been seen in children [330], adolescents [331,332], and the elderly [310]. Because of small sample sizes in these studies, few were able to examine characteristics related to underreporting, and their results were mixed, with some finding more underreporting with higher BMI [329,330] and others finding no relationship [310,326,333]. Although the diet history approach was extensively used as the main study instrument in European cohorts initiated in the 1990s, the approach is seldom used now in new cohort studies as other approaches have evolved. The approach is sometimes used as a reference instrument [334-336].

F Blended Instruments

Better understanding of various instruments' strengths and weaknesses has led to creative blending of approaches with the goal of maximizing the strengths of each instrument. For example, a record-assisted 24-hour recall has been used in several studies with children [337,338]. The child keeps notes of what he or she has eaten and then uses these notes as memory prompts in a later 24-hour recall. Several researchers have combined elements of a 24-hour recall and FFQ, often to assess specific dietary components. For example, in one assessment of fruits and vegetables, a limited set of questions is asked about the previous day's intake and the information is combined with usual frequency of consumption of common fruits and vegetables [17,339]. Similarly, the Nutritionist Five Collection Form combines a 2-day dietary recall with food frequency questions [340]. Thompson *et al.* [341] combined information from a series of daily checklists (i.e., precoded record) with frequency reports from an FFQ to form checklist-adjusted estimates of intake. In a validation study of this approach, validity improved for energy and protein but was unchanged for protein density [341].

A recent advance is the development of statistical methods that seek to better estimate usual intake of episodically consumed foods. A two-part statistical model developed by NCI uses information from two or more 24-hour recalls, allowing for the inclusion of daily frequency estimates derived from a food propensity questionnaire (a frequency questionnaire that does not ask about portion size), as well as other potentially contributing characteristics (e.g., age and race/ethnicity), as covariates [342]. Frequency information contributes to the model by providing additional information about an individual's propensity to consume a food—information not available from only a few recalls. The recalls, however, provide information about the nature and amount of the food consumed. A similar approach has been used in EPIC, which combined information from two non-consecutive 24-hour recalls with a food propensity questionnaire to identify those who do not consume each food [100]. Such methods are used to better measure usual intakes (see Section V.G).

Another statistical advance is the demonstration of enhanced accuracy and statistical power of combining 24-hour recall reports and biomarkers to estimate associations between diet and disease [343]. Carroll *et al.* [222] explored the number of days of 24-hour recall required to estimate associations between diet and disease in a cohort study and whether an FFQ, in addition, is beneficial. They concluded that for most nutrients and foods, 4 non-consecutive days of 24-hour recall report is optimal. The combination of FFQ and multiple 24-hour recalls was superior in estimating some nutrients and foods, especially for episodically consumed foods.

Developing hybrid instruments as well as developing new analytical techniques that combine information from different assessment methods may hold great promise for furthering our ability to accurately assess diets.

Table 1.1 summarizes the important characteristics of the main self-report dietary assessment methods.

III DIETARY ASSESSMENT IN DIFFERENT STUDY DESIGNS

The choice of the most appropriate dietary assessment method for a specific research question requires careful consideration. The primary research question must be clearly formed, and questions of secondary interest should be recognized as such. Projects can fail to achieve their primary goal because of too much attention to secondary goals. The choice of the most appropriate dietary assessment tool depends on many factors. Questions that must be answered in evaluating which dietary assessment tool is most appropriate for a particular research need include the following [195]: (1) Is information needed about foods, nutrients, other food components, or specific dietary behaviors? (2) Is the focus of the research question on describing intakes using estimates of average intake, and does it also require distributional information? (3) Is the focus of the research question on describing relationships between diet and health outcomes? (4) Is absolute or

TABLE 1.1 Comparison of Self-Report Dietary Assessment Methods by Important Characteristics

	Dietary record	24-hour recall	FFQ	Diet history	Screener
Type of information attainable					
Detailed information about foods consumed	X	X		X	
General information about food groups consumed			X		X
Meal-specific details	X	X		X	
Scope of information sought					
Total diet	X	X	X	X	
Specific components					X
Time frame asked					
Short term (e.g., yesterday, today)	X	X		X	
Long term (e.g., last month, last year)			X	X	X
Adaptable for diet in distant past					
Yes			X	X	X
No	X	X			
Cognitive requirements					
Measurement or estimated recording of foods and drinks as they are consumed	X				
Memory of recent consumption		X		X	
Ability to make judgments of long-term diet			X	X	X
Potential for reactivity					
High	X				
Low		X	X	X	X
Time required to complete					
<15 minutes					X
>20 minutes	X	X	X	X	
Suitable for cross-cultural comparisons without instrument adaptation					
Yes	X	X		X	
No			X	X	X

relative intake needed? (5) What level of accuracy and precision is needed? (6) What time period is of interest? (7) What are the research constraints in terms of money, interview time, staff, and respondent characteristics?

A Cross-Sectional Surveys

One of the most common types of population-level studies is the cross-sectional survey, a set of measurements of a population at a particular point in time. Such data can be collected solely to describe a particular population's intake. Alternatively, data can be used for surveillance at the national, state, and local levels as the basis for assessing risk of deficiency, toxicity, and overconsumption; to evaluate adherence to dietary guidelines and public health programs; and to develop food and nutrition policy. Cross-sectional data also may be used for examining associations between current diet and other factors including health. However, caution must be applied in examining many chronic diseases believed to be associated with past diet because the currently measured diet is not necessarily related to past diet. Any of the dietary instruments discussed in this chapter can be used in cross-sectional studies. Some of the instruments, such as the 24-hour recall, are appropriate when the study purpose requires quantitative estimates of intake. Others, such as FFQs or behavioral indicators, are appropriate when qualitative estimates are sufficient—for example, frequency of consuming soda and frequency of eating from fast-food restaurants.

When measurements are collected on a sample at two or more times, the data can be used for purposes of monitoring dietary trends. To assess trends in intakes over time, it would be ideal for the dietary surveillance data collection methods, sampling procedures, and food composition databases to be similar from survey to survey. As a practical matter, however, this is difficult, and the benefits of trend analysis may not outweigh the benefits of improving the methods over time. The dietary assessment method used consistently throughout the years in U.S. national dietary surveillance is the interviewer-administered 24-hour recall. However, recall methodology has improved over time based on cognitive research, the addition of multiple interviewing passes, standardization of probes, automation of the interview, and automation of the coding.

Another issue that affects the assessment of trends over time is changes in the nutrient or food grouping databases and specification of default foods. Changes in the food supply are reflected in additions or subtractions to food composition databases, whereas changes in consumption trends may lead to subsequent reassignment of default codes for foods not fully specified in 24-hour recalls or records (e.g., when type of milk is not specified, the default code is now 2% milk as opposed to whole milk in the past). Food composition databases, too, are modified over time because of true changes in food composition, improved analytic methods for particular nutrients, or inclusion of information for new dietary components. Reflecting true changes over time is especially beneficial in trend analysis.

