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SECTION 2

Methods of Evaluation: Dietary Methods

CHAPTER 4

Measuring Nutrient Intake

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CHAPTER OUTLINE

LEARNING OBJECTIVES

After completing this chapter, the reader should be able to:

1. Discuss the relationship between diet and health.
2. List the methods for measuring usual diet intake.
3. Describe the methods for measuring food and nutrient intake.
4. Explain the various challenges encountered with diet assessment methods.
5. Explain methods for measuring and estimating portion sizes.

Introduction

Nutrient intake is a major factor in health and nutritional status. Measuring an individual's nutrient and dietary intake can be extremely difficult and labor intensive. Many factors can affect the reliability of dietary assessment methods. One factor that influences the reliability of data used in nutrition-assessment methods is that nutrition professionals frequently rely on information provided by individuals other than actual patients or clients. Aside from that, self-reported intake has a tendency to differ from actual intake. Memory recall and portion-size errors may create systematic errors in intake measurement.[1]

In this chapter, we will discuss the relationship between diet and disease, as well as the various methods for measuring nutrient intake, their strengths, and their limitations. Challenges involving measuring nutrient intake such as reliability or reproducibility and validity will be reviewed.

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Relationship Between Diet and Health

Preview Researchers seek to measure nutrient intake for various reasons. Food and nutrition are important components of health at both the individual and population levels. Monitoring and evaluating eating patterns is important when assessing the effectiveness of public-health interventions to improve diet and health.

Nutritional Epidemiology

Nutritional epidemiology is a sub-discipline of epidemiology that provides data about the relationship between diet and disease. The data collected is used to define diet–disease associations that are converted into the practice of prevention by public-health nutrition practitioners.[2] Nutritional epidemiology is the study of the nutritional factors that contribute to disease in human populations.

Dietary intake normally includes all foods and beverages consumed via the oral cavity. Clinicians such as registered dietitian nutritionists (RDNs) and public-health practitioners measure dietary intake in efforts to acquire quantitative data on the quantities of energy and nutrients accessible for metabolism. Measuring dietary intake is a way of describing the actual food intake of both individuals and groups.[3]

Data collected from dietary intake records are vital in determining relationships between diet and health as well as relationships between diet and disease. For instance, data on food intake and the use of supplements before and during pregnancy helped define the association between low intake of folic acid and neural tube defects in offspring; this was later determined to be a causal relationship.[1,4]

In addition, dietary data are important to assist researchers in identifying populations at risk for inadequate nutrient intake, whether deficiency or excess. Information gathered from research studies can be used to develop interventions, programs, and policies that can aid in health education and promotion.[5]

Recap Collecting dietary intake data is an important component of monitoring individuals and community health.

Methods for Measuring Usual Dietary Intake

Preview Researchers, RDNs, nurses, and other healthcare professionals use various methods to measure food intake. Each method has its own advantages and disadvantages. Study design and characteristics of study participants are also presented.

Research Design

Research falls into two major categories of design type: observational and experimental.[6] Observational studies include cohort, cross-sectional, and case-control. Experimental studies include randomized controlled trials (RCTs). Observational study designs are widely used in studies measuring nutrient intake. **Cohort** studies are generally used to identify factors that may cause a disease to develop in a certain group over time—that is, the natural history of disease development.[6]

Studies can be either prospective or retrospective. A prospective analysis involves observing a group of subjects over an extended period of time to predict an outcome. A retrospective study—also known as a *historic cohort study*—is a study design in which a cohort

of individuals is categorized as either having some outcome (case) or not (control). The outcome of interest might be a disease and the medical history associated with that outcome.[7] These research designs are used to collect dietary data. Tools such as **24-hour recall** record, a **food-frequency questionnaire (FFQ)**, or a **food record** are often used to collect nutrient-related data.

In a **longitudinal study**, data are repeatedly gathered for the same subjects over a determined period of time. Longitudinal research projects can extend over many years or decades. For example, the Framingham study is the first longitudinal study that followed a large cohort of subjects to study the etiology of cardiovascular diseases in the United States.[8,9]

The origin of the Framingham study is closely linked to the cardiovascular health of President Franklin D. Roosevelt, who died prematurely from hypertensive heart disease and stroke in 1945.[8] In the year 1948, 5,209 men and women from Framingham, Massachusetts formed the original cohort to identify heritability of cardiovascular diseases and related risk factors.[9] The cohort has contributed to the current understanding of cardiovascular disease and its risk factors.[8]

In healthcare research, a cross-sectional study (also referred to as a *cross-sectional*, *transversal*, or *prevalence study*) is a category of observational study that examines data collected from a population or from a representative subset at a specific point in time.[6] It typically represent a "snapshot" of the group of interest, including exposure to a specific risk factor, disease outcome, and distribution patterns. Dietary data collected on cross-sectional samples provide information that can be applied to the health and dietary habits of general segments of the population. The diet assessment tool of choice for cross-sectional studies is the 24-hour recall. The National Health and Nutrition Examination Survey (NHANES) is a cross-sectional study in which a sample of the population ages 1 to 74 years was examined in the early 1970s to look at the health and habits of Americans.[10] Subsequent cross-sectional NHANES surveys have been carried out periodically, and the data have been used to examine associations among variables such as dietary intake and prevalence of risk factors for chronic diseases. Health planners depend on disease-prevalence information to allocate sufficient resources to ensure adequate population care.

Cohort studies are used to estimate the incidence of a condition—that is, the proportion of the population susceptible to developing a disease over time. Cross-sectional studies provide information about the prevalence of a specific outcome to describe the proportion of the population that have a disease or demonstrate a specific outcome at one point in time.

Studies done for **case control** retrospectively compare subjects that have an illness or an outcome of interest (cases) to individuals who do not have the condition or the desired outcome (controls). This type of study compares how the frequency of exposure to a risk factor present in the case and control groups determines the relationship between the risk factor and the disease.

Case-control studies are observational because no intervention is tried and no effort is made to modify the development or progression of the disease. These studies are intended to estimate odds.[6]

In both the cohort and case-control studies, the groups are matched or correlated to disease causes. These studies help outline how factors in the past contribute to an existing disease. Nutrition assessment tools used to measure nutrient intake in these types of studies include FFQs. A study by Jansen et al. examined the relationship between fruit and vegetable consumption and pancreatic cancer[11] using a case-control design. The study matched 1,648 patients to 1,514 control subjects from an overall 2,473 patients from a database of patients with pancreatic adenocarcinoma cases. Both groups completed food-frequency questionnaires (FFQs) defining intakes of fruits and vegetables. The results pointed to a statistically significant inverse association between vegetables, fruits, and dietary fiber consumption and pancreatic cancer occurrence.[11]

Characteristics of Study Participants

Dietary assessment methods are used to measure nutrient intake in a variety of populations, including children, adults, and the elderly. Segments of research populations have different learning needs and concerns that may impact measuring intake in these groups. Factors that should be considered when determining the best research method to use for collecting data with each group include communication, literacy level, and memory. These constraints dictate the most appropriate dietary assessment method for data collection. For individuals who have difficulty communicating or who may experience memory loss, dietary data may need to be collected from another person, such as a parent, a child, or a spouse.[12]

HIGHLIGHT

NHANES and Nutrition Data

The website for the Centers for Disease Control and Prevention (CDC) offers an orientation tutorial on NHANES dietary data survey.

The survey orientation course provides five modules:

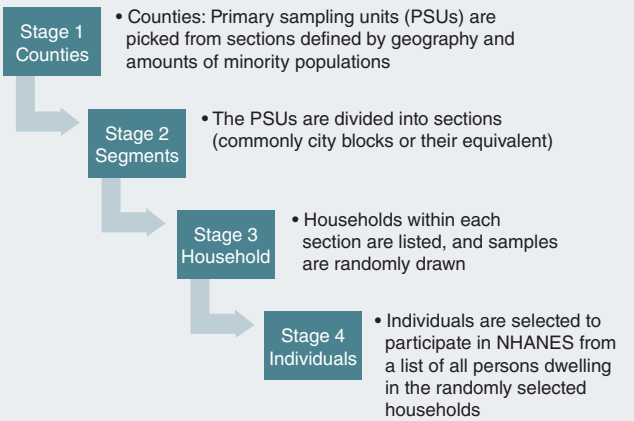
- Dietary Data Survey
- Navigate NHANES website
- Dietary Data Structure and Contents
- Resources for Dietary Data Analysis
- Overview of NHANES Survry Deesign and Weighting

These modules offer a broad synopsis of the dietary data collected by the NHANES, the NHANES website, the structure and contents of NHANES dietary data, supplementary databases and tools that can be used to prepare dietary analyses, and the NHANES survey design and weighting principles.

The NHANES sample is intended to be nationally representative of the civilian, noninstitutionalized American population. The sample does not include data from institutionalized individuals or those who live overseas.

A multifaceted, multistage probability sampling design is used to identify study participants. The NHANES sampling procedure consists of Four stages.

NHANES Sample Selection Process



Modified from Center for Disease Control and Prevention. Dietary Data Survey Orientation. https://www.cdc.gov/nchs/tutorials/dietary/SurveyOrientation/intro.htm Accessed July 25, 2017.

