ANNUAL REVIEWS

Annual Review of Nutrition

National Food Intake Assessment: Technologies to Advance Traditional Methods

Alanna J. Moshfegh, Donna G. Rhodes, and Carrie L. Martin

Food Surveys Research Group, Beltsville Human Nutrition Research Center, Agricultural Research Service, United States Department of Agriculture, Beltsville, Maryland, USA; email: alanna.moshfegh@usda.gov, donna.rhodes@usda.gov, carrie.martin@usda.gov

Annu. Rev. Nutr. 2022. 42:401–22

The *Annual Review of Nutrition* is online at nutr.annualreviews.org

https://doi.org/10.1146/annurev-nutr-062320-110636

Keywords

dietary assessment technology, food composition data, food intake, mobile application, national dietary surveillance

Abstract

National dietary surveillance produces dietary intake data used for various purposes including development and evaluation of national policies in food and nutrition. Since 2000, What We Eat in America, the dietary component of the National Health and Nutrition Examination Survey, has collected dietary data and reported on the dietary intake of the US population. Continual innovations are required to improve methods of data collection, quality, and relevance. This review article evaluates the strengths and limitations of current and newer methods in national dietary data collection, underscoring the use of technology and emerging technology applications. We offer four objectives for national dietary surveillance that serve as guiding principles in the evaluation. Moving forward, national dietary surveillance must take advantage of new technologies for their potential in enhanced efficiency and objectivity in data operations while continuing to collect accurate dietary information that is standardized, validated, and publicly transparent.

Contents

1. INTRODUCTION

National food intake assessment of the US population is essential for informing and evaluating national policies in food and nutrition (31). To ensure that policies are rational and effective requires an evidence-based approach dependent on the availability of accurate, comprehensive, and timely data (47). The US Food and Drug Administration relied on the dietary data in the update of the Nutrition Facts food label (95). The Dietary Reference Intakes development also relied on national dietary data, as did the most recent Dietary Guidelines for Americans (DGA), 2020–2025 (91). Additional policy uses are provided in **Table 1**.

National dietary surveillance is a contributing factor in critical policies and is used for many different purposes; therefore, it requires continual innovations to improve the methods of data collection, quality, and relevance. National surveillance, although based on assessment of individuals, is designed to assess intakes representative of population groups and subgroups. It requires a sample representative of the US population, including individuals of all ages from diverse racial, ethnic, and socioeconomic backgrounds. The eating behaviors of a population must also be considered in surveillance design.

This review article critically evaluates the strengths and limitations of current and newer methods in national dietary data collection, underscoring the use of technology and emerging technology applications. We offer four objectives for national dietary surveillance, as detailed in **Table 2**. These foremost objectives serve as guiding principles in the evaluation.

2. FOOD INTAKE ASSESSMENT OF THE US POPULATION

National food consumption surveys conducted by the US Department of Agriculture (USDA) since 1935 (80) were integrated with the US Department of Health and Human Services'

Table 1 Select federal policies informed by US national dietary data

Policy	Department	Purpose
Federal regulations		
Nutrition Facts label serving sizes	US Food and Drug Administration (FDA)	Nutrition information on food packages includes serving sizes that are required by law to be based on the amount of a food or beverage that people typically consume during one eating or drinking occasion, known as Reference Amounts Customarily Consumed. The nutrient information on the label is based on the serving size (95).
Folic acid fortification of enriched grain products	FDA	Cereal grain products labeled as enriched (breads, pastas, rice, and cereals) are required to be fortified with 140 μg of folic acid per 100 g of flour as a public health intervention to prevent pregnancies affected by and babies born with neural tube defects (94).
Exposure assessment from pesticides in food	US Environmental Protection Agency	Assessing exposure of pesticide residues from the foods eaten is part of regulating pesticides to ensure that their use does not pose unreasonable risks to human health or the environment and that exposure to pesticide residues in food is safe (93).
Nutrition-related programs		
Thrifty Food Plan (TFP)	US Department of Agriculture (USDA)	TFP specifies categories and amounts of foods necessary to provide adequate nutrition, serving as the basis for Supplemental Nutrition Assistance Program allotments (90).
Special Supplemental Nutrition Program for Women, Infants, and Children (WIC) food packages	USDA	WIC food packages provide supplemental foods designed to meet special nutritional needs of low-income pregnant, breastfeeding, and nonbreastfeeding postpartum women; infants; and children (89).
Nutrition recommendations		
Dietary Guidelines for Americans (DGA)	USDA and US Department of Health and Human Services (HHS)	DGA, 2020–2025 provides recommendations for a healthy diet from infancy to older adulthood and is used to develop federal food, nutrition, and health policies and programs (91).
Healthy People 2030 nutrition and healthy eating objectives	HHS	This initiative provides 27 objectives to improve health by promoting healthy eating and making nutritious foods available (92).
Dietary reference intakes	Food and Nutrition Board, National Academy of Medicine	Dietary reference values for the intakes of nutrients are used for planning and assessing diets applicable to healthy individuals in the United States and Canada (37).