Since 1999, the major cross-sectional surveillance survey in the United States has been the NHANES [344]. This survey is conducted by the National Center for Health Statistics. The dietary component of the survey, called "What We Eat in America" [71], consists of 24-hour recalls collected using the USDA's AMPM (see Section II.B). The USDA also processes and analyzes the data. The 24-hour recalls in NHANES query the intake of dietary supplements as well as foods and beverages. In NHANES 2003—2004, 2005—2006, 2007—2008, and 2009—2010, two 24-hour dietary recalls were conducted, allowing for estimation not only of average usual intake but also of the distributions of usual intake of the dietary components (see Section V.G).

NHANES provides high-quality dietary intake data at the national level, but these data are of limited use for state and local researchers planning and evaluating their programs and policies [345]. Collection of state and local data is often constrained by lack of resources or interview time, leading to the frequent use of less expensive brief instruments. For example, the CDC has used telephone-administered screeners to periodically assess fruit and vegetable intake within the BRFSS [249]. The California Department of Public Health, in its California Dietary Practices Survey, has assessed dietary practices among adults biennially since 1989 [346]. The California Health Interview Survey used telephone-administered screeners to assess fruit and vegetable intake in 2001, 2005, and 2009 [228].

B Case—Control (Retrospective) Studies

A case—control study design classifies individuals with regard to current disease status (as cases or controls) and relates this to past (retrospective) exposures. For dietary exposure, the period of interest could be either the recent past (e.g., the year before diagnosis) or the distant past (e.g., 10 years ago or in childhood). Because of the need for information about diet before the onset of disease, dietary assessment methods that focus on current behavior, such as the 24-hour recall, are not useful in retrospective studies. The food frequency and diet history methods are well suited for assessing past diet and are therefore the only viable choices for case—control (retrospective) studies.

In any food frequency or diet history interview, the respondent is not asked to recall specific memories of each eating occasion but, rather, to respond on the basis of general perceptions of how frequently he or she ate a food. In case—control studies, the relevant period is often the year before the diagnosis of a disease or onset of symptoms or at particular life stages, such as adolescence and childhood. Thus, in assessing past diet, an additional requirement is to orient the respondent to the appropriate period.

The validity of recalled diet from the distant past is difficult to assess because definitive recovery biomarker information (doubly labeled water or urinary nitrogen) is not available for large samples from long ago. Instead, relative validity and long-term reproducibility of various FFQs have been assessed in various populations by asking participants from past dietary studies to recall their diet from that earlier time [347,348]. These studies have found that correlations between past and current reports about the past vary by nutrient and by food group [111,349], with higher correspondence for very frequently consumed and rarely consumed foods compared to that for foods consumed moderately often [349,350]. Evidence suggests that correspondence between past and recalled past decreases with the length of time between reports [347]. In particular, retrospective reports of diet in adolescence after long recall periods (i.e., >30 years) have shown little correspondence with the original reports [351]. Maternal reports about diets of their children in early childhood or adolescence have also shown low correspondence with the original reports [352,353].

Correspondence of retrospective diet reports with the diet as measured in the original study has usually been greater than the correspondence of current diet with past diet. This observation implies that if diet from years in the past is of interest, it is usually preferable to ask respondents to recall it than to simply consider current diet as a proxy for past diet. Nonetheless, the current diets of respondents may affect their retrospective reports about past diets. In particular, retrospective diet reports from seriously ill individuals may be biased by recent dietary changes [347,354]. Studies of groups in whom diet was previously measured indicate no consistent differences in the accuracy of retrospective reporting between those who recently became ill and others [355,356].

C Cohort (Prospective) Studies

In a cohort study design, exposures of interest are assessed at baseline in a group (cohort) of people and disease outcomes occurring over time (prospectively) are then related to the baseline exposure levels. In prospective dietary studies, dietary status at baseline is measured and related to later incidence of disease. For many chronic diseases, large numbers of individuals need to be followed for years before enough new cases with that disease accrue for statistical analyses. A broad assessment of diet is usually desirable in prospective studies because many dietary exposures and many disease end points will ultimately be investigated and areas of interest may not even be recognized at the beginning of a cohort study.

In order to relate diet at baseline to the eventual occurrence of disease, a measure of the usual intake of foods (see Section V.G) by study subjects is needed. Although a single 24-hour recall or a dietary record for a single day would not adequately characterize the usual diet of individual study subjects in a cohort study, such information could be later analyzed at the group level for contrasting the average dietary intakes of subsequent cases with those who did not acquire the disease. Typically, researchers are interested in estimating additional parameters, and therefore, 24-hour recalls or dietary records, if used, may require multiple administrations. Multiple dietary recalls, multiple records, diet histories, and food frequency methods have all been used effectively in prospective studies. Cost and logistic issues tend to favor food frequency methods because many prospective studies require thousands of respondents. However, because of concern about significant measurement error and attenuation attributed to the FFQ [217,220,221,357-360], other approaches are being considered. One approach is the use of automated self-administered 24-hour recall instruments (see Section II.B). Another approach is collecting multiple days of dietary records at baseline, with later coding and analysis of records for those respondents selected for analysis, using a nested case-control design [361,362]. Incorporating emerging technological advances in administering dietary records, such as using mobile phones, increases the feasibility of such approaches in prospective studies.

If using an FFQ in the cohort, it is desirable to include multiple recalls or records in subsamples of the population (preferably before beginning the study) to construct or modify the food frequency instrument and to calibrate it (see Section V.B). Information on the foods consumed could be used to ensure that the questionnaire includes the major food sources of key nutrients, with appropriate portion size categories. Because the diets of individuals change over time, it is desirable to measure diet throughout the follow-up period rather than just at baseline. If diet is measured repeatedly over years, repeated calibration is also desirable. Information from calibration studies can be used for three purposes: to give design information, such as the sample size needed [197]; to relate values from the food frequency tool (or a brief food list thus derived) to values from the recalls/records [214]; and to determine the degree of attenuation/measurement error in the estimates of association observed in the study (e.g., between diet and disease) [209,212,214,216,363-367] (see Section V.B).

D Intervention Studies

Intervention studies range from relatively small, highly controlled, clinical studies of targeted participants to large trials of population groups. Intervention studies may use dietary assessment for two purposes: (1) initial screening for inclusion (or exclusion) into the study and (2) measurement of dietary changes resulting from the intervention. Not all intervention trials require initial screening. For those that do, screening can be performed using very detailed instruments or less burdensome instruments. For example, food frequency instruments were used in the Women's Health Trial [251] and in the Women's Health Initiative Dietary Modification Trial [368] to identify groups with high fat intake and thus determine eligibility.