In some cases, meal observations may be required, as in the case of extremely young children or older adult populations. The 24-hour recall, FFQs, and food records have been used in research studies involving children. For individuals who have literacy challenges, the 24-hour recall or the administered FFQ has been the most effective.[12]

Factors Affecting Method Selection

Measuring nutrient intake in research studies can be an expensive process from both a monetary and human resource standpoint. The 24-hour recall method requires a trained research interviewer to conduct the recall. This method is labor intensive, and the training for the interviewer can be expensive. In addition, there is daily variation in the reported food intakes, so repeated 24-hour recalls need to be used to control for systematic error measurement.[6] The use of food records requires that research study subjects be trained to complete their intake in the food-record tool. Both the 24-hour recall and food records are demanding because individuals must enter data into a computer for nutrient analysis. Some researchers have found that multiple food records may need to be considered as replacements for multiple or repeated 24-hour recalls because of the reduced respondent burden of memory recall.[13] Another method, the FFQ, can be self-administered,depending on the skill level of the study participants. This questionnaire is least labor intensive because the responses are recorded on a form and then scanned into a computer for analysis.

Overall, for studies requiring a smaller number of subjects, either the 24-hour recall or food record is the preferred method. For large-scale research studies, the FFQ serves as the most appropriate method commonly used.[14]

VIEWPOINT

Social Determinants of Health and Their Impact on Obesity

Diane R. Bridges, PhD, MSN, RN, CCM

Obesity in the United States can be considered an elusive epidemic. The prevalence of obesity for both adults (those age 20 years and older) and children has been shown to be high in the United States.[1] More than one-third of the adult population is obese, along with one in six children considered obese.[2,3]

Obesity is a condition that crosses many demographics such as ethnicity, gender, and age. Middle-aged and older persons have a higher prevalence (40.2%); 38.8% of women between ages 40 and 59 years were found to be obese.[1] Non-Hispanic black and Mexican American women were found to have a risk of obesity that is twice that of non-Hispanic white women.[4]

Vaccinations are available to treat many viral illnesses, but there is no vaccination to prevent or erase obesity.[5] It can affect the development of chronic diseases from pure physical stress to inflammatory processes, diabetes, arthritis, cardiovascular disease, and other chronic conditions.[4] In addition, the medical costs to treat obesity were shown to be $147 billion annually.[6]

What causes obesity? Many people think obesity can be attributed solely to poor nutrition; typically, the consumption of processed packaged foods high in fructose is to blame. Others contend, however, that a lack of activity and a sedentary lifestyle lead to obesity.[7]

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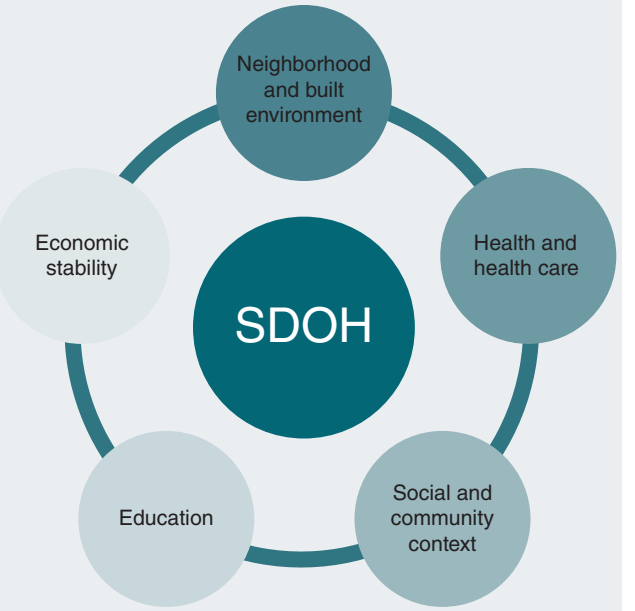

FIGURE A Social determinants of health (SDOH) impact one's risk of obesity

Reproduced from Healthy People 2020. U.S. Department of Health and Human Services. https://www.healthypeople.gov/2020/topics-objectives/topic/social-determinants-of-health.

Still others say genetics, race, and ethnicity may all contribute to obesity.[5]

But these are not the only things that affect the rise of obesity. It is the social determinant of health of an individual impact one's risk to obesity as well (see **FIGURE A**). Social determinants of health are "the structural determinants and conditions in which people are born, grow, live, work and age."[8] Income, education, employment, support, stress, food accessibility, transportation, age, race, and ethnicity are all in some way social determinants of health.

Efforts to manage obesity have included education, placing nutritional labels on food packaging, posting nutritional information in restaurants, improving urban development, improving accessibility to food choices, taxing sugared drinks, and policy development.[5] These efforts appear to have had little impact on the prevalence of obesity and adults continue to self-report as obese even in light of their knowledge about the risk of obesity.[5] We need to take on strategies to lower rates of childhood obesity through improved nutritional choices in school, increased physical activity, and allocating more resources to address this important issue.[9]

We need to continue to raise awareness of obesity and other issues in the communities we serve. Students need to be educated in the social determinants of health so they can then become part of the solution.

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One must become involved in helping to improve the lives of our population by addressing issues that can be prevented.

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Recap Researchers use a variety of diet-assessment methods to collect, measure, and analyze nutrient intake. The selection of the assessment tool is primarily determined by the study goal.

Methods Designed to Measure Food and Nutrient Intake

Preview Measuring nutrient intake can help researchers and care providers across the healthcare spectrum explore the association between diet and disease, determining whether a causal relationship exists between diet and disease, and whether past factors have contributed to current diseases.

Dietary assessment data can reveal information about the long-term past, short-term or immediate past, and current dietary habits. Three types of dietary assessment methods are commonly used: the 24-hour dietary recall, the food record, and the FFQ. Each method has its own purposes in collecting dietary data, along with several advantages and limitations.[14] **FIGURE 4.1** is an example of a 24-hour FFQ.

24-Hour Dietary Recall

One common method for assessing dietary intake is the 24-hour dietary recall. This dietary recall is based on verbal self-reports concerning everything a person ate and drank during a specified time period—the past 24 hours. The interviewer is responsible for recording the dietary data for analysis. Based on this information, generalized assumptions about the individual's eating habits are made. During the interview,

Date:

Name:

Instructions: In the past three (3) months did you consume the foods listed below?						
Food Group	**Frequency**					
	Never	Less than one time per week	1-6 times per week	1-3 times per day	4 or more times per day	Serving size
Dairy: milk, cheese, yogurt						
Chicken: grilled chicken, baked chicken, fired chicken, etc.						
Turkey: turkey sandwich, soup, breast, roasted, etc.						
Beef: meatballs, steak, etc.						
Pork: cured ham, fresh ham, ribs, pork chops, pulled pork, etc.						
Fish and seafood: shrimp, scallops, fish, shellfish						
Other Meat: lamb, duck, etc.						
Nuts: walnuts, cashews, peanuts, etc.						
Beans: red beans, chick peas, chili, etc.						
Egg: omelet, hard-boiled egg, etc.						
Vegetables: broccoli, cauliflower, green beans, etc.						
Fruit: banana, strawberry, apple, pear, melon, etc.						
Grains: rice, bread, cereal, etc.						
Sweets: cakes, cookies, pies, etc.						
Beverages: coffee, tea, sodas, juices, etc.						

FIGURE 4.1 Example of a 24-hour food-frequency questionnaire

Data from Poulain JP, Smith W, Laporte C, Tibere L, Ismail MN, Mognard E., Aloysius M, Neethiahnanthan AR, & Shamsul AM. Studying the consequences of modernization on ethnic food patters: Development of the Malaysian Food Barometer (MFB). Anthropol food. 21 April 2015. Accessed online 26 February 2017 https://aof.revues.org/7735.

the interviewer assists the subject in recalling everything that was consumed during the specified time period. In addition, the interviewer helps the subject estimate the portion sizes of all consumed food items and beverages. The interviewer typically prompts subjects to recall everything they ate in a 24 hour period usually beginning at midnight. During the interview, the subjects are often asked about their activities during the day to facilitate their ability to remember everything they ate or drank during the previous 24 hours. Typically, the researcher reviews the information collected with the subject to ensure that all of the required information has been recorded and to identify errors. Once the data are collected, they can be analyzed using a diet-analysis computer software program.[14]

The 24-hour recall tool can be used in clinical, research, and community settings. It is frequently used in the clinical setting because it has been found to help improve the accuracy of the data reported. With the advent of digital technology, the use of this tool reduces the burden on the respondent.[15–17]

Advantages

Regardless of the care setting, the 24-hour recall method has a number of advantages. First, the 24-hour recall is relatively quick and convenient.[18] It is typically inexpensive and places little burden on the subject, who is more willing to respond. Refusals to answer requests for data in this format are less likely. One of the main strengths of the 24-hour recall is that it facilitates comparisons among population groups while describing their unique dietary intakes.[18,19] For example, the NHANES 24-hour recalls have been used to collect data on two consecutive days for describing populations' nutrient intake and group comparisons for identifying relationships between food and diseases between and within groups.[19]

Because this method relies on short-term memory, usual diet and eating habits are less likely to be altered.[18] The 24-hour recall is considered more objective and the preferred method among diet assessment methods.[20,21]

Limitations

Several limitations have been identified using the 24-hour recall method. These methods are not specific to the clinical setting. An individual's diet intake may vary from day to day, and a 24-hour period may not represent daily variation, which is why collecting data on two nonconsecutive recalls is a best practice when using the 24-hour recall to estimate usual daily dietary intake.[22] To manage limitations, multiple 24-hour recalls on nonconsecutive days be conducted before applying the results to the individual's regular eating habits.[23]

Inaccurate reporting has been identified as another limitation of the 24-hour recall method. Both overreporting and underreporting of actual food intake is common and may occur for various reasons, including inaccurate memory recall, distorted perceptions of portion sizes, and deliberate misreporting to avoid social stigma.