National Health and Nutrition Examination Survey (NHANES) in 2000 to form What We Eat in America (WWEIA), the dietary intake component of the NHANES (2). The NHANES collects two 24-h dietary recalls, the first in person (Day 1) and the second by telephone (Day 2), on a yearly representative sample of approximately 5,000 individuals who reside in households.

Table 2 Foremost objectives essential for national dietary surveillance

Objective	Description
1	Capturing eating behaviors of a diverse population with a standardized validated method
2	Compelling respondent participation to collect accurate dietary information
3	Ensuring transparency of a dietary database that supports collection
4	Guaranteeing timely data that are publicly available

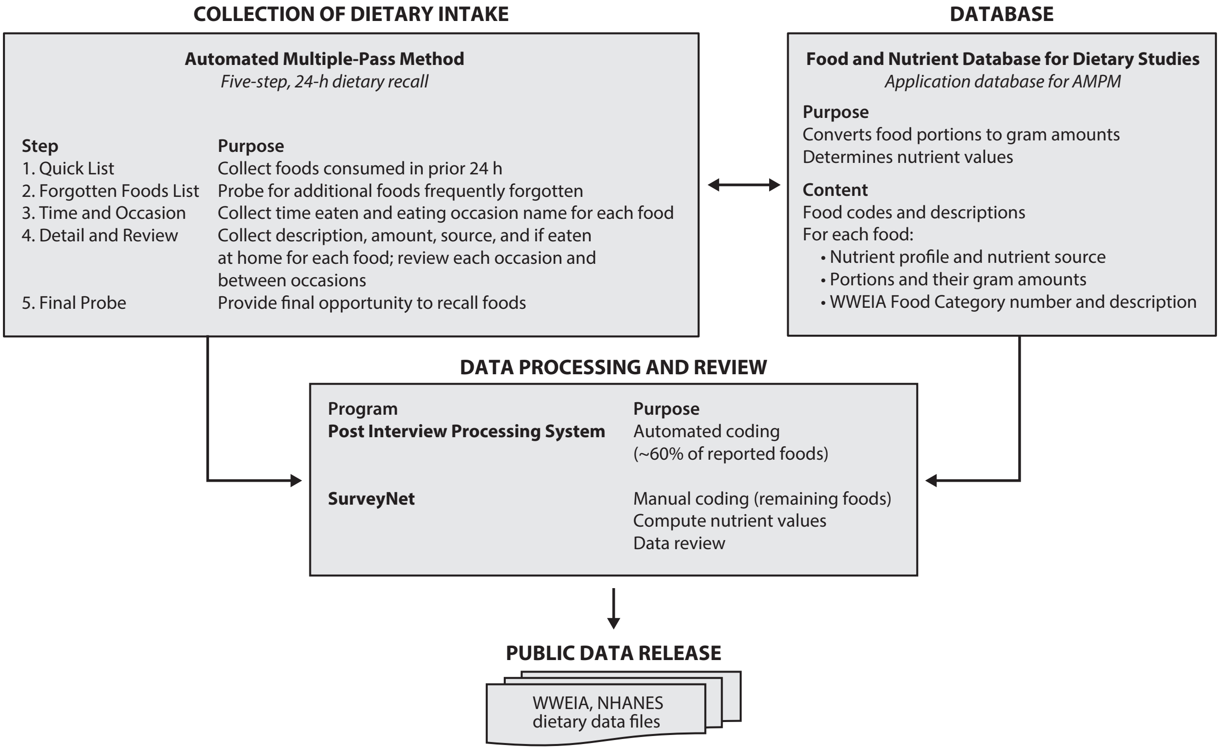

Figure 1

WWEIA, NHANES components: from collection of dietary intake to public data release. Abbreviations: AMPM, Automated Multiple-Pass Method; NHANES, National Health and Nutrition Examination Survey; WWEIA, What We Eat in America.

Additionally, demographic, socioeconomic, medical, dental, laboratory, and other health-related data are collected. The NHANES data are publicly released in two-year cycles.