The need for careful planning and formative research in designing useful community intervention trials has been described [369]. A critical element is the existence of evidence that a particular intervention would create a measureable change in a particular group and setting. Measurement of the effects of a dietary intervention requires a valid measure of change from baseline to the conclusion of the intervention period. Often, post-intervention diet is also measured to assess the durability of any dietary change. Some work has been done to examine the validity of methods to measure dietary change in individuals or in populations [279,370]. Researchers have found that dietary records and scheduled 24-hour recalls were associated with changed eating behavior during the recording days and had less correspondence with biological measures [371], expected weight change [372], and increased underreporting [373]. One study using dietary screeners and a reference measure of multiple non-consecutive unannounced 24-hour recalls found that the change in fruit and vegetable intake was overestimated relative to the control group [248]; however, in the same study, the screener and the 24-hour recalls were consistent in finding no change in percentage energy from fat in the two groups [374]. Because of resource constraints, large intervention studies have often relied on less precise measures of diet, including FFQs and brief instruments. However, resource constraints may be less relevant with the availability of automated self-administered 24-hour recall instruments and less burdensome dietary records.

Intentional behavior change is a complex and sequential phenomenon, as has been shown for tobacco cessation [375], and this is also true for dietary change [376]. Measurement of specific dietary behaviors in addition to, or even in place of, dietary intake could be considered in intervention evaluations when the nature of the intervention involves education about specific behaviors. If, for instance, a community-wide campaign to choose low-fat dairy products were to be evaluated, food selection and shopping behaviors specific to choosing those items could be measured. The effects of educational interventions might also be assessed by measuring knowledge, attitudes, beliefs, barriers, and perceptions of readiness for dietary change, although the reliability of these types of questions has not been well assessed.

Whether an intervention is targeting individuals or the entire population, repeated measures of diet among study subjects can reflect reporting bias in the direction of the change being promoted [370]. Although not intending to be deceptive, some respondents may tend to report what they think investigators want to hear. Social desirability [377] and social approval [378] biases can be measured and the resulting scales incorporated into intervention analyses. Because of their greater subjectivity, behavioral questions, screeners, and the food frequency method may be more susceptible to social desirability biases than the 24-hour recall method [69,225]. On the other hand, greater awareness of diet and enhanced reporting skills because of the intervention may enhance the accuracy of reports [379]. Dietary records and scheduled 24-hour recalls are vulnerable to reactivity. If assessment is by 24-hour recalls, unannounced administration would avoid reactivity but possibly at the expense of participation. Because self-reports of diet are subject to bias in the context of an intervention study [370], an independent assessment of dietary change should be considered. For example, food availability and/or sales in worksite cafeterias, school cafeterias, or vending machines could be monitored. One such method useful in community-wide interventions is monitoring food sales [380]. Often, cooperation can be obtained from food retailers [381]. However, because the number of food items may be large, it may be possible to monitor only a small number, and the large effects on sales of day-to-day pricing fluctuations should be carefully considered. Another method to consider is measuring changes in biomarkers of diet, such as serum carotenoids [379,382] or serum cholesterol [383], in the population. Consistency of changes in self-reported diet and appropriate biomarkers provides further evidence for real changes in the diet. See Chapters 10 and 11 for more in-depth discussions of the evaluation of diet in nutrition interventions and use of biomarkers in intervention studies respectively.

Table 1.2 summarizes the dietary methods commonly used in different study designs.

IV DIETARY ASSESSMENT IN SPECIAL POPULATIONS

A Respondents Unable to Self-Report

In many situations, respondents are unavailable or unable to report about their diets. For example, in case—control studies, surrogate reports may be obtained for cases who have died or who are too ill to interview. Although the accuracy of surrogate reports has not been examined using the reference biomarkers of doubly labeled water or urinary nitrogen, the comparability of reports by surrogates and subjects has been studied with the goal that surrogate information might be used interchangeably with information provided by subjects [384]. Common sense indicates that individuals who know most about a subject's lifestyle would make the best surrogate reporters [385]. Adult siblings provide the best information about a subject's early life, and spouses or children provide the best information about a subject's adult life. When food frequency instruments are used, the level of agreement between subject and surrogate reports of diet varies with the food and possibly with other variables, such as number of shared meals, interview situation, case status, and sex of the surrogate reporter. Mean frequencies of use computed for individual foods and food groups between surrogate reporters and subject

TABLE 1.2 Dietary Assessment Methods Commonly Used in Different Study Designs

Study design	Methods
Cross-sectional	24-Hour recall, FFQ, brief instruments
Case—control (retrospective)	FFQ, diet history
Cohort (prospective)	FFQ, diet history, 24-hour recall, dietary record
Intervention	FFQ, brief instruments, 24-hour recall

reporters tend to be similar [386–388], but agreement is much lower when detailed categories of frequency are compared. Several studies have shown that agreement is better for alcoholic beverages, coffee, and tea than for foods.

When subjects themselves report intakes in the extremes of a distribution, their surrogates seldom report intakes in the opposite extreme, although the surrogates tend to report intakes in the middle of the distribution [389]. This may limit the usefulness of surrogate information for individual-level analyses that rely on proper ranking. Furthermore, the quality of surrogate reports between spouses of deceased subjects and spouses of surviving subjects may differ substantially [390]. Thus far, however, little evidence suggests that dietary intakes are systematically overreported or underreported depending on the case status of the subject [391–393]. Nonetheless, use of surrogate respondents should be minimized for obtaining dietary information in analytical studies. When used, analyses excluding the surrogate reports should be done to examine the sensitivity of the reported associations to possible errors or biases in the surrogate reports. If planning a study using surrogate reports, the sample size should be inflated to account for a higher incidence of missing data, the inability to recruit surrogates for some number of cases, and the reduced precision of dietary estimates.

B Ethnic Populations

The widespread use of many ethnic foods in the United States throughout the population and the increasing diversity of the population have broadened the food composition databases and food lists used for the general population. Nonetheless, special modifications may be needed in the content of dietary assessment methods when the study population is composed of individuals whose cuisine or cooking practices are not mainstream [394]. If the method requires an interview, interviewers of the same ethnic or cultural background are preferable so that dietary information can be more effectively communicated. If dietary information is to be quantified into nutrient estimates, examination of the nutrient composition database is necessary to ascertain whether ethnic foods are included and whether those foods and their various preparation methods represent those consumed by the target population [395]. It is also necessary to examine the recipes and assumptions underlying the nutrient composition of certain ethnic foods. Some very different foods may be called the same name, or identical foods may be called by different names [396,397]. For these reasons, it may be necessary to obtain detailed recipe information for all ethnic mixtures reported.