Evidence shows there are gender differences related to the inaccuracies seen in reporting intake on 24-hour recalls.[24] Females have a higher rate of underreporting food intake than males. Among overweight and obese adults, more 24-hour recalls are needed for women than men to reflect an accurate estimate of food intake. As previously mentioned, to control for underreporting systematic biases, collecting data with multiple-pass 24-hour recalls is recommended.[24,25]

The 24-hour recall requires the interviewer and respondent to evoke the previous day's intake several times to obtain accurate information.[25] Depending on the research question, the interviewer might explore facts such as food-preparation methods and the composition of mixed dishes. The quantities of each food consumed are appraised in reference to a commonly used size container such as cups and glasses, standard measuring utensils such as cups and spoons, three-dimensional food models, or visual aids such as food pictures. One advantage of the 24-hour recall is that little burden is placed on the subject. Conversely, one limitation is that data collection depends on the subject's memory and the proficiencies of a well-trained interviewer to diminish recall bias.[14] To reduce limitations and ensure the accuracy of the data collected, adequate, intensive, and thorough training of interviewers is recommended.[26] **TABLE 4.1** shows the advantages and limitations of the 24-hour recall method.

TABLE 4.1 Advantages and limitations of the 24-hour recall method

Advantages	Limitations
Quick	Diet variation
Convenient	Inaccurate reporting
Inexpensive	Misreporting
Relies on short-term memory	
Does not alter the diet	

Modified from Shim J-S, Oh K, Kim HC. Dietary assessment methods in epidemiologic studies. Epidemiology and Health. 2014;36(e2014009). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4154347/. Accessed May, 1, 2017.

Food Record: Diary

The food record or food diary is a subjective dietary intake collection method that relies on the use of open-ended, self-administered questionnaires (see **FIGURE 4.2**). This tool is used to attain detailed information about all foods and beverages consumed over a specified period of time, which can be one or more days.

This open-ended tool offers clinicians and researchers few limitations as to how many items can be inquired about. Normally, subjects are asked to record foods and beverages as they are consumed throughout the day. This is a real-time accounting of their intake. Data collected can include the consumption of dietary supplements. Multiple administrations of a specified number of days are frequently used.

Usually, study participants are provided with a form to record their intake. Oral or written directions (or both) are provided to help participants record pertinent details for all foods and beverages they consume (such as brand name, preparation method, and where consumed). Portion size is either estimated using food models, pictures, or other visual aids; or it is measured using weight scales or volume measures.

The use of food records is widely used not only in research but also in the clinical setting. The information recorded is used to develop nutrition care plans.

Food records or diaries can take different forms. The most simple and cheapest form includes a blank notebook that is small enough to be carried around throughout the day. Typically, when filling out a food diary, the individual estimates meal portion sizes using household measuring utensils such as cups and spoons or measurement scales.[18]

Food Diary

Use this chart to track the foods you eat over the week. Write in the foods you eat and mark the corresponding check boxes for each serving from a food group to track whether you are meeting recommended servings. Don't forget to include beverages.

	SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
Milk & Milk Products Vegetables Fruits Grains Meat & Beans	○○○ ○○○ ○○ ○○○○○○ ○○	○○○ ○○○ ○○ ○○○○○○ ○○	○○○ ○○○ ○○ ○○○○○○ ○○	○○○ ○○○ ○○ ○○○○○○ ○○	○○○ ○○○ ○○ ○○○○○○ ○○	○○○ ○○○ ○○ ○○○○○○ ○○	○○○ ○○○ ○○ ○○○○○○ ○○
Breakfast							
Snack							
Lunch							
Snack							
Dinner							
Evening Snack							

FIGURE 4.2 Example of a food diary

Reproduced from: National Council of California. http://www.healthyeating.org/Healthy-Eating/Healthy-Living/Weight-Management/Article-Viewer/Article/230/Food-Diary.aspx. 2012. Accessed 27 February 2017.

The record includes measures of dietary intake and fluids consumed at breakfast, lunch, and dinner; as well as snacks.

Innovative approaches for evaluating dietary intake are vital in effort to decrease subjects' strain in completing dietary surveys, increase participation rates and thus improve the sample size. It is also important to decrease the effect of quantifying dietary intake on a subject's food choices during the recording period. One method of decreasing the burden placed on those logging dietary intake is to substitute the weighing of foods with approximations of portion size by using tools such as food photographs.

An additional form of food diary that is increasingly popular uses technology-based programs, many of which offer online websites and phone applications (apps) that make logging food intake easy and convenient. Among these programs are MyFitnessPal, Fitbit, MyPlate, and Lose It! Typically, the apps are downloaded to a smartphone where individuals track their food intake. Some programs allow users to digitally scan barcodes on food packaging for quick item entry. Other apps allow users to take pictures of their meals and have the app estimate portion sizes. Technology-based records also allow users to save a favorite or frequently consumed food to minimize the search time when entering items in the food database.

Advantages

There are several advantages of food records. For one, they do not rely on an individual's memory, because the data are recorded at the time of consumption.

Young adults prefer technology-based food diaries because they are more accessible and convenient. Kerr et al. found that digital and image-based diet food records could lead to improved cooperation and motivate participants to engage in behavior change such as losing weight, suggesting that digital food diaries may be a useful tool for future health interventions.[11]

Limitations

Using a food record or diary also has several limitations, regardless of care setting. First, the timing of collecting and recording dietary intakes may be atypical for a participant's regular food intake.[18] Second, subjects who agree to complete a food record may not be representative of the study's target population. Third, completing a food record requires a high literacy level, perhaps excluding those who are not proficient in English. Lack of language proficiency can be an important limitation to consider, because the participant's ability to understand instructions on recording food intake will influence the quality of record keeping.[31] Fourth, this method requires detailed documentation, which may cause individuals to either not fully complete the record for the entire specified time period or cause them to reduce the number of foods eaten. Likewise, the method requires a high level of cooperation, commitment, and compliance.[32] Fifth, the method may alter an individual's diet; participants may decide to eat simpler meals to make record keeping easier, thus eliminating snacks or sugar-sweetened beverages.[32] Sixth, food records provide data on current diet, whereas food intake in the past may be dissimilar. Finally, the method is labor intensive and expensive because of the high cost of training interviewers, administering the tool, and data analysis. **TABLE 4.2** shows the advantages and limitations of food diaries.

Food-Frequency Questionnaire

FFQs consist of an extensive list of foods and beverages with a range of consumption frequencies that participants can select from for each food. Serving sizes may or may not be present.[18] To evaluate the actual true diet, the number of foods and beverages probed usually ranges from 80 to 120. FFQs are normally created for each study group and research question to ensure that specific characteristics such as ethnicity, culture, an individual's preferences, economic status, and so on are identified. Depending on the interests of the investigator, FFQs can emphasize the collection of data for a specific nutrient and nutritional exposures linked to a disease process, or they can comprehensively assess various nutrients.[22] Through their responses, respondents state how many times a day, week, month, or year they usually consume the foods in question. Although some FFQs include portion sizes, most use a standard portion size based on an amount per serving for a specific age and gender group.[33,34]

There are three basic types of FFQs: the nonquantitative, the semiquantitative, and the quantitative FFQs.[18] The simple or **nonquantitative FFQ** asks respondents how frequently they consume a certain food item per day, week, month, or year; portion sizes are disregarded.[34]

The **semiquantitative FFQ** includes a list of food items, each accompanied with predefined portion sizes, and asks respondents how many times a day, week, month, or year they eat a certain food item (**FIGURE 4.3**).[35]

An FFQ can be used in both clinical and community settings because of its low administration cost and respondent burden. Also, it can be used to measure long-term intake as well as usual intake.[36]

The **quantitative FFQ** asks respondents to describe the daily frequency of food consumption and record the portion size of their serving according to their usual habits.[18] In some instances, respondents are asked to define the portion serving size as small, medium, or large.[37] The usefulness of questions in FFQs related to portion size has been controversial. Some researchers support that between-person deviations in portion size are not significant, because the variation seems to be smaller than the variation in frequency of eating the item.[38] FFQs are normally self-administered. Interviewer administration is done sporadically, usually in cases of low literacy.[18] Once the form is completed, it can be scanned and responses can be downloaded into a computer for analysis.

Three FFQs are widely used in nutrition epidemiological studies: the Harvard Willett Questionnaire, the Block Questionnaire, and the Diet History Questionnaire. The 131-item Harvard Willett includes items such as major sources of nutrients and

TABLE 4.2 Advantages and limitations of a food-frequency questionnaire

Advantages	Limitations
Does not rely on memory Provides detailed dietary intake data Can provide personalized dietary feedback	Timing of data collection may not be feasible High literacy level required High response burden on participants Labor intensive

Modified from Johnson RK, Yon BA, Hankin JH. Dietary assessment and validation. In: Monsen ER, VanHorn L, eds. Research Successful Approaches. 3rd ed. Chicago IL: Diana Faulhaber; 2008:187–204.

How often, in the past 3 months, did you eat the following?	never	Less than 1 time per week	1-6 times per week	1-3 times per day	4 or more times per day
Dairy (cheese, milk, yogurt, etc.)					
Chicken (fried chicken, in soup, grilled chicken, etc.)					
Turkey (turkey dinner, turkey sandwich, in soup, etc.)					
Fish and Seafood (tuna, shrimp, crab, etc.)					
Pork (ham, pork chops, ribs, etc.)					
Beef (steak, meatballs, in tacos, etc.)					
Other Meat (duck, lamb, venison, etc.)					
Eggs (omelet, in salad, in baked goods, etc.)					