Assessing dietary intake requires collecting accurate information on the consumption of foods and beverages. Foods and beverages are hereafter referred to as foods. Additionally, the amount consumed must be combined with a specific nutrient profile to calculate nutrient intakes. The components used in WWEIA, NHANES to collect and process dietary data and to publicly release data files are detailed in **Figure 1**. The dietary collection method used is the USDA Automated Multiple-Pass Method (AMPM). Food models aid respondents in estimating food amounts. Three-dimensional measuring guides are used for Day 1, and the USDA Food Model Booklet, which contains two-dimensional drawings comparable to the measuring guides, is used for Day 2 (56). The AMPM companion component, the USDA Food and Nutrient Database for Dietary Studies (FNDDS) (86), contains data to convert foods and their amounts reported in the AMPM into gram amounts and determine their nutrient values.

The AMPM and FNDDS are interrelated. AMPM questions and response options are the basis for the foods and their portion options in the FNDDS. These two more recognized components are augmented by a data processing and review component. Tasks undertaken after dietary collection is completed or during postcollection include food and amount coding, nutrient intake computation, and data review. Food and amount coding is accomplished by an automated program and a manual program. Once coding is completed, nutrient values are computed, and data are reviewed and prepared for release.

Table 3 What We Eat in America, National Health and Nutrition Examination Survey components: strengths, limitations, and technology applications

Component	Strengths	Limitations	Technology applications
Collection of dietary intake			
Automated Multiple-Pass Method (AMPM)	Standardized and validated protocol Effective administration Detailed intake data	Respondent burden Limited availability Delay in data release	Automated instrument programmed in Blaise® Structured multipath interview progression Streamlined food pathway questions Interactive data integrity checks
Database			
Food and Nutrient Database for Dietary Studies	Designed to support the AMPM Transparent public availability Linked to additional variables	Generic food information Limited updates Currency and quality of composition values	Increased transparency Multiple formats for analysis
Data processing and review			
Post Interview Processing System and SurveyNet	Automated coding Supports manual coding and data review	Not integrated within the AMPM Time consuming	Computerized systems for automated and manual coding and data review

3. AUTOMATED MULTIPLE-PASS METHOD

The AMPM is a five-step dietary interview that includes multiple passes during which respondents receive cues to help them remember and describe foods they consumed through the 24 h of the previous day. **Figure 1** illustrates the five-step multiple-pass method used in the interviewer-administered AMPM (64). The purpose of each step is briefly described in the figure. The AMPM also includes multiple memory cues with standardized wording within the steps to elicit recall of all possible foods.

The AMPM is a research-based approach designed to encourage complete and accurate food recall and to reduce respondent burden. This dietary recall program has been successfully used to collect more than 140,000 dietary recalls in WWEIA, NHANES for the past 20 years. The AMPM and related components have been adapted and utilized by research organizations within the United States and globally.

3.1. Strengths of the Automated Multiple-Pass Method

The current strengths, limitations, and technology applications of the AMPM are highlighted in **Table 3**.

3.1.1. Standardized and validated protocol. The AMPM provides a structured interview with standardized questions that accomplish the five-step and multiple-pass methodology. The AMPM also has unstructured opportunities for respondents to use individual strategies to remember and report foods (9, 50). Standardized questions to substantiate food descriptions and determine amounts consumed are structured in more than 130 pathways grouped by similar foods. Select pathways are reviewed and food detail and amount questions are updated to keep pace with food supply changes and to ease respondent burden. However, the five-step and multiple-pass methodology remains unchanged, as it must be maintained in a continuous surveillance system such as that of the NHANES. An updated version of the AMPM is launched at the beginning of each

2-year survey cycle of the NHANES. In addition to the standardization, the AMPM has been validated using biomarkers for energy (8, 53) and sodium (66); results show it reduces bias.

The AMPM design aids collection of food details across a diverse population and changing food environment. One aspect of our changing food environment that creates challenges in assessing dietary intakes is that the instances of eating away from home have doubled in the past four decades (69). In 2017–2018, half of individuals reported eating at least one food or beverage from a restaurant, accounting for one-fourth of mean daily energy intake (84). When a respondent is uncertain or does not know a food, a variety of options are available to the interviewer that provide standardized text for capturing details about the food. This uncertainty occurs in situations such as when a respondent did not prepare the food or consumed the food at a restaurant or at other peoples' homes. Standardization is a hallmark of the AMPM, particularly for national surveillance of individuals with diverse backgrounds and food experiences.

3.1.2. Effective administration. Administration of the AMPM is designed for an interviewer to be able to lead respondents effectively through the standardized interview and assures that the protocol is followed. Interviewer administration allows for collection from respondents at all ages and levels of literacy. Therefore, no technology literacy or reliable access to internet service is required by the respondent.

The AMPM is adaptable for the interview mode to be successfully administered either in person or by telephone. Dietary recalls in WWEIA, NHANES are conducted in person in the Mobile Examination Center for Day 1 and by telephone 3–10 days later for Day 2. Research shows no difference in mean daily energy intakes of adults between the in-person or telephone administration of the AMPM (75). Effective administration by telephone allowed the NHANES to relaunch data collection during the fall of 2021 after being paused since March 2020 due to the coronavirus disease 2019 pandemic. The relaunch included collection of both dietary recalls by telephone.