To examine the suitability of the initial database, preliminary information about typical diets should be collected from individuals in the ethnic groups. This information could come from recalls or records with accompanying interviews or from focus group interviews. These interviews should focus on the foods eaten and the ways in which foods are prepared in that culture. Recipes and alternative names of the same food should be collected, and field interviewers should be familiarized with the results of these focus groups. Recipes and food names that are relatively uniform should be included in the nutrient composition database. Even with these modifications, it may be preferable for the field interviewers to collect detailed descriptions of ethnic foods reported rather than to directly code these foods using preselected lists most common in computer-assisted methods. This would prevent the detail of food choice and preparation from being lost by *a priori* coding.

USDA continues to incorporate new foods into the National Nutrient Database for Standard Reference (SR) (see Section V.E). For example, approximately 200 foods identified as Native American or Alaskan Native have been incorporated into the SR24 and also are available in the University of Minnesota Nutrient Database System. If a newly reported food is not available in the food composition database being used, a default code that is thought to closely mirror the nutrient composition of the new food can be used.

Use of FFQs developed for the majority population may be suboptimal for many individuals with ethnic eating patterns. Many members of ethnic groups consume both foods common in the mainstream culture and foods that are specific to their own ethnic group. Modification of the existing food list can be accomplished through expert judgment, qualitative interviews with the target population, and/or examination of the frequency of reported foods in the population from a set of dietary records or recalls. FFQs for Navajos [398], Alaska Natives [399], Chinese Americans [400], individuals in northern India [401], Hispanics [146,402], Israelis [403], and African Americans in the southern United States [404] have been developed using these approaches.

In addition to the food list, however, there are other important issues to consider when adapting existing FFQs for use in other populations. The relative intake of different foods within a food group line item may differ, thus requiring a change in the nutrient database associated with each line item. For example, Latino populations may consume more tropical fruit nectars and less apple and grape juice than the general U.S. population and therefore would require a different nutrient composition standard for juices. In addition, the portion sizes generally used may differ [405]. For example, rice may be consumed in larger quantities in Latino and Asian populations; the amount attributed to a large portion for the general population may be substantially lower than the amount typically consumed by Latino and Asian populations. Adaptation of an existing FFQ considering all of these factors has been done for an elderly Puerto Rican population [406], for white and African American adults in the Lower Mississippi Delta [407], and for the Hawaii-Los Angeles Multiethnic Cohort Study [408]. The Southern Community Cohort Study incorporated both race/ethnicity and geographic region into its FFQ database [409].

With some ethnic populations, it may be preferable to administer an FFQ using an interviewer rather than self-administration because literacy and language barriers may limit participation in the study as well as quality of response. In addition, portion size models, which interviewers can bring to a home interview, may be preferable to portion size pictures available in a self-administered instrument [399].

The NCI Dietary Calibration/Validation Studies Register [199] can be used to search for studies using FFQs in specific race/ethnicity groups. Performance of FFQs varies across ethnic groups [410]. Questionnaires aimed at allowing comparison of intakes across multiple cultures have been developed. Although some studies have found no appreciable validity differences across various race/ethnicity groups [259], most have found validity differences [145,406,408,411-413]. Understanding these validity differences is crucial to the appropriate interpretation of study results.

C Children

Assessing the diets of children is considered to be even more challenging than assessing the diets of adults. Children tend to have diets that are highly variable from day to day, and their food habits can change rapidly. Younger children are less able to recall, estimate, and cooperate in usual dietary assessment procedures; so much information by necessity has to be obtained by surrogate reporters. Although they are more able to report, adolescents may be less interested in giving accurate reports. Baranowski and Domel [414] have posited a cognitive model of how children report dietary information.

Dietary assessment in children and adolescents has been discussed and reviewed [415-422]. The 24-hour recall, dietary records (including precoded checklists [10]), dietary histories, FFQs, brief instruments [423-425], and blended instruments such as a dietary record-assisted 24-hour recall [337] have all been used to assess children's intakes. The use of direct observation of children's diets has also been used extensively, most often as a reference method to compare with self-reported instruments [426,427]. As predicted from Baranowski and Domel's model, it has been found that children's estimates of portion size have large errors [428], and they are less able than adults to estimate portion sizes [429] (see Section V.D). Overall, the consensus seems to be that the characteristics of different age groups call for the use of different assessment approaches.

For preschool-aged children, information is obtained from surrogates, usually the primary caretaker(s), who may typically be a parent or an external caregiver. If information is obtained only from one surrogate reporter, the reports are likely to be less complete. Even for periods when the caregiver and child are together, foods tend to be underestimated [430]. A "consensus" recall method, in which the child and parents report as a group on a 24-hour recall, has been shown to give more accurate information than a recall from either parent or child alone [431]. Sobo and Rock [432] describe such interviews and suggest tips for interviewers to maximize data accuracy.

For older children, extensive research has been conducted on the 24-hour recall approach [433]. Baxter *et al.* [434] found that among fourth graders, 24-hour recall improves as the time between reporting and eating decreases, and meal-specific intrusions (i.e., reports of foods not consumed) are fewer in an open format interview than in a time-forward format interview (i.e., beginning at the earliest meal in the time period and working forward to the next meal). These intrusions are often associated with additional intrusions at the same meal [434]. Because accuracy of recall is greater when the time between eating and reporting is shorter, there will be differential error by meal; meals further away (e.g., at the beginning of the 24-hour recall period) will have substantially more error [435,436].

To make 24-hour recalls more feasible, self-administered automated 24-hour recall tools have been developed and tested for children [85]. An interviewer-administered 24-hour recall and a self-administered 24-hour recall using the Food Intake Recording Software System (FIRSSt) were compared to unobtrusive observations in fourth graders. Compared to observed intake, the interviewer-administered 24-hour recall was associated with a 59% match, 17% intrusion, and 24% omission rates, whereas the automated recall was associated with a 46% match, 24% intrusion, and 30% omission rates [85]. Baranowski *et al.* are developing a second-generation version of the FIRSSt with tailored food lists and prompts [437,438].

Other self-administered web-based tools have been developed for school-age children and adolescents. The Web-Span, developed in Canada, includes a dietary component [439,440] and has been used in school-age children and adolescents in school. When two non-consecutive days of Web-SPAN were compared with 3-day records, reported energy intake was significantly higher on the Web-SPAN than on the records; correlations between the two methods ranged from 0.24 to 0.40 [440]. The Synchronized Nutrition and Activity Program (SNAP), a web-based program, directs children to report the previous day's food intake by ticking the number of times they consumed each of 40 foods and nine drinks. However, compared to a 24-hour recall for the same period, SNAP generally underestimated counts of the foods assessed, and the accuracy decreased with increasing counts [441].