FIGURE 4.3 Example of a weekly food diary

Reproduced from: National Council of California. http://www.healthyeating.org/Healthy-Eating/Healthy-Living/Weight-Management/Article-Viewer/Article/230/Food-Diary.aspx. 2012. Accessed 27 February 2017.

foods of interest.[39] Open-ended questions are used to identify brands of margarine, cooking oils, vitamin or mineral supplements, ready-to-eat cereals, and other foods consumed one time a week. The Harvard Willett questionnaire has one standard portion size for each food item, and respondents are asked to indicate the relative frequency of consumption from nine different response alternatives ranging from less than one time per month to six or more times per day.[39] The self-administered questionnaire is best used in circumstances where intake of simple sugars, sweet foods, and fructose is of major concern.[18]

The 60-item, semiquantitative Block Questionnaire was originally developed by the National Cancer Institute. As a self-administered tool, it can be used in two ways: pen and paper and web based.[39] Several versions to address the needs of many subpopulations such as children, adolescents, adults, and dialysis patients have been developed, as has a Spanish version. Food screeners for adults address nutrients such as sodium, fiber, sugar, and folic acid as well as food groups such as fruits and vegetables.[40] Respondents are asked to estimate their consumption frequencies—daily, weekly, monthly, yearly, rarely, or never—by indicating the exact number of times each food was eaten.[39] Participants also must indicate whether their usual portion size is small, medium, or large compared with a standard.[18,39] For children and adolescents, the Block Kids Food Screener has been used for ages 10 to 17 years. It assesses the intake by food group.[41] Other FFQs used in children and adolescents are Block Questionnaires for ages 2–7 years and 8–17 years, English and Spanish versions, and Block Food Screeners for ages two to 17 years.[42]

To assist participants in estimating the portion sizes, the questionnaire may be accompanied by different sample portion sizes of each food item, geometric models, or food photographs in three portion sizes.[18] Completed questionnaires are checked for accuracy and completeness. Daily intakes of energy and nutrients are estimated by multiplying frequency responses with the specified portion sizes and the nutrient values assigned to each food item in the nutrient database. No information on dietary supplements is usually collected.

A comparison between the Block and Willett questionnaires showed that the Block instrument yielded an overall underestimation bias. The comparison also showed that the Block questionnaire was more accurate in calculating the participants' percent intake of energy from fat and carbohydrate. The Willett questionnaire, in turn, showed no overall underestimation bias and was accurate in determining the intake of vitamin A and calcium.[39]

The Diet History Questionnaire is another self-administered instrument and includes 124 questions about such items as portion sizes and nutrition supplement intake.[43] The questionnaire was developed by the US National Cancer Institute's Risk Factor Monitoring and Methods Branch. This tool is also available in print and web forms.

TABLE 4.3 shows the advantages and limitations of FFQs.

Advantages

Regardless of the setting, the FFQ method can be self-administered, takes little time to complete (30–60 minutes), and places minimal burdens on study participants.[44] Administrating this tool to large population groups is inexpensive and can assess current or past diet. The short versions can focus on precise nutrients with few food

TABLE 4.3 Advantages and limitations of a food-frequency questionnaire

Advantages	Limitations
Self-administered Inexpensive Representative of usual intake	Relies on memory recall Consumption is not quantifiable Lack of homogeneity in food choices

Modified from Adamson AJ, Collerton J, Davies K, et al. Nutrition in advanced age: dietary assessment in the Newcastle 85+ study. *Eur J Clin Nutr*. 2009;63(S1):S6-S18.

sources. Data received from this method are representative of usual intake and capture habitual food intake. The advantages listed make the FFQ the preferred method for evaluating diet–disease relationships in epidemiologic studies.[45]

Limitations

Data collected through the use of FFQ have non-negligible limitations and are not unique to one particular care setting. Facts generated are subjective because of reliance on participant memory recall.[44] Unlike the 24-hour recall and food record methods, that are completed soon after the food is eaten, FFQs describe average consumption and are not as quantifiably precise. Information such as food preparation, specific food and beverages consumed, and brand names for products is not recorded. Because FFQs consist of a prespecified food list, no one single FFQ could reflect the eating patterns of a given population. The use of a FFQ in one group of participants is not transferable to a different population.[46] Moreover, FFQs are limited to 150 items that may not represent the usual foods of respondents or provide meal-pattern information.[44] Another major limitation in interpreting data from FFQs is the absence of consistency in food-composition tables.[46]

FIGURE 4.4 shows different ways to estimate portion sizes.

Measuring and Estimating Portion Sizes

Why Do Portion Sizes Matter?

Portion size can be defined as the total amount of food one chooses to eat at a single eating occasion regardless of the location and meal (home, restaurant, lunch meal, or snack).[47] The inclusion of portion sizes in 24-hour recalls, food records, or FFQs is important because it may lead to greater consumption of certain foods and explain within- and between-person variations.[14] Figure 4.4 shows an example of methods used to measure portion sizes. Considerable evidence indicates that portion sizes have increased incrementally over the last three decades, contributing to the rising incidence obesity and chronic diseases.[14,47–49] Rolls et al. showed that excess energy intake is portion-size dependent in that larger portions of food led to greater food consumption across adult men and women.[48] In this study, participants consumed 30% more energy when offered larger portion sizes of an entrée on one day compared to smaller portion sizes offered on another day. Portion sizes also influenced the energy intake of children three to five

HIGHLIGHT

Technological Advances in Diet-Assessment Methods

Nutrition-assessment methods have been used in the United States since the early 1900s. These methods have evolved from traditional paper-and-pencil ways to computer and digital methods. The National Institutes of Health has sponsored several projects that focus on improving food records using mobile phone apps.

One project, the Technology Assisted Dietary Assessment (TADA), has developed algorithms to allow the use of a single image (picture) in estimating food volume. TADA uses a standard or point of reference within the image to fragment the different food components on the plate. When the location and identification of each food item is recognized, the volume of food is identified. The volume-assessment procedure used by TADA involves categorizing each picture section into a geometric class such as a sphere, cube, or mound and then developing measurements from the image and employing a formula to calculate volume. These calculations can be conducted using a handheld device. TADA have been used to determine the accuracy of food-volume estimation.

Data from Stumbo PJ. New technology in dietary assessment: a review of digital methods in improving food record accuracy. *Proc Nutr Soc*. 2013;72(1):70–76.

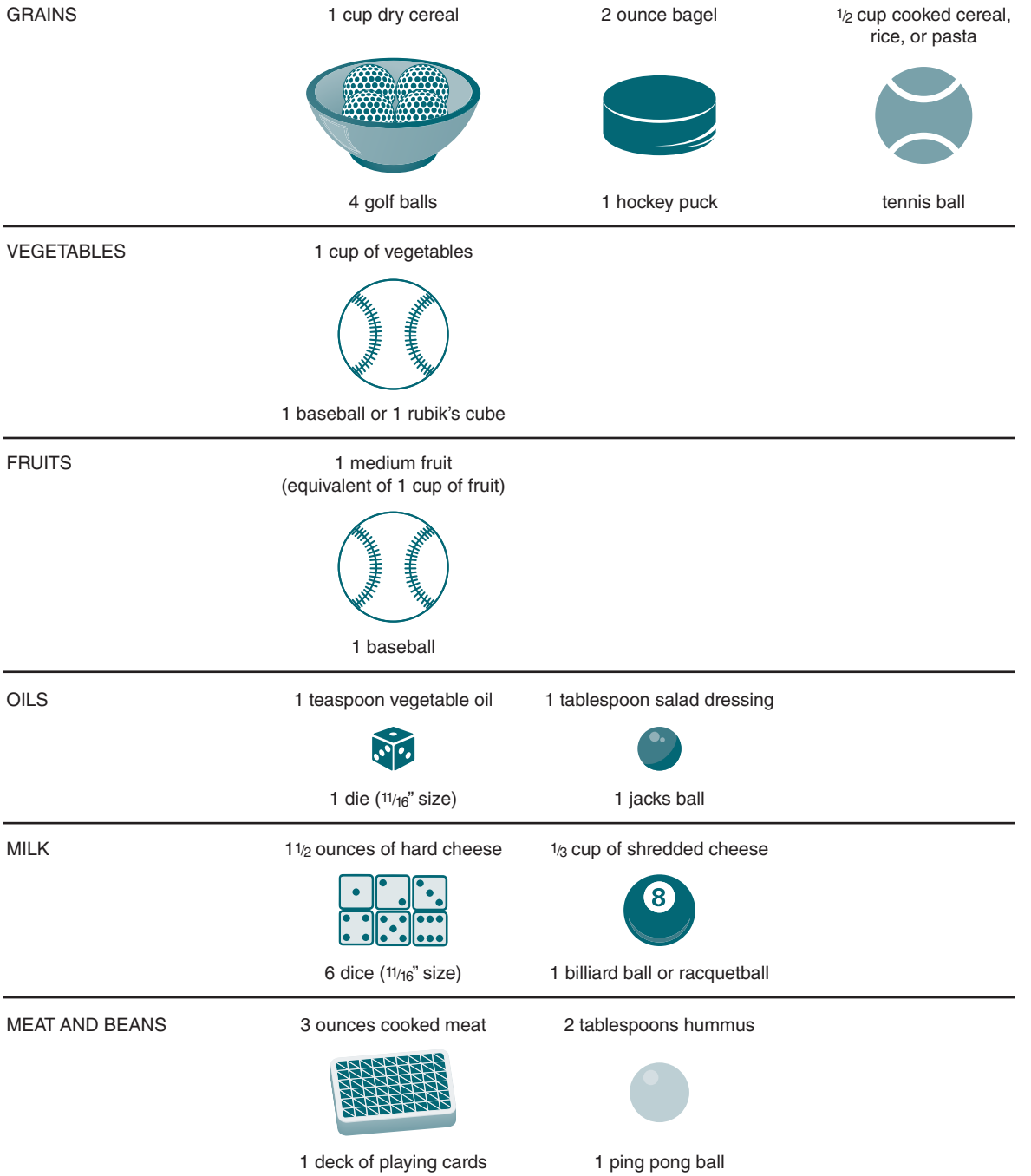

FIGURE 4.4 Estimating portion sizes

years old, making parent-focused, portion-education interventions imperative.[48] Portion sizes also determined the extent of energy self-regulation for the dietary intakes of young children from 4 to 24 months of age.[50] Fox et al. found that portion sizes were negatively associated with energy consumption.[50] Children who eat more often during the day consume smaller-than-average portion sizes compared with those who eat less often during the day and consume larger-than-average portion sizes.[51]