The AMPM is also adaptable for the interviewer's background. While a requirement of the NHANES is that dietary interviewers are nutritionists, this is not a requirement of administering the AMPM. The AMPM has been administered successfully by lay interviewers and conducted in the home. DiGrande et al. (20) assessed the feasibility of administering the AMPM in participants' homes by lay interviewers compared with nutritionists. In addition, three types of portion estimation were tested: food models such as those used in the NHANES, the USDA Food Model Booklet, and an emerging technology in which food model images are rendered via augmented reality (AR) in a tablet. Although there was little difference observed in the AMPM data collected, the tablet was unnecessarily complicated, particularly when engaging with older adults who may not be accustomed to tablet use or AR. The authors believe that AR technology needs to advance before large-scale use.

3.1.3. Detailed intake data. The extensive details collected beyond the type and amount of food yield a more complete assessment on eating patterns and behaviors of the population. These details include the following: if the food was eaten at home, the source (where the food was obtained), and the time and name of the eating occasions, as well as any additions to a food and the noting of combinations of foods consumed together. WWEIA data have been used to illustrate emerging patterns that have implications for health, including adult late-night eating associated with overall daily intakes higher in energy and lower in nutrient density (72) and the rising importance of convenience stores as a source of dietary intakes for both children and adults (51, 52). Other details related to dietary patterns are also collected following the 24-h dietary recall but within the AMPM interview, including whether the person's intake on the previous day was usual or unusual, the source of tap water consumed, the use of salt, special diet use, and the frequency of fish and shellfish consumption during the past 30 days.

The DGA, 2020–2025 (91) recommends that all sources of a nutrient or food component, whether from food or a dietary supplement, be considered when assessing an individual's dietary pattern. Since 1999, the NHANES has collected data on participants' use of dietary supplements in the past 30 days during the household interview. Since 2007, data have been collected on the use of dietary supplements as well as nonprescription antacids as part of the dietary interview component directly following the dietary recall. While not part of the AMPM, dietary supplement use data are collected and released in the NHANES dietary interview component.

3.2. Limitations of the Automated Multiple-Pass Method

The current limitations of the AMPM indicate challenges in advancing national dietary surveillance. Technology applications provide opportunities for advancement.

3.2.1. Respondent burden. The AMPM method results in an interview that averages 14 reported foods and beverages and takes 20–30 min to administer (on the basis of dietary recalls collected in WWEIA, NHANES 2017–2018). Keeping pace with the food supply and decreasing respondent burden have been continual priorities in updating AMPM food question pathways during the NHANES over the past 20 years. The number of questions asked per respondent about details of foods has decreased by an estimated 9% between the 2007–2008 and 2017–2018 WWEIA, NHANES. Using burgers as an example, in the 2007–2008 WWEIA, up to 16 questions were asked in the AMPM about the burger compared with up to 8 questions asked in the 2017–2018 WWEIA. Similar reductions in questions were made for other types of sandwiches, a food that is reported by approximately half of adults on any given day (71).

It is important that reducing respondent burden continues to be optimized to support the goal of compelling respondent participation. Studies of other 24-h dietary recall tools have identified a concise food list and the capture of fewer food descriptors as a means of decreasing both participant burden and the effort required in coding and data handling without sacrificing nutrient intake estimates (24, 99). Ongoing evaluation and modernizing of these options without sacrificing data quality will continue as a priority of the USDA.

3.2.2. Limited availability. The AMPM was written using Blaise® (Blaise version 4.5, 2001). Blaise is an off-the-shelf programming language first developed in the 1980s and designed for authoring computer-assisted data collection instruments including many preprogrammed functions that simplified the programming (64). Used in large-scale survey data collection in locations around the globe, Blaise offers numerous capabilities needed for a dietary recall questionnaire. These capabilities were optimized in the AMPM design (74). However, the complex program structure of the AMPM does not easily allow for public availability. To make the AMPM and its related data processing and training programs available to the research community, the USDA has established collaborations with numerous federal agencies and research organizations within the United States and internationally. In the future, priority must be given to exploring options for making collection features such as questions and response options publicly available.

3.2.3. Delay in data release. The 2-year cycle of dietary intake data from WWEIA, NHANES is publicly released an average of 18 months postcollection. This delay from collection to public release is a limitation. In part, the delay is due to typical survey tasks that come at the end of a large-scale survey such as the NHANES. These tasks include finalizing field operations, constructing sample weights, and data quality review. However, a major factor contributing to the lag in the dietary data release is the task of applying the nutrient values to reported intakes, a process that