New technology has also been incorporated into other dietary assessment approaches. Williamson *et al.* [442] developed and tested digital photography in school cafeterias. This observation method consists of standardized photography of the food selected before the meal and the plate waste following the meal. Using reference portions of measured quantities of the foods, expert judgment is used to estimate the amount of each food consumed [442].

Another approach that has been taken with school-age children is a blended instrument, the record assisted 24-hour recall, in which the children record only the names of foods and beverages consumed throughout a 24-hour period. This information serves as a cue for the later 24-hour recall interview. The European Food Consumption Validation Project, a consortium of 13 institutes from 11 European countries, provisionally recommended a similar approach—a food recording booklet for foods eaten away from home—for schoolchildren 7-14 years old. Studies examining the validity of this approach have had mixed results [337,338,443].

Adaptation of food frequency instruments originally developed for adults requires consideration of the instrument itself (food list, question wording and format, and portion size categories) and the database for converting responses to nutrient intakes. Food frequency instruments, some web administered, have been developed and tested for use in child and adolescent populations [7,184,444-446]. A web-based food behavioral questionnaire underestimated the intake of middle-school children compared to a multiple-pass 24-hour recall [447]. Generally, correlations between food frequency type instruments and more precise reference instruments have been lower in child and adolescent populations than in adult populations. New technology-based methods, such as disposable cameras, mobile phones with cameras [28], and smart phones, are being developed for collecting records and may be particularly useful among adolescents, who prefer these methods to traditional methods [448].

For school-age children and adolescents, there is no consensus of which dietary assessment method is most accurate. The choice of which instrument to use may depend on the study objectives and study design factors, all of which will influence the appropriateness and feasibility of different approaches [449].

D Elderly

Measuring diets among the elderly can, but does not necessarily, present special challenges [450-452]. Both recall and food frequency techniques are inappropriate if memory or cognitive functioning is impaired. Similarly, self-administered tools may be inappropriate if physical disabilities such as poor vision are present. Interviewer administration is difficult when hearing problems are present [452]. Direct observation in institutional care facilities [450] or shelf inventories for elders who live at home can be useful. Even when cognitive integrity is not impaired, several factors can affect the assessment of diet among the elderly. Because of the frequency of chronic illness in this age group, it is more probable that special diets (e.g., low sodium, low fat, and high fiber) would have been recommended. Such recommendations could not only affect actual dietary intake but also bias reporting because individuals may report what they should eat rather than what they do eat. Alternatively, respondents on special diets may be more aware of their diets and may more accurately report them. When dentition is poor, the interviewer should probe regarding foods that are prepared or consumed in different ways. Relative to other age groups, the elderly are more apt to take multiple types of nutritional supplements [453], which present special problems in dietary assessment (see Chapter 2). Because of the concern of malnutrition among the elderly, specific instruments to detect risk of malnutrition, such as the Nutrition Screening Initiative in the United States [454,455], the Australian Nutrition Screening Initiative [456], the Mini Nutritional Assessment [457], the Geriatric Nutritional Risk Index [458], and the Simplified Nutritional Appetite Questionnaire [459], have been developed.

Some researchers have suggested that the short-term memory required for the 24-hour recall may be more difficult for the elderly, who are more adept at long-term memory [450]. However, interviewers conducting a FFQ among elderly respondents noted difficulty in maintaining interest and concentration, whereas these issues were not found during the more engaging 24-hour recall interview [451].

Validation studies using doubly labeled water and/or urinary biomarkers among the elderly are limited [40,460-462]. Generally, energy underreporting has been found to be positively related to elevated BMI and lower education, similar to younger populations.

However, in the NIH-funded Health, Aging, and Body Composition Study cohort, Shahar *et al.* [462] found that a substantial portion of elderly reporters were undereaters, losing more than 2% of their weight over a year.

Adaptations of standard dietary assessment methods have been suggested and evaluated, including using memory strategies, notifying the respondent prior to the dietary interview [463], combining methods [464], and adapting existing instruments [465]. Specific adaptations that have been made in elderly populations include the use of household measures rather than pictures to portray portion size for sight-impaired respondents [451] and tailoring the food list and portion sizes to be characteristic of the elderly rather than all adults in food frequency questionnaires and their related databases [466].

Some have suggested including measures of cognitive function within a study to aid the interpretation of results, but one such study found no relationship between the cognitive functioning score and the validity of a food frequency questionnaire [467].

The variability in functional status among the elderly suggests the need for a flexible approach in assessing dietary intake. Mixed mode design in survey research [468] has certain advantages with regard to enhancing coverage and decreasing nonresponse, but it may cause other biases [469].

Table 1.3 summarizes optimal assessment strategies for special populations.

TABLE 1.3 Optimal Strategies for Special Populations

Special population	Optimal strategies
Respondents unable to self-report	Use the best-informed surrogate. Analyze the effect of potential bias on study results.
Ethnic populations	Use interviewers of same ethnic background. Use nutrient composition database reflective of foods consumed. For FFQs, use an appropriate food list and nutrient composition database.
Children	For young children, use caretakers in conjunction with the child. For older children and adolescents, blended instrument and other creative ways of engagement and motivation may work best. For FFQs, use an appropriate food list and portion size categories.
Elderly	Assess any special considerations, including: memory, special diets, dentition, use of supplements, etc., and adapt methods accordingly.

V SELECTED ISSUES IN DIETARY ASSESSMENT METHODS

A Cognitive Testing Research Related to Dietary Assessment

Nearly all studies using dietary information about subjects rely on the subjects' own reports of their diets. Because such reports are based on complex cognitive processes, it is important to understand and take advantage of what is known about how respondents remember dietary information and how that information is retrieved and reported to the investigator. The need for and importance of such considerations in the assessment of diet has been discussed by several investigators [347,414,470–472], and research using cognitive testing methods in dietary assessment has been reported [12,136,230,246,295,313,471,473–477]. A thorough description of cognitive interviewing methods is found in Willis [478].

Specific and generic memories of diet are distinctly different. Specific memory relies on particular memories about episodes of eating and drinking, whereas generic memory relies on general knowledge about typical diet. A 24-hour recall relies primarily on specific memory of all actual events in the very recent past, whereas a FFQ that directs a respondent to report the usual frequency of eating a food during the previous year relies primarily on generic memory. As the time between the behavior and the report increases, respondents may rely more on generic memory and less on specific memory [471].

Investigators can do several things to enhance retrieval and improve reporting of diet. Research indicates that the amount of dietary information retrieved from memory can be enhanced by the context in which the instrument is administered and by use of specific memory cues and probes. For example, for a 24-hour recall, foods that were not initially reported by the respondent can be recovered by interviewer probes. The effectiveness of these probes is well-established and is therefore part of the interviewing protocol for all standardized high-quality 24-hour recalls, including those administered in the NHANES. Probes can be useful in improving generic memory too, when subjects are asked to report their usual diets from periods in the past [347,472]. Such probes can feature questions about past living situations and related eating habits.