Accounting for the quantity of food consumed is an important part in assessing the dietary intakes of populations and individuals. Individuals who consume foods based on expected satiation formed by pleasure foods have a tendency to underestimate the portion sizes they consume when compared to actual food intake. Conversely, healthy adults who ate based on hunger accurately estimated the portion sizes they consumed compared with their actual food intake.[51] These findings reinforce the significance of

measuring portion sizes as part of the dietary assessment routine.

Food models are the most common and simplest method to measure portion sizes in a clinic or research setting. Portion sizes can also be measured using household artifacts (such as measuring cups and spoons), premeasured portion sizes, or food photographs. Measurements can be from two-dimensional and three-dimensional food forms. Familiar household items such as cups and spoons or bowls and plates are commonly used by study participants for estimating portion sizes. The use of food photographs of various food-portion sizes has increased in the research setting.

Food Artifacts

Household artifacts are portion-size estimation objects intended to help people estimate food-portion sizes.[52] Household measures are widely used because they resemble real-life, authentic objects and serve as tangible, visual objects.[53] People with varying literacy levels can best recall and estimate food-portion sizes using visualization and comparison aids. They often estimate portion sizes based on the size or shape of the container while using their hands to indicate the equivalent portions.[52]

Chaudhry et al. found that people associate estimates of liquids with the household containers they usually use—for instance, estimating the portion size of coffee with a drinking cup.[52] The association with the containers is made without the necessarily knowing the actual volume. People also tend to estimate portion sizes of solid food container based on the similarity to the shape of the actual container.[52]

In a recent study, Gibson et al. compared the accuracy of "the width of the fingers," fist and fingertips for estimating portion sizes with that of household measures (cups and spoons).[54] Estimated weights were compared with true weights, using a percentage difference to compare the precision between the hand and household measures. University of Sydney staff and students estimated the portion sizes of multiple foods and beverages. Surprisingly, the hand method, which yielded a rough estimation of portion sizes, was more accurate than the household method. The hand estimation was 80% within the ±25% of the true weight of foods, and 13% were within the ±10% of accuracy. Conversely, the household estimation accuracy produced only 29% within the ±25% of the true weight of foods, and 8% were within the ±10%. The researchers concluded that the finger-width method for portion-size estimation was superior to using the household measures, particularly for geometrically shaped foods.[54]

Research supports that household measures and other food models produce poor accuracy in estimating portion sizes when used by children.[55] Children ages 4 to 16 years of age who used food photographs or an interactive portion-size assessment were more accurate in their portion-size estimation of foods served at school. Using household measures and other food models, the participants' estimation was least accurate.[55] Overall, these findings showed that household measures are not always the best option for estimating food-portion size.

Unit Measurement

Food intake can be measured by different units of portion sizes—for example, grams versus servings.[56] Note that the two units are not interchangeable because they represent different entities. Although a portion is the amount an individual consumes, a serving relates to a standardized amount of food listed on a food label or the information about a food within a food group such as in dietary guidance.[57,58] Moreover, different foods are associated with different serving sizes, such as measured cups, ounces, grams, slices, or numbers (three crackers), which indicates that a portion size may not match a serving size.[57] Nöthlings et al. examined whether the portion-size unit—for example, grams versus servings—may have different impacts on food consumption.[56] Using a cohort study of more than 200,000 participants, the authors found that the two measures could be interchangeable in predicting disease risk. Inversely, Herman and Policy[59] affirmed that norms related to portion sizes were determined by the amount of food served versus the number of food items provided. For example, when served pizzas were cut into different sizes, more food was eaten when portion sizes were larger because of a cognitive bias.[47,59] Geier et al. further confirmed that there is a unit bias—that is, larger portion sizes subconsciously encourage people to consume more food.[60] Likewise, the normal amount of food that should be eaten will determine the amount served. Could larger portion sizes of food also encourage the consumption of large portion sizes of fruit and vegetables that are not energy dense? Unfortunately, evidence showed that larger servings of vegetables and fruit did not result in their greater intake. Together, these findings point to the limitations of using subjective unit measures to determine their impact on food intake.[49]

Food Photographs

Food photographs have been used as alternative methods to estimate food-portion sizes.[56,61] Foster et al.

found that both food photographs and an interactive portion-size assessment resulted in good accuracy of portion-size estimates in relation to the true food intake.[55] When compared to using household measures and food models, children using food photographs and an interactive method were more effective in improving accuracy in estimating portion sizes. Food photographs and the interactive portion-size assessment produced more accurate estimation of the amount of food served rather than that consumed.[55] Steyn et al. confirmed that two-dimensional real-life drawings and as well as three-dimensional food models produce a high degree of portion sizes' accuracy that closely resembled the real food portion presented to children.[61] Two-dimensional food drawings provided better estimates of total energy intake for fats and carbohydrates than did three-dimensional food models. The study found significant ethnic differences in using one tool over the other. Overall, black children selected the use of drawings and models more often than white children. As a result, both aids probably could be used in dietary interviews using urban black children as subjects. With adolescents, using food models will increase accuracy.[61]

The effectiveness of accuracy when using digital portion-size photographs was investigated using adult subjects.[62] Participants viewed different computerized portion sizes and selected the most-appropriate portion size of food served at a buffet the previous day. The results indicated that no one image produced the most-accurate estimation of food served. However, the number of images presented at one time influenced accuracy in estimating portion size. Accuracy outcomes were not statistically significant, indicating that one image form was not more accurate than another. Accuracy results showed that the use of eight images rather than four yielded greater accuracy. Results also confirmed that showing simultaneous images was preferred to showing sequential images.[62] Food photographs also yielded a high agreement between estimated energy intake and actual weight of food when rated by trained researchers.[63] Trained raters estimated the weight of food served in two schools, and found that food photographs resulted in high precision of meals served by staff rather than self-serving portion sizes. The bias of the method was more pronounced with bigger portion sizes. Overall, food photographs can constitute acceptable estimates of energy intake but were limited in their validity and generalization.[63]

Recap The use of 24-hour recall, food-record diaries, and FFQ methods for assessing dietary intake has both advantages and limitations. The introduction of other measures such as portion sizes increases accuracy in estimating dietary intake. Including portion sizes in dietary assessment methods may lead to greater accuracy for measuring actual food intake.

Challenges in Food and Nutrient Intake Measurement Methods

Preview There is no gold standard for measuring food and nutrient intake. Various diet-assessment methods have been developed; each method has its own set of challenges or limitations. Underreporting seems to be the major and most common challenge among diet-assessment methods.

Reliability

Reliability, also known as *reproducibility*, represents the internal consistency of an instrument to provide repeated results with the same group of participants. A reliability study links intake results from two administrations of a tool in the same group of participants. In a reliable instrument, the mean of the measurements (for instance, the mean intake of a nutrient) should not vary significantly between the two administrations. Furthermore, correlation coefficients for the outcomes of interest (i.e., intake of a specific nutrient) assessed from the two administrations of the research instrument in the same group of subjects should be high and usually in the matching range of 0.6–0.7. Reliability is an easy measure and provides a level of certainty as to the accuracy of a research tool.[64] Overall, reliability values range from 0.00 to 1.00, where a value of $r \geq 0.7$ is considered sufficiently reliable for dietary assessments.[65]

In general, reliability is instrument specific and reflects errors because of the use of a specific dietary assessment instrument. Therefore, ideally, the reliability of each new food questionnaire should be determined for each new population being assessed.[66]

Reliability can take different forms under different situations. The interrater reliability indicates the extent of agreement of dietary assessment among judges.[66] The internal consistency reliability,

commonly expressed by Cronbach's α, reflects the extent to which all the items within a single instrument measure the same concept and yield similar results.[65,67] Equivalent form reliability describes how two different forms of the same instrument yield the same results. Test–retest reliability designates the extent to which a single instrument produces the same results for the same individuals on two different occasions.[66] Of the four reliability forms, the test–retest reliability is closely related to reproducibility.[68] *Reproducibility* refers to the variation in measurements made on a single assessment instrument for the same respondents under changing conditions.[68] In dietary-intake assessments, the changing conditions are prone to error measurement over some time period. A dietary assessment is reliable or reproducible if the same instrument yields similar results for repeated measures of the same respondents under different passages of time between administrations.[66] For example, respondents may complete a dietary assessment twice within a two-week period or on the first day of the month and again on the first day of the following month.

