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Overview of Dietary Assessment Methods for Measuring Intakes of Foods, Beverages, and Dietary Supplements in Research Studies

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Abstract

Measuring the dietary intakes of individuals for research and monitoring purposes is notoriously challenging and is subject to both random and systematic measurement error. In this review, the strengths and limitations of current methods to assess dietary and supplemental exposures are described. Traditional methods of dietary assessment include food records, food frequency questionnaires, 24-hour recalls, and screening tools; digital and mobile methods that leverage technology are available for these traditional methods. Ultimately, the choice of assessment method is dependent upon the research question, the study design, sample characteristics, and the size of the sample, to name just a few. Despite their challenges, dietary assessment tools are an important dimension of nutrition research and monitoring.

Keywords

diet assessment; nutrition; measurement error; 24-hour recall; FFQ

Introduction

Accurate assessment dietary intake enables the understanding of diet effects in human health and disease and the formulation of nutrition policy and dietary recommendations (e.g., foods and diet patterns) for individuals, groups, and communities. However, accurately measuring dietary exposures through self-report are notoriously difficult to measure accurately and reliably. Traditional methods of dietary assessment include food records, food frequency questionnaires, and 24-hour recalls; digital and mobile methods that leverage technology are available for the traditional methods, and this field is quickly evolving (1). Several screening tools and diet history methods also exist.

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In general methods of assessment can be categorized based on the scope of interest (e.g. the total diet or a limited number of dietary components), study design, and reference time frame (Table 1). Short-term instruments aim to capture recent or current dietary estimates, whereas long-term instruments aim to capture dietary data for a period of weeks up to a year. Long-term or habitual dietary exposures are the most appropriate means of capturing dietary exposures in both research and monitoring of a population or sub-group (2) given that most dietary recommendations are intended to be met over time (3) to determine group or population adequacy and to determine associations with health outcomes, respectively. Nevertheless, there are certain research questions for which temporal or recent dietary exposures may be of interest, such as relating sodium intakes to blood pressure (4). Ultimately, the choice of assessment method is dependent upon the research question, the study design, sample characteristics, and the size of the sample, to name just a few (Table 1). In this brief review, methods of dietary assessment for research and their strengths and limitations will be discussed.

The Food Record

A food record is a comprehensive recording of all foods, beverages, and dietary supplements that a participant in a research study consumed within a designated period of time. Usually 3–4 days of intake are recorded as participant burden generally causes a decline in the quality of information recorded if more days are recorded. Ideally dietary intakes are weighed and measured, but are more often estimated by participants preceding and after consumption (5). Training of participants greatly enhances the accuracy of reporting. The use of food records requires a literate and motivated population. Previous reports have described reactivity as an issue with record keeping, that is changing usual dietary patterns for ease of recording or social desirability to report foods perceived as "healthy".

The 24-hour dietary recall (24HR)

A 24HR is a means to assess an individual's intake over the previous 24 hours. Ideally, multiple 24HRs on non-consecutive, random days would be collected. The 24HR has traditionally been interviewer administered over the phone or in person (6); but 24HR are also collected in person or online (e.g. Automated-Self-Administered (7)). The use of ASA-24 in general reduces interviewer burden and costs, allows the participant to answer questions at their own pace, and is free; but, may not be feasible for all study populations.

The use of probing questions aids the ease of responses and has been shown to enhance data accuracy (8). The probes include food preparation methods, additions made after preparation (i.e. condiments, butter, spices) as well as time of the eating occasion (5). Multiple 24HR are needed to account for large day-to-day variation in dietary intakes. Other factors such as day of the week (i.e. week day vs weekend), mode of interview (telephone, face to face, over the Internet), and the number and sequence of the 24HRs are known to influence reported energy intakes. Macronutrient estimates obtained from the 24HR are generally more stable than those of vitamins and minerals (9). Other dietary components, like cholesterol, are found in many foods but are not as consistent as macronutrients. Some foods and dietary components (e.g. liver and Vitamin A) are consumed in large quantities by some individuals but, rarely or never others (9). Large day-to-day variability has been reported for cholesterol, Vitamin C and Vitamin A (10, 11). For these reasons, some foods and nutrients can be accurately quantified by a few days of 24HR whereas other nutrients require upwards of weeks. As with the food record, participant motivation decreases with longer periods of assessment, leading to reduce data quality (12).

Multiple benefits of the 24HR over other dietary assessment strategies exist. First, literacy of subject is not required (if collected over the phone). Second, the 24HR allows for data collection of individuals with physical disability (e.g. blindness, lack of ability to write due to injury or arthritis). If administered by an interviewer, the recall is collected in "real time" and thus interpretation problems are minimized because subjects can clarify directly to the interviewer. This also eliminates errors in response and missing data. The recall has the potential to capture a wider variety of foods and dietary supplements that may be limited by specific dietary questionnaires or screeners. For research purposes, the 24HR is administered on random days, after the foods and beverages have been consumed, reducing reactivity.