The way in which questions are asked can affect responses. Certain characteristics of the interviewing situation may affect the social desirability of particular responses for foods viewed as "good" or "bad." For example, the presence of other family members during the dietary interview may increase social desirability bias, especially for certain items such as alcoholic beverages. An interview in a health setting, such as a clinic, may also increase social desirability bias in reporting about foods that were previously proscribed or recommended in that setting. In all instances, interviewers should be trained to refrain from either positive or negative feedback and should repeatedly encourage subjects to accurately report all foods.

B Validation/Calibration Studies

It is important and desirable that any new dietary assessment method be validated or calibrated against more established methods [213,214,216,479]. Furthermore, even if an instrument has been evaluated, its proposed use in a different population may warrant additional validation research in that population. The purpose of such studies is to better understand how the method works in the particular research setting and to use that information to better interpret results from the overall study. For example, before a new FFQ or brief assessment questionnaire is used in the main study, it should be evaluated in a validation/calibra-tion study that compares the questionnaire to another more detailed dietary assessment method, such as 24-hour recalls or dietary records, obtained from the same individuals and, preferably, to biological markers such as doubly labeled water or urinary nitrogen. The NCI maintains a register of validation/calibration studies and publications on the web [199].

Validation studies yield information about how well the new method is measuring what it is intended to measure, and calibration studies use the same information to relate (calibrate) the new method to a reference method using a regression model. Validation/calibration studies are challenging because of the difficulty and expense in collecting independent dietary information. Some researchers have used observational techniques to establish true dietary intake [109,430,480,481]. Others have used laboratory measures such as the 24-hour urine collection to measure protein, sodium, and potassium intakes and the doubly labeled water technique to measure energy expenditure, using it as a gold standard for energy intake when subjects are in energy balance [39–45,93,154,202,203,205,482,483]. However, the high cost of this latter technique can make it impractical for most studies. The overall validity of energy intake estimates from the dietary assessment can be roughly checked by comparing weight data to reported energy intakes, in conjunction with the use of equations to estimate basal metabolic rate [42,54,57,58,62,64,107,108,482,484,485].

The validation process can address the accuracy of reports for specific foods. Many studies using observers to accurately assess foods and amounts consumed relative to reported intakes have characterized reporting errors as intrusions and exclusions in the foods reported and erroneous portion size reports [486]. The granularity of this misreporting can be used to understand and potentially remedy errors in reporting. NCI will conduct an evaluation of its ASA24 instrument in an observational feeding study to examine food-specific reporting errors.

Because they are relatively expensive to conduct, validation/calibration studies are done on subsamples of the total study sample. However, the subsample should be sufficiently large to estimate the relationship between the study instrument and a reference method with reasonable precision. Increasing the numbers of individuals sampled and decreasing the number of repeat measures per individual (e.g., two non-consecutive 24-hour recalls on 100 people rather than four recalls on 50 people) often can help to increase precision without extra cost [487]. As often as possible, the subsample should be chosen randomly.

The subsequent analyses quantify the relationship between the new method and the reference method, and the resulting statistics can be used for a variety of purposes. Because, in most cases, the reference method (usually dietary records or 24-hour recalls) is itself imperfect and subject to within-person error (day-to-day variability), measures such as correlation coefficients may underestimate the level of agreement with the actual usual intake. This phenomenon, referred to as "attenuation bias," can be addressed through the use of measurement error models that allow for within-person error in the reference instrument, resulting in estimates that more nearly reflect the correlation between the diet measure and true diet [365,488]. The corrected correlation coefficients also give guidance with regard to the sample size required in a study because the less precise the diet measure, the more individuals will be needed to attain the desired statistical power [488]. The estimated regression relationship between the new method and the reference method can also be used to adjust the relationships between diet and outcome as assessed in the larger study [197]. For example, the mean amounts of foods or nutrients, and their distributions, as estimated by a brief method, can be adjusted according to the calibration study results [489]. In addition, methods to adjust estimates of the relationships measured in studies (e.g., the relative risk of disease for subjects with high nutrient intake compared to those with low intake) have been described [209,210,365,490,491]. Many of these adjustments require the assumption that the reference method is unbiased [209,363]. However, much evidence indicates that, at least for some nutrients, the reported intakes from recalls and records are biased in a manner correlated with the tool of interest (e.g., an FFQ) [135], violating this assumption. Violation of this assumption would lead to overestimates of validity. For these reasons, researchers have sometimes used biomarkers such as urinary nitrogen and doubly labeled water as reference measures, that have been shown in feeding studies to be unbiased measures of intake. Currently, only a few such biomarkers are known. Another area in need of further study is the effect of measurement error in a multivariate context because most research thus far has been limited to the effect on univariate relationships [212,216,492,493].

C Mode of Administration

Instruments may be interviewer-administered or self-administered. Interviewer-administered questionnaires may be in person or by telephone. A self-administered instrument may be completed on paper or electronically. All of these modes are currently used for dietary assessment.

For interviewer-administered instruments, telephone administration is less costly than in-person administration. However, concern is increasing about response rates in telephone surveys, given the public's distaste for prevalent telemarketing, technology that allows for the screening of calls, the increase in the proportion of the population (especially young adults [494]) who use only wireless telephones, and the general resistance of the public to engage in telephone interviews. For these reasons, response rates obtained using random digit dialing techniques have been dropping.

Despite these difficulties, many surveys and studies do collect dietary data over the telephone. For example, BRFSS [249] and the California Health Interview Survey [228] both include dietary screeners. NHANES [344] administers an initial 24-hour recall at the examination site and a second 24-hour recall later by telephone. For 24-hour recalls collected by telephone, the difficulty of reporting serving sizes can be eased by mailing picture booklets or other portion size estimation aids to participants before the interview. Many studies have evaluated the comparability of data from telephone versus in-person 24-hour recall interviews. Several have found substantial but imperfect agreement between dietary data collected by telephone and that estimated by other methods, including face-to-face interviews [70,495–497] or observed intakes [498]. Godwin *et al*. [499] and Yanek *et al*. [500] examined the accuracy of portion size estimates for known quantities of foods consumed that were assessed by telephone and by in-person interviews. Both estimates were found to be similarly accurate.

Self-administration is less costly than interviewer-administration. In addition, self-administered surveys tend to minimize social desirability bias [501]. However, self-administration may not be feasible for segments of the population who have low literacy levels or limited motivation. Thus, selection bias is a potential problem.