There are fundamental challenges relating to the reliability of dietary assessment reports. Dietary assessments of respondents' records are subjected to memory bias.[69] Cardoso et al. found a low to moderate reliability of the FFQ (0.52–0.75) within one-month intervals of three 24-hour dietary recalls among 93 low-income women.[69] In addition, the long-term reliability (one-year interval) of the same instrument was lower (0.30–0.56), reflecting memory bias. Andersen et al. administered a dietary assessment with both 24-hour recall and food-frequency questionnaire portions within two weeks of the initial assessment to sixth-grade students.[70] The results indicated no significant differences in responses between the two time periods. The authors attributed the high reliability to short time periods between the assessment as students remember their responses to the initial asse\ssment, and record them on the subsequent assessment.[70]

Although longer periods between testing minimize the risk of participants replicating previous answers, they introduce a new challenge. If periods are too long between assessments, seasons may change during that time, which can affect the types of foods eaten or the food-frequency consumption. Marchioni et al. administered FFQs to high school sophomores in Brazil three times each, one month apart.[71] Although the test–retest reliability was reasonable for most of the nutrients assessed, the FFQ internal consistency of the second assessment was lower than that of the initial assessment, as reflected by the corresponding intraclass correlation coefficient values of the two FFQs. Researchers suggested the students consumed different seasonal foods during the study duration because they came from low-income populations for which seasonal changes could affect food availability.[71]

To control the time interval variable, four to eight weeks are suggested as an acceptable time duration between dietary assessments.[33] Hebden et al. established that a one-month period was appropriate for investigating the FFQ reliability.[72] In this study, two FFQs were administered to Australian male and female students four weeks apart. The results indicated good reliability for all nutrients of interest and for fruit and vegetable servings. Researchers declared that one month was enough to easily administer FFQs and obtain good reliability for assessing diet in young adults.[72] Fallaize et al. also administered two FFQs to students at the University of Reading in the United Kingdom four weeks apart.[73] This study found insignificant differences of macronutrient and micronutrient dietary intakes between the first and second FFQs. Based on their results, researchers maintained that four weeks was the best time interval between repeated measures of FFQs to obtain reproducibility or test–retest reliability because it could minimize changes and error measurement in reporting dietary intake.[73] In a similar study, Filippi et al. administered two online FFQs to 185 Italian adolescents ages 14 to 17 four weeks apart.[74] Analysis of the results showed that differences in dietary intake estimates were not statistically significant for all food groups, indicating that the FFQ was a reliable instrument for estimating food groups, energy, and nutrient intakes for this population.[74]

Dietary assessment self-reports could also be dependent on individual characteristics, thus reducing their reliability. Neuhouser et al.[75] found that individuals also tended to report dietary data quite differently, depending on their age, body mass index, and ethnicity. Specifically, their findings indicated that participant characteristics correlated with energy and protein intake misreporting, confirming the existence of systematic bias in dietary self-reports and reducing the reliability of dietary assessment self-reports.[75] Together, these findings help to define the importance of obtaining good reliability for dietary assessment instruments.[66]

Validity

Reliability concerns the internal consistency of dietary assessment items, but **validity** refers to the extent to which an instrument measures what it

purports to measure.[66,76–79] Validity is important in the development of a tool and vital in evaluating the performance of the developed tool. Validity necessitates that an instrument be reliable, but an instrument can be reliable without being valid. This means an assessment tool can consistently deliver similar outcomes but not that the results are necessarily accurate.[80] Most dietary assessments aim to measure the participants' usual food intake over a defined time period.[77]

Accuracy is defined as a measurement of the degree of closeness of measurements of a quality to that quantity's true value.[81] This trait is particularly relevant to dietary assessment because of the large variability in people's eating habits.[18]

Validity evidence is fostered over time, with validations taking place in different populations. Validity can take four forms.[66] **Face validity** is the extent to which the instrument is assumed to measure a characteristic based on the participants' judgment.[66,67] **Relative validity** compares a new measurement method with at least one established method that is believed to have a greater degree of demonstrated face validity. **Content validity** explores the relevance and comprehensiveness of a tool's content (tool construction). It is usually evaluated by a group of experts who consider the appropriateness of the tool in relation to its planned purpose and use. **Construct validity** emphasizes the extent to which an assessment parameter performs in agreement with theoretical expectations.[82] In other words, if the tool's performance is consistent with expectations, then construct validity is established in relation to the variables tested. This type of validity is a conclusion based on gathering evidence from several studies using a specific measuring instrument. All confirmation of validity, including content- and criterion-related validity, adds to the evidence of construct validity.[77] **Criterion validity**, in turn, is the extent to which an instrument correlates with an external reference tool that has already been validated, signifying the most accurate estimates of food intake.[66,67] For example, the doubly labeled water (DLW) method is a reference standard in energy metabolism that measures free-living **energy expenditure** in humans. It can be used to independently validate self-reported energy intake and detect true reporting bias.[77,83] Measuring food and nutrient intake may require the comparison of multiple valid instruments to determine the best tool for the project.

Studies validating tools to evaluate nutritional intake have been limited.[18] Most have been traditionally conducted by comparing dietary data collected from an FFQ with data obtained from food records or 24-hour recalls to determine which tool provides greater accuracy.[18,34,84,85] For instance, Vioque et al. developed and evaluated the reliability and validity of a modified FFQ compared with the average of three 24-hour recalls in 169 young Spanish children.[45] The findings demonstrated low to moderate reliability, ranging from 0.3 to 0.7, while the validity was lower across nutrients (average $r = 0.30$). Liese et al. also developed a modified SEARCH FFQ for collecting nutrient intake from youth with type 1 diabetes and examined its validity against three 24-hour recalls within one month.[86] Participants were given two FFQ forms to complete one month apart; in between they also completed the three 24-hour recalls. The results indicated that the SEARCH FFQ demonstrated lower relative validity compared to that of the 24-hour recalls.[86] The 24-hour recalls reported higher nutrient intakes in all food groups when compared to the SEARCH FFQ for all food items except meat, nuts, seeds, fats, and oils.[45] Overall, the SEARCH FFQ demonstrated low to moderate reliability, highlighting the importance of demonstrating both reliability and validity in dietary assessments.

Wong et al. further investigated the test–retest reliability and relative validity of the New Zealand Adolescent FFQ (NZAFFQ) to assess food-group intake in 52 adolescents ages 14 to 18 years.[87] The NZAFFQ was administered twice within two weeks to measure reliability, whereas four food records were used to assess the instrument's validity. Results showed that the new FFQ has good to excellent reliability, ranging from 0.54 to 0.89 across nutrients, whereas the validity was poor to reasonable, ranging from 0.32 to 0.70. Estimates of some of the vegetable intakes was particularly inaccurate.[87]

Christian et al. validated their 24-hour Child and Diet Evaluation Tool (CADET) recall against a one-day weighed food record in the United Kingdom intended for children 8 to 11 years old.[88] The CADET exhibited good validity compared against weighed food records, especially for fruits, vegetables, and their combination ($r = 0.7$). The CADET also recorded higher amounts of macronutrient intakes when compared to the weighed food record.[88]

Some researchers question the use of FFQs in nutrition epidemiological research because it limits the interpretability studies' results.[89] In some studies, the FFQ significantly underestimated fat and protein intakes and overestimated carbohydrate intake with the high-fat diet compared with a food record.[90] Others doubt the use of food records and 24-hour recalls as the criterion method.[90,91]

Determining the reliability and validity of dietary intake assessments can be an arduous task. As a rule, the traditional dietary intake methods (24-hour recalls, food records, and FFQs) rely on subjective participants' self-reports. To reduce error rate in the data collected, objective measures should be defined.[18] Also, to control for errors in measurement, the validity and reliability of the instrument should be considered when selecting the assessment tool.[66] Instruments with a low validity contribute to errors related to measuring the wrong characteristics, whereas an instrument with low reliability lacks precision. To address these issues, biomarkers and energy-expenditure tests can be added to dietary assessment because they reflect a more objective, accurate measurement of dietary intake.[18]

Sensitivity and Specificity

Sensitivity and specificity are statistical measures for evaluating the results of diagnostics and screening tests. *Sensitivity* measures the amount of the actual positives, and *specificity* accounts for the proportion of the negatives. Sensitivity measures the number of positive results that are correctly identified as such. This is also called a *true positive rate*—that is, the ratio of sick people who are correctly recognized as having the illness.[92] Specificity is defined as the number of individuals without disease who are properly identified by a screening test.[93]

A highly sensitive test shows few false-negative results—that is, few actual cases are missed, and therefore it has a strong value for screening.[92] A negatively sensitive test means that the proportion of persons who have a disease are diagnosed with negative test results—that is, as not having the condition.[94]

Specificity is the test's ability to correctly diagnose an individual without the disease as negative.[92] A highly specific test means there are few false-positive results, making it valuable because of low false-positive errors. In contrast, a negatively specific test erroneously diagnoses many individuals without the disease as having the condition. A negatively specificity test can potentially lead to providing unnecessary treatment such as invasive, risky, or expensive follow-up diagnostics.[92] DeVellis noticed that the higher the specificity of a test, the stronger the test indicators correlate with one another.[95]

The goal is to use tools with high sensitivity and specificity and thereby minimizing the misclassifications. To that end, sensitivity and specificity are used to establish reference intervals against which nutrition-assessment instruments can be compared to determine their effectiveness.[94]

Use of Biological Markers

All of the traditional dietary assessments—the 24-hour recall, food records, and FFQs—rely on subjective self-reports that involve systemic bias and error in measurement.[66,96–98]

The National Academy of Medicine (formerly the Institute of Medicine) has debated whether **biological markers** could predict functional outcomes and chronic diseases. They should thus be used as external, independent criteria to validate overall diet quality measured as total energy intake or the intake of selected nutrients.[18,97]