Weaknesses of the 24HR also exist. Extensive training of the interviewer, combined with the necessary software to collect 24HR makes it an expensive technique. The expense precludes the availability of this method for large sample sizes, such as those participants in large epidemiological studies. This assessment tool relies on memory. Seasonal variability (i.e. the time of the year that the data are collected) can introduce a bias estimate of food and nutrient intakes. These and other factors contribute to within-person variation. Nevertheless, statistical tools to mitigate this within-person variation to help to make multiple 24HRs (i.e. short terms assessment methods) reflective of usual or habitual intakes have been described intakes (13–17).

Food-frequency Questionnaires (FFQ)

FFQs assess usual intake over a specified period of time, generally a longer reference period, and query how frequently a person consumes food items, often combining multiple food items with similar nutrient profiles into a category. FFQs offer a more cost-effective alternative to the 24HR because the subject usually self-completes the tool and are generally used in research studies with for large sample sizes. FFQs can be quantitative, semi-quantitative, or qualitative (18). Qualitative FFQs do not assess the amount of food that is eaten, only the frequency; the most commonly consumed portion sizes are assumed, reducing the quality of the data but this strategy also reduces participant burden. Quantitative FFQs are based on data that indicate a correlation between the frequency and weight of food data from diet records (18). Semi-quantitative FFQs query portion sizes of foods consumed, in addition to frequency (10). FFQs can be created or adapted to measure a variety of dietary components and can be nutrient-specific or foods or population specific (19–21). FFQs are intended to assess overall dietary intake or a change in intake overtime (22–24). Given that FFQs group foods and beverages together, the exact amounts of nutrients is not as precise as other more detailed methods; but, FFQs have the ability to rank order individuals in a group with regard to their nutrient exposure which is critical to examining diet and diet relationships. However, the FFQ limits the scope of foods that can be queried. FFQs are not precise to measure absolute intakes of different food components. The FFQ may create participant burden, and it may be difficult or confusing to complete. This technique requires literacy and physical ability to complete.

Screening Tools

Screening tools are generally used when specific information is desired such as dietary estimates of a particular nutrient (e.g. calcium), food groups (e.g. fruits and vegetables), or dietary fat (21, 25–30). Screening tools should be developed and validated prior to use, and should be population-specific. The time frame of various screening tools varies but is thought to generally represent the prior month or year. Similar limitations exist with screeners as described above for FFQs, but by their nature they also query only a limited number of items. However, if a narrow focus is of interest these tools provide a rapid and cost-effective method, and usually with little participant burden (31). Both FFQs and screeners also rely on generic memory rather than specific memory and may be easier to complete by some population sub-groups. The screening tools for dietary assessment previously mentioned do not represent nutrition risk screening, which is a separate category of screeners utilized primarily in clinical settings.

Accuracy of Self-reported dietary data

The accuracy of self-reported data can be assessed by comparison with recovery biomarkers or other concentration biomarkers. Recovery biomarkers are much more rigorous means to evaluate the accuracy of self-reported dietary assessment because the majority of what is consumed is “recovered”, but these biomarkers only exist for energy, protein, sodium, and potassium.

Recovery Biomarkers and Concentration Biomarkers

While all methods of dietary assessment have systematic error that tend to be in the direction of energy underreporting, the 24HR is that least biased estimator of energy intake at present (32). Previous research indicates pervasive errors in self-reported energy intakes (33–38). Under-reporting of energy intake ranges from 10 to 50% lower than estimated caloric needs in validation studies using doubly-labeled water (32, 37, 39, 40). Doubly-labeled water (DLW) studies can determine inaccurate dietary reports in weight stable individuals. DLW studies are built on the premise that energy intake is equivalent to expenditure in weight stable individuals. The overall premise is that oxygen turnover in the body is related to body water, inspired oxygen and expired carbon dioxide (41). The challenges with DLW are that it is expensive and technically difficult to perform (41) and subjects must collect multiple urine specimens and reduce travel during the study period (42). For this reason, various mathematical and statistical algorithms for physiologically impossible dietary reports have been developed to screen out implausible diet reports by comparing predicted energy expenditure to reported energy intake (38, 43–45). Recovery biomarkers, like DLW, exhibit a direct relationship with food components consumed, but are limited to energy, potassium, sodium, and protein (46). Concentration biomarkers reflect dietary intakes, but are also impacted by many other factors (31, 47, 48) and therefore, are not useful for estimating measurement error.

Concentration biomarkers reflect or correlate with dietary intakes, but because many other factors (i.e. genetics, hydration, fasting status, etc.) affect them they are not useful for addressing measurement error (31, 47, 48), but can provide valuable information for research purposes.