Web-administered questionnaires have cost advantages and have become popular as the penetrance of the Internet increases. However, it is estimated that only 69% of households in the United States had Internet access in 2009 [502]. Various FFQs [183], dietary history questionnaires [503], screeners [291,504], and 24-hour recall instruments [72,85,439] have been developed for web administration. In general, it has been found that initial response rates for web questionnaires are substantially lower than those for mailed or telephone interviewer questionnaires [505]. One study conducted in Sweden found a lower initial response rate to a web questionnaire compared to a mailed printed questionnaire but greater compliance in answering follow-up questions over the web [506]. Web-administered questionnaires may be more effective than telephone interviewer-administered questionnaires for the presentation of complex questions that are better processed visually than aurally by respondents and that can be answered at a pace set by the respondent rather than by the interviewer [507]. Beasley *et al*. [508] found that the responses to questions about diet on a web-administered FFQ were not significantly different from responses on a paper version of the same questionnaire. Dietary assessment with wireless phones is also an area of great potential. As these new modes of administration become more prevalent, it will be important to examine comparability with in-person and telephone-administered modes, as well as the potential for self-selection biases.

D Estimation of Portion Size

Research has shown that untrained individuals have difficulty in estimating portion sizes of foods, both when examining displayed foods and when reporting about foods previously consumed [88,429,437,499,509–525]. One study indicates that literacy, but not numeracy, is an important factor in an individual's ability to accurately estimate portions size [526]. Furthermore, respondents appear to be relatively insensitive to changes made in portion size amounts shown in reference categories asked on

FFQs [527]. Portion sizes of foods that are commonly bought and/or consumed in defined units (e.g., bread by the slice, pieces of fruit, and beverages in cans or bottles) may be more easily reported than amorphous foods (e.g., steak, lettuce, and pasta) or poured liquids [88,524]. Other studies indicate that small portion sizes tend to be overestimated and large portion sizes underestimated [511,523,528].

Aids are commonly used to help respondents estimate portion size. The NHANES, What We Eat in America, uses an extensive set of three-dimensional models for an initial in-person 24-hour dietary recall; respondents are then given a Food Model Booklet developed by the USDA [80] along with a limited number of three-dimensional models (e.g., measuring cups and spoons) for recalls collected by telephone. The accuracy of reporting using either models or household measures can be improved with training [529-532], but the effects deteriorate with time [533]. Studies that have compared three-dimensional food models to two-dimensional photographs in adults have shown that there is little difference in the reporting accuracy between methods [428,499,534,535]. One study in children, however, showed that using food models resulted in somewhat larger error than using digital images [521]. With the increased use of technology in dietary assessment, photographs and digital food images in multiple portion sizes are being tested. Studies have investigated the effects of a number of portion pictures, the size of picture, and concurrent versus sequential display on the accuracy of reports [88,437,520]. Such studies indicate preferences by respondents but generally little difference in accuracy. In one study, however, accuracy was higher when more portion size choices were offered [88]. An emerging use of digital technology removes respondent judgments of portion size, instead relying on digital photography of foods taken before and after consumption. Computer software is then used to both identify foods and estimate the amount consumed [536,537].

E Choice of Nutrient and Food Database

It is necessary to use a nutrient composition database when dietary data are to be converted to nutrient intake data. Typically, such a database includes the description of the food, a food code, and the nutrient composition per 100 grams of the food. The number of foods and nutrients included varies with the database. Research on nutrients, other dietary components, and foods is ongoing, and there is constant interest in updating current values and providing new values for a variety of dietary components of interest.

Some values in nutrient databases are obtained from laboratory analysis; however, because of the high cost of laboratory analyses, many values are estimated based on conversion factors or other knowledge about the food [538]. In addition, accepted analytical methods are not yet available for some nutrients of interest [539], analytical quality of the information varies with the nutrient [539,540], and the variances or ranges of nutrient composition of individual foods are in most cases unknown but are known to be large for some nutrients [541]. Rapid growth in the food processing sector and the global nature of the food supply add further challenges to estimating the mean and variability in the nutrient composition of foods eaten in a specific locale.

One of the USDA's primary missions is to provide nutrient composition data for foods in the U.S. food supply, accounting for various types of preparation [542]. Information about the USDA's nutrient composition databases is available at the USDA's Nutrient Data Laboratory home page [543]. The USDA produces and maintains the Nutrient Database for Standard Reference (SR). New releases are issued yearly; these include information on new foods and revised information on already included foods, and they identify foods deleted from the previous version of the database. The most recent release, SR24, includes information on up to 146 food components for more than 7900 foods [544], and it is available online.

Interest in nutrients and food components potentially associated with diseases has led the USDA to develop specialized databases for a smaller number of foods, such as flavonoids, proanthocyanidins, choline, and fluoride [545]. A separate database developed by the USDA Food Surveys Research Group—the Food and Nutrient Database for Dietary Studies (FNDDS)— is used by many investigators in analyses of foods reported in NHANES' What We Eat in America dietary recalls and is based on nutrient values in the USDA SR database [89].

Nutrient composition data are also compiled by a number of other countries, and the International Network of Food Data Systems maintains an international directory of nutrient composition tables [546]. Combining different food composition databases across countries poses comparability challenges, however. The European Food Information Resource [547] was formed to support the harmonization of food composition data among the European nations. The International Nutrient Databank Directory, an online compendium developed by the National Nutrient Databank Conference, provides information about the data included in a variety of databases, national reference databases, and specialized databases developed for software applications, such as the date the database was most recently updated, the number of nutrients provided for each food, and the completeness of the nutrient data for all foods listed [548].

In addition to nutrient databases, databases that can relate dietary intake to dietary guidance have been developed in the United States [549,550]. The USDA Food Patterns provide quantities of foods to consume from specific food groups in order to attain a diet consistent with the guidelines at a variety of calorie levels [551]. Just as FNDDS provides a nutrient profile for each food, the Food Patterns Equivalents Database (FPED) provides food group data for each food in FNDDS in order to allow assessment of the intake in terms of these Food Patterns. The FPED contains 32 food group components (e.g., dairy, fruits, and vegetables) and provides the amount of each food group per 100 grams of each food [552].

Other databases are available in the United States for use in analyzing dietary records and 24-hour recalls, but most are based fundamentally on the USDA SR database, often with added foods and specific brand names. One prominent such database is the University of Minnesota's Nutrition Coordinating Center's (NCC) Food and Nutrient Database [553]. This database includes information on 162 nutrients, nutrient ratios, and other food components for more than 18,000 foods, including 8000 brand-name products. The NCC is constantly updating its database to reflect values in the latest release of the USDA SR.

One limitation in all nutrient databases is the variability in the nutrient content of foods within a food category and the volatility of nutrient composition in manufactured foods. Recent changes in the sodium and fatty acid composition of manufactured foods, for example, illustrate the difficulty in maintaining accurate nutrient composition databases [554]. Obviously, a key consideration is how the database is maintained and supported.