Sources of biological markers include DLW for energy expenditure, urine, blood, and tissue for specific nutrients.[18,75,97,101] These markers are generally readily accessible and can objectively assess food and nutrient intake without bias and self-reported dietary intake.[96]

Urinary nitrogen, sodium, potassium, vitamin E, vitamin C, carotenoids, and fatty acids in adipose tissue are among the most commonly used biomarkers in research. Although numerous studies have used biomarkers as tools for validation, few studies translate their results in terms of the validity coefficient.[102–105]

Doubly Labeled Water: The Gold Standard for Energy Expenditure

Doubly labeled water is an established biomarker that is considered the gold standard for validating total energy intake or energy-expenditure measurement.[18,75] The DLW method is considered the most relevant, although costly, technique for calculating energy expenditure in animals and humans. It is based on the exponential disappearance from the body of the stable isotopes deuterium (^{2}H) and oxygen (^{18}O) after a bolus dose of water labeled with both isotopes. The ^{2}H is lost as water and the ^{18}O as both water and carbon dioxide (CO_2). After correction for isotopic fractionation, the excess disappearance rate of ^{18}O relative to ^{2}H is a measure of the CO_2 production rate.[106] Urine or saliva samples are collected and analyzed to measure the disappearance of the isotopes.[101] This rate can be transformed to an approximation of total energy expenditure by using a known or estimated respiratory quotient and the principle of indirect calorimetry.[107] When weight conditions are stable, energy intake equals energy expenditure.[108]

The doubly labeled water biomarker provides a more objective method of assessing energy intake and is often used to assess underreporting in dietary assessments.[75,101] A study by Neuhouser et al. found

that women who participated in the Women's Health Initiative Dietary Modification Trial underreported energy intake by 32% as measured by a DLW protocol.[75] African Americans and Hispanic women underreported energy intake more than Caucasians.[75] Participants in the Observing Protein and Energy Nutrition Study underreported total energy intake as measured by the 24-hour recalls as FFQs as compared with the DLW protocol.[101] Men underreported energy intake by 12%–14% on the 24-hour recalls and 31%–36% on FFQs, whereas women underreported energy intake by 16%–20% on 24-hour recall and 27%–32% on FFQs.

The use of the DLW technique has both advantages and limitations. Advantages include the fact that it has been deemed an accurate, objective measurement of energy expenditure. Other advantages include ease of administration, participants' ability to engage in daily activities, and restriction-free settings.[18]

Limitations to using the DLW technique include the assumption of a constant rate of CO_2 and a consistent water pool throughout the measurement period. Aside from this, there is variability in the process researchers process to calculate the isotope pool spaces, the constant elimination rate, the fractionation factors, and the mode of CO_2 transformation into energy.[83] Other challenges with using DLW in dietary assessments include the high cost of stable isotopes and the expertise required to activate a sophisticated spectrometer.[18]

One important aspect to consider is that the DLW is time restricted because it is held by the body for only 14 days. Some researchers have tried to compensate for this time restriction by distributing surveys. In doing so, the DLW technique is no longer objective.

Nutritional Biomarkers

When compared to using self-reported nutrition intake instruments, the use of nutritional biomarkers has been deemed more accurate in assessing nutritional intake or status. Nutritional biomarkers have been used to validate self-reported intake, assess intake of food items when food-composition databases are inadequate, and more accurately link eating patterns with disease risk and nutritional status.

Nutritional biomarkers can be classified into short-term, medium-term, and long-term markers or indicators. Short-term indicators suggest intake for the past few hours or days. Medium-term markers reflect intakes for the past few weeks or months. Long-term nutritional markers show the individual's intake for the past months or years. The type of sample used is the main determinant of time (blood, hair, adipose tissue).[109] The use of hair and nail samples are easily obtained and can be used to address trace elements. The validity of using these samples has not been established.[110] Venipuncture blood samples are the preferred biologic specimen for large-scale studies. Blood samples are simple to obtain add negligible burdens on the subjects, and can be easily managed for large-scale studies. Spot blood samples are used for nutrients such as vitamin A and folate.[111,112] Samples of fatty acids may not be truly reflective of the amount of fatty acid consumed via the diet.[113] Blood fatty acids from phospholipids have also been used to validate the traditional dietary measurement because of their relationship with chronic diseases.[114]

Intake of dietary essential fatty acids (eicosapentaenoic acid and docosahexaenoic acid) found in fish were related to blood fatty acids.[18] Fatty acids from adipose tissues showed comparable results for odd numbers of fatty acids but were not valid biomarkers for saturated and monounsaturated fatty acids.[115] Apparently, dietary essential fatty acids were better biomarkers for validation. Plasma concentration of carotenoids, tocopherols, retinol, folic acid, vitamin C, vitamin B_{12}, and flavonoids also performed well as biomarkers and reflected accurately their corresponding ingested foods.[18,114,116]

Serum concentrations of carotenoids and ascorbic acid (vitamin C) were indicative of fruit and vegetable consumption.[18] For example, moderate correlations between fruit and vegetable intake and changes in plasma concentration of vitamin C and specific carotenoids (r = 0.39 and 0.37, respectively) have been found among women in the Netherlands.[117] Similarly, Scott et al. showed that the dietary intakes of lutein, lycopene, and beta-carotene found in fruits and vegetables correlated with changes in plasma concentrations of lutein, lycopene, and beta-carotene (r = 0.64, 0.47, and 0.45, respectively).[118] Serum concentration of folate, vitamin B_{12}, and α-tocopherol (vitamin E) were strongly linked to fruits and vegetables, whole and fortified grains, and enriched breakfast cereals.[97,100] Note that biomarkers do not always perform better than other assessments of dietary intake because of their limitations.[115]

Biomarkers are subject to individual variability and may be influenced by confounding factors other than the nutrient of interests.[119] Moreover, rapid turnout of nutrient concentrations in the blood because of half-life (e.g., carotenoids) or to preserve homeostasis limits their sensitivity as biomarkers in the long run.[115,119] Some enzyme activities may serve as functional biomarkers that mirror long-term status but are influenced by confounding factors or several micronutrients that

limit their generalizability.[66,119] Likewise, biomarkers' effectiveness depends on the existence of reference values and cutoff points for populations of interest.[119]

Although nutritional biomarkers usually offer a more accurate reflection of the subjects' dietary intake, influences that may not be present in traditional dietary assessment methods could distort biomarker measures of dietary intake. Factors that can distort biomarker measures involve genetic inconsistency, lifestyle habits (such as high consumption of alcohol), dietary factors such as nutrient–nutrient interactions, and analytical procedures.[120] More research is needed in this area. As a result, when using nutritional biomarkers, it is vital to evaluate a biomarker's validity, reproducibility, aptitude to distinguish changes over time, and generalizability across various populations. Strengths and limitations for the different biomarkers needs to be assessed.

In summary, nutritional biomarkers are objective and valid measures of dietary estimates but should complement other subjective estimates, such as 24-hour recalls, food records, or FFQs because of their limitations.[14]

Recap Accurately assessing the intake of food and beverages is essential to nutrition and health research, including surveillance, epidemiology, and intervention studies. Dietary intake and the process for consuming food and beverages is dynamic and complex. Dietary intake habits change over time and through the different stages of the life cycle. The area of evaluating food intake is filled with challenges.

Chapter Summary

Nutrient intake determines an individual's health and nutritional status. Dietary intake plays a crucial role in assessing nutrient deficiencies intended to regulate disease prevention or develop management strategies for chronic diseases among target populations. Current assessment methods include subjective and objectives measures. The three most common subjective methods of dietary measurement are 24-hour recalls, food records, and food-frequency questionnaires. Each method has its advantages and limitations as supported by evidence-based research, unveiling problems in reliability and validity that restrict the ability to predict true dietary intake. Limitations of the dietary-intake tools underscore the need to also include biological biomarkers because they are objective, independent measures that can improve the estimates of dietary consumption. Specific biomarkers mirror the status of selected nutrients or dietary components, either as recovery-based markers that indicate a direct relationship to nutrient intake, as in the case of a 24-hour urinary nitrogen for protein intake or urinary excretion of potassium; or concentration-based markers of a specific nutrient such as plasma or serum concentration of carotenoids or ascorbic acid signifying fruit and vegetable intake. Because nutritional biomarkers have several limitations, current recommendations include the use of both subjective dietary measures and objective nutritional biomarkers as a way to improve the accuracy and precision of dietary intake measurement.

CASE STUDY

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Childhood obesity continues to remain a nationwide epidemic. Since the late 1990s, rates have significantly increased among ethnic minorities.

You have been assigned a research project in an urban school district. As part of the project, you need to research all of the factors that can contribute to unhealthy diet intake and physical inactivity among children and adolescents.

Questions:

1. What type of nutrient-assessment methods will be used in your methodology?
2. What validation or reproducibility issues may arise in your selected nutrient-assessment methods?
3. In addition to nutrient assessment, will you need to use biomarkers?

Learning Portfolio

Key Terms

24-hour recall
Biological marker
Case control
Cohort
Construct validity
Content validity
Criterion validity
Energy expenditure
Face validity
Food-frequency questionnaire (FFQ)
Food record
Longitudinal study
Nonquantitative FFQ
Nutritional epidemiology
Quantitative FFQ
Relative validity
Reliability
Semiquantitative FFQ
Validity

Study Questions

1. Observational studies include all of the following except:
   a. cohort.
   b. cross-sectional.
   c. randomized controlled trial.
   d. case control.
2. What is the purpose of cohort studies?
   a. To collect data in one point in time
   b. To investigate two groups at a time
   c. To investigate factors that may cause a disease to develop in a particular group over time
   d. To compare and contrast disease prevalence in multiple groups
3. What is the Framingham study?
   a. A case-control study investigating diabetes
   b. A correlational study investigating fiber and colon cancer
   c. A cohort study investigating obesity in children
   d. A longitudinal study investigating cardiovascular disease
4. What does NHANES stand for?
   a. Nutrition Health Assessment and Nutrition Education System
   b. National Health Assessment Nutrition Education Surveillance
   c. Nutrition Health and National Examination System
   d. National Health and Nutrition Examination Survey
5. Cross-sectional studies are also known as
   a. incidence studies.
   b. large approach studies.
   c. small-scale studies.
   d. prevalence studies.
6. Case-control studies are used to investigate two groups known as
   a. case and control.
   b. case and exposure.
   c. case and placebo.
   d. subject and control.
7. What is incidence?
   a. The proportion of the population that is not susceptible to develop a disease immediately
   b. The proportion of the population that has the disease at one point in time
   c. The proportion of the population that is susceptible to develop a disease over time
   d. The proportion of the population that is more susceptible to develop a disease at one point in time
8. What is prevalence?
   a. The proportion of the population that does not develop a disease over time
   b. The proportion of the population that has the disease at one point in time
   c. The proportion of the population that is susceptible to develop a disease over time
   d. The proportion of the population that develops the disease over time.

9. For individuals who have literacy issues, what is the most effective diet-assessment method?
   a. Food-frequency questionnaire
   b. Food record
   c. Diet History Questionnaire
   d. 24-hour recall

10. For large-scale studies, what is the most effective diet-assessment method?
   a. Food Record
   b. 24-hour recall
   c. Food-frequency Questionnaire
   d. Weighed Food Record

11. The 24-hour dietary recall is defined as:
   a. a self-report of everything an individual eats and drinks during a specified time period.
   b. the record of everything an individual eats and drinks over a consecutive three days.
   c. an extensive list of all foods and beverages an individual has consumed over the past month.
   d. an extensive questionnaire of foods frequently consumed by individuals over the past week.

12. Advantages of 24-hour dietary recall includes all of the following except
   a. Quick
   b. Convenient
   c. Inexpensive
   d. Captures usual dietary intake

13. What are the limitations to a 24-hour dietary recall?
   a. It does not account for diet variation.
   b. It is expensive.
   c. It is quick.
   d. It captures usual dietary intake.

14. A food diary requires participants to track all foods and beverages over what time period?
   a. During the previous time period
   b. Over the past month
   c. During a specified time period
   d. Over the past week

15. What is an advantage to the food diary method?
   a. It relies on information in the past.
   b. It relies on memory.
   c. It is labor intensive for the subject.
   d. It does not rely on memory.

16. All of the following are limitations to the food diary method except:
   a. timing of data collection may not be convenient for subject.
   b. a high literacy level is needed.
   c. a method may alter an individual's diet.
   d. it is quick.

17. Which of the following data are collected through the use of a food-frequency questionnaire?
   a. Frequency of consumption of specific foods and nutrients
   b. Intake within the past 24 hours
   c. Current intake
   d. Historical intake

18. What are advantages of the FFQ?
   a. It quantifies intake.
   b. No standard method exists.
   c. It is self-administered.
   d. It is not culturally tailored.

19. Limitations of the FFQ include all of the following except:
   a. it relies on memory.
   b. items may not represent usual intake.
   c. data may not be quantifiable.
   d. it reduces participants' burden.

20. What is the Harvard Willet Questionnaire?
   a. a 131-item questionnaire
   b. a 150-item questionnaire
   c. a 300-item questionnaire
   d. a 250-item questionnaire

21. What is the reliability value range?
   a. 0 to 1
   b. 1.5 to 2.5
   c. 3 to 4
   d. 0.5 to 1.5

22. All of the following are forms of validity, except:
   a. face.
   b. criterion.
   c. content.
   d. structure.

23. What are not sources of biological markers?
   a. Urine
   b. Blood
   c. Carbohydrates
   d. Vitamin E

24. What is the gold standard for validating total energy intake?
   a. Mineral water
   b. Doubly labeled water
   c. Plasma levels
   d. 24-hour recall

25. What is an example of a recovery-based marker?
   a. Plasma levels of carotenoids
   b. Adipose tissue
   c. 24-hour urinary nitrogen
   d. Tocopherols

26. All of the following are forms of reliability except:
    a. internal consistency.
    b. test–retest.
    c. reproducibility.
    d. equivalence.
27. All of the following are examples of food models except:
    a. household artifacts.
    b. food photographs.
    c. premeasured portion sizes.
    d. food demonstrations.
28. Food artifacts are most widely used for the following reasons:
    a. They resemble authentic objects.
    b. They have historical value.
    c. They are edible.
    d. They are accessible.
29. Food intake can be measured in which of the following units?
    a. Weights
    b. Kilometers
    c. Grams
    d. Scales
30. Food photographs are most useful during which of the following nutrient-assessment methods?
    a. Food-frequency questionnaire
    b. Food record
    c. Biomarkers
    d. 24-hour recall
31. Food photographs are most useful during which of the following nutrient-assessment methods?
    a. Food-frequency questionnaire
    b. Food record
    c. Biomarkers
    d. 24-hour recall

Discussion Questions

1. Reflect on the impact of nutrition epidemiology studies. Many of these studies investigate a specific nutrient and disease. Data on intake of foods and supplements before and during pregnancy revealed the association between low folic acid intake and neural tube defects in offspring; this was later determined to be a causal relationship. Design a research study focused on a particular nutrient and disease. What specific nutrient-assessment methods could be used? Why? Write your research proposal.
2. You have been assigned the role of a research assistant to collaborate in a research study investigating the relationship between fiber and gastrointestinal diseases. Your target population is 60 years of age and older. What nutrient-assessment methods would be most appropriate for the study? Why?
3. You are conducting a literature review focused on the dietary intake of children younger than 10 years. You are planning to replicate one of the research studies. What steps should you take to ensure your results are reliable and valid?

Activities

Individual Activities

1. Evaluation of various diet-assessment tools:
    a. Work with a partner. You are trying to determine if your subject consumes sufficient fruits and vegetables in a day. Which of the tools listed below will you have your subject complete? Why?
        i. a 24-hour dietary recall
        ii. a three-day food record
        iii. the National Cancer Institute's Diet History Questionnaire
    b. Discuss the advantages and disadvantages of each tool.
2. Nutrient analysis of diet-assessment tools:
    a. Using the data from the diet-assessment tool used in Activity 1, complete a nutrient analysis using a nutrient-analysis software such as MyDietAnalysis, iProfile, or MyPlate.
        i. After completing the nutrient analysis of the tools, discuss the nutrient deficiencies and excesses, as well as nutrients that were met for each analysis.
        ii. Include recommendations and suggestion for how individuals can improve or maintain their nutrient status.

Group Activities

1. Diet assessment and diet-related diseases:
   a. Identify five diet-related diseases.
   b. Assign each member of the group one diet-related disease.
   c. For each disease, identify a research design that can be used to investigate the diet and disease relationship.
   d. Identify a diet-assessment tool.
   e. Identify a validation method.

Online Resources

Diet History Questionnaire II (DHQ II) and Canadian Diet History Questionnaire II (C-DHQ II)

This website provides access to two web-based food-frequency questionnaires. Both can be used by researchers, clinicians, and teachers without permission. The DHQ II has a food list that consists of 134 food items and eight dietary-supplement questions. The C-DHQ II has a food list of 153 food items and 10 supplement questions that reflects the diet of Canadians. The website includes a nutrient database, paper-based forms, web-based questionnaire, and the Diet*Calc Analysis Software. The questionnaire is sponsored by the National Cancer Institute. Go to https://epi.grants.cancer.gov/dhq2/

National Health and Nutrition Examination Survey

This website provides information about the NHANES survey and the key research studies that have used the survey. In addition, it provides information for participants in research studies, information for health professionals regarding the benefits of the data, questionnaires, dataset, and proposal guidelines for the survey. See https://www.cdc.gov/nchs/nhanes/

What's in the Foods You Eat Search Tool

This website provides nutrient profiles for commonly eaten foods in the United States. Go to https://www.ars.usda.gov/northeast-area/beltsville-md/beltsville-human-nutrition-research-center/food-surveys-research-group/docs/whats-in-the-foods-you-eat-emsearch-toolem/

Automated Multiple Pass Method—USDA

This website provides a computerized method for collecting interviewer-administered 24-hour dietary recalls either in person or on the telephone. The method is research based and uses five steps to ensure accurate recall and reduce response burden. See https://www.ars.usda.gov/northeast-area/beltsville-md/beltsville-human-nutrition-research-center/food-surveys-research-group/docs/ampm-usda-automated-multiple-pass-method/

Short Dietary Assessment Instruments

This website provides a list of tools that have been evaluated and have been used in large population studies. These tools assess the intake of fruit and vegetables and the percentage energy from fat, fiber, added sugars, whole grains, calcium, dairy products, and red and processed meats. See https://epi.grants.cancer.gov/diet/screeners/index.html#screeners

Healthy Eating Index

This website provides information about the USDA's Healthy Eating Index. This is a measure of diet quality that assesses conformance to the *Dietary Guidelines for Americans*. This can be used to evaluate 24-hour recall. See https://www.cnpp.usda.gov/healthyeatingindex

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