Sources of Measurement Error

All dietary assessment methods are subject to measurement error. The type of errors vary with the method used; error is broadly classified as random or systematic. Random error in dietary assessment is usually in the form of the large within person day-to-day variation, coming from changes in what people eat and drink every day. Random error will decrease precision of an instrument (49); lower precision compromises statistical power. Random errors, but not systematic errors, can be minimized by increasing the number of observations. Both types of errors can be reduced but never entirely mitigated if procedures are built in to an assessment method (49).

Several types of systematic measurement exist with self-reported dietary data. For example, social desirability can cause a general tendency to over-report foods that are perceived as healthy and under-report less healthy foods; however, between-individual variation in susceptibility to this tendency induces additional person-specific bias (e.g., yielding both under- and over-reporting in a group of individuals). Differential ability to assess and recall portion sizes (necessary skill for most dietary assessment techniques) can introduce additional sources of person specific bias that is unpredictable, but may be related to factors like age or gender (50). Individuals employ various strategies to recall portions sizes including visualization, estimations, and the use of measurement aides (e.g. food models) (51) (52). Research indicates subject training yields better portion estimation of some foods (53) (54). Likewise, interviewer bias can also be introduced by the researcher or the method used to collect and enter dietary data (49). Finally, all estimates of dietary intakes rely on the accuracy and currency of the food composition databases used to translate the reported intakes to energy and nutrient amounts.

Both types of errors can be reduced but never entirely mitigated if procedures are built in to an assessment method (49). Taken together, both types of measurement error tend to attenuate diet and health relationships and decrease statistical power; but, when appropriately accounted for yields significance testing that while less powerful to detect relationships is still valid for drawing inferences (3).

Dietary Supplements

Traditionally, studies investigating diet and health relationships have failed to include nutrient exposures from dietary supplements. However, more than half of US adults and one-third of children use DS and because DS are not restricted by energy, the majority of these products contain higher amounts of nutrients than are usually found in foods (55–59). Given the pervasive use of dietary supplements, collecting information on their use is critical. Dietary supplement use can be measured using the same techniques as dietary assessment of foods and beverages but much less is known about measurement error in self-report of dietary supplements (60). A supplement product inventory is perceived as the gold-standard.

A product inventory usually occurs through a home visit or when a participant brings all supplement containers to a scheduled visit with trained research professional. The interviewer records all information relevant from the supplement label including the name, manufacturer, dose/amount per serving, and form (e.g., tablet, powder, or liquid). This information is then combined with self-reported information, such as how often, in what doses, and for how long a supplement has been used. Rarely is such a level of detail collected in research studies.

Supplements, like multivitamin-minerals are generally consumed daily; but other product types can be consumed episodically, complicating accurate assessment of usual intakes. Most databases for DS rely on label declarations that introduces another source of error because analytical estimates are often higher than labeled amounts especially for certain nutrients (61–63). Exposure to nutrients can come from other sources like prescription drugs (e.g., niacin or omega-3 fatty acids), over-the-counter medications (e.g., antacids), minerals found in tap and bottled water (e.g., sodium or other minerals) and vitamin D produced from UV exposures; these sources may contribute substantially towards total nutrient intakes (64–67).

Summary

The most common methods used in nutrition research are the diet record, 24HR, and FFQ. Each method has benefits and drawbacks; however, the 24HR is the most accurate means to assess food and nutrient intake at present. Given the episodic nature of our food choices, utilizing a combination of methods has been preferred for both foods and beverages (68) as well as dietary supplements (69). All dietary assessment techniques are prone to both random and systematic measurement error. Furthermore, these techniques require motivation, honesty, and memory of the research participants as well as skillful interviewing and careful instrumentation by investigators. The choice of which method to utilize can be determined based on several factors, such as those described in Table 1. Even though dietary assessment tools have measurement error, it does not render them unimportant for research, monitoring, and policy settings (46).

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Abbreviations:

24HR	24-hour dietary recall
ASA-24	Automated-Self-Administered
FFQ	food frequency questionnaire

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Table 1.

Comparing Self-Reported Dietary Assessment Methods across Various Dimensions of Interest[1]

		24-Hour Recall	Food Record	Food Frequency Questionnaire	Screener or History
Scope of interest	Total diet	X	X	X	
	One or a few components			X	X
Time frame of interest	Short term	X	X		
	Long term			X	X
Can be used to query diet in distant past	Yes			X	X
	No	X	X		
Allows cross-cultural comparisons	Yes	X	X		
	No			X	X
Main type of measurement error	Random	X	X		
	Systematic			X	X
Potential for reactivity	High		X		
	Low	X		X	X
Time required to complete	<15 minutes				X
	>20 minutes	X	X	X	
Memory requirements	Specific	X			
	Generic			X	X
	None		X		
Cognitive difficulty	High			X	X
	Low	X	X		
Study Design	Cross-sectional	X	X	X	X
	Retrospective			X	X
	Prospective	X	X	X	X
	Intervention	X		X	X

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