Estimates of nutrient intake from 24-hour recalls and dietary records are often affected by the nutrient composition database that is used to process the data [555-557]. Inherent differences in the database used for analysis include factors such as the number of food items included in the database, how recently nutrient data were updated, and the number of missing or imputed nutrient composition values. Therefore, before choosing a nutrient composition database, a prime factor to consider is the completeness and accuracy of the data for the nutrients of interest. For some purposes, it may be useful to choose a database in which each nutrient value for each food also contains a code for the quality of the data (e.g., analytical value, calculated value, imputed value, or missing). Investigators need to be aware that a value of zero is assigned to missing values in some databases, whereas for other databases, the number of nutrients provided for each food may fluctuate depending on whether or not a value is missing, and for others all unknown values may be imputed.

The nutrient database should also include weight/volume equivalency information for each food item. Many foods are reported in volumetric measures (e.g., 1 cup) and must be converted to weight in grams in order to apply nutrient values. The number of common mixtures (e.g., spaghetti with sauce) available in the database is another important factor. If the study requires the precision of nutrient estimates, then procedures for calculating the nutrients in various mixtures must be developed and incorporated into nutrient composition calculations.

Developing a nutrient database for an FFQ presents additional challenges [558] because each item on the FFQ represents a food grouping rather than an individual food item. Various approaches that rely on 24-hour recall data, either from a national population sample or from a sample similar to the target population, have been used [114,138,559]. Generally, individual foods reported on 24-hour recalls are grouped into FFQ food groupings, and a composite nutrient profile for each food grouping is estimated based on the individual foods' relative consumption in the population. For this approach to be effective, the 24-hour recall data must be representative of the population for whom the FFQ is designed and connected to a trustworthy nutrient database.

F Choice of Dietary Analysis Software

Data processing of 24-hour recalls and dietary record requires creating a file that includes a food code and an amount consumed for each food reported. Computer software then links the nutrient composition of each food on the separate nutrient composition database file, converts the amount reported to multiples of 100 g, multiplies by that factor, stores that information, and sums across all foods for each nutrient for each individual for each day of intake. Many software packages have been developed that include both a nutrient composition database and software to convert individual responses to specific foods and, ultimately, to nutrients. A listing of many commercial dietary analysis software products has been compiled [548].

Software should be chosen on the basis of the research needs, the level of detail necessary, the quality of the nutrient composition database, and the hardware and software requirements [560]. If precise nutrient information is required, it is important that the system be able to expand to incorporate information about newer foods in the marketplace and to integrate detailed information about food preparation by processing recipe information (e.g., the ingredients and cooking steps for homemade stew). Sometimes the study purpose requires analysis of dietary data to derive intake estimates not only for nutrients but also for food groups (e.g., fruits and vegetables), food components other than standard nutrients (e.g., nitrites), or food characteristics (e.g., fried foods). These additional requirements limit the choice of appropriate software.

The semi-automated food coding system used for NHANES is USDA's Dietary Intake System, consisting of the AMPM for collecting food intakes; the Post-Interview Processing System, which translates the AMPM data and provides initial food coding; and the Survey Net food coding system for the final coding of the intake data [83]. Survey Net is a network dietary coding system that provides online coding, recipe modification and development, data editing and management, and nutrient analysis of dietary data; multiple users can use the software to manage their survey activities. It is available to government agencies and the general public only through special arrangement with the USDA. A similar program is available in a commercial software program called the Food Intake Analysis System [561], which is available from the University of Texas School of Public Health.

Many diet history and food frequency instruments have also been automated. Users of these software packages should be aware of the source of information in the nutrient database and the assumptions about the nutrient content of each food item listed in the questionnaire.

G Estimating Usual Intakes of Nutrients and Foods

In theory, usual intake is defined as the long-term average intake of a food or nutrient. The concept of long-term average daily intake, or "usual intake," is important because dietary recommendations are intended to be met over time and diet-health hypotheses are based on dietary intakes over the long term. Consequently, it is the usual intake that is often of most interest to policymakers (when they want to know the proportion of the population at or below a certain level of intake) or to researchers (when they want to examine relationships between diet and health). However, until recently, sophisticated efforts to capture this concept have been limited at best.

For estimates of mean usual intake in the population, data from a single day of recall or record can be used. Multiple days of recalls and records are needed to estimate the distribution of intakes. However, simple averages of intakes from these instruments across a few days do not adequately represent individuals' usual intake [562] because of the large day-to-day variability of individuals' diets. Distributions generated from averaging only a few days of data are generally substantially wider than those of true usual intakes, thereby overestimating the proportion of the population above or below a certain cut point. Sophisticated methods based on statistical modeling have evolved for this purpose [562,563]. These methods rely on a minimum of two administrations of 24-hour recalls or dietary records to capture day-to-day variation, although more administrations are better.

For clinical assessment of an individual's intake, researchers have found that averaging as many as 7-14 days of 24-hour recalls may be required to adequately approximate an individual's usual intake for most nutrients and food groups [564-567]. However, for assessing relationships between usual diet and health outcomes in a population, a minimum of only 2 days is required. Data from FFQs, 24-hour recalls, and dietary records have all been used to estimate usual intake. FFQs are limited in their ability to estimate usual intake well and are known to contain a substantial amount of measurement error (see Section II.C) [55,75,95-98,135]. Dietary recalls or records, which also contain error, provide rich detail about types of foods and amounts consumed over short time periods, and they can be used in diet-disease research if usual intakes are estimated through statistical modeling.

Statistical modeling mitigates some of the limitations of having only a few days of intake by analytically estimating and removing the effects of day-to-day variation in dietary intake [562]. The earliest efforts at statistical modeling of the usual intake were developed by the Institute of Medicine [568] for nutrients, most of which are consumed nearly every day by most everyone, and then extended and updated for nutrients or foods that are more episodically consumed (e.g., dark green vegetables) by researchers at Iowa State University [569-571]. Others have developed usual intake models as well [223,572-575]. The NCI model uses a minimum of two 24-hour recalls to estimate intake of both nutrients and episodically consumed foods. This model as well as others [223] allow for covariates such as sex, age, race/ ethnicity, or information from a FFQ to supplement the model [574]. The use of frequency information from a FFQ as a covariate in a statistical model designed to estimate usual intakes is novel. One study using the NCI method showed that including FFQ data as covariate in modeling usual intakes from 24-hour recalls increased precision for assessing the relationship of a highly episodically consumed food, fish, with blood mercury levels [224]. Modeling usual intakes to assess relationships to health outcomes by combining data from a few 24-hour recalls with an FFQ has been shown to provide better estimates compared to a single FFQ or a few 24-hour recalls alone [222,223,342]. The NCI Measurement Error Webinar Series [576] provides a thorough discussion of dietary measurement error, including usual intake estimation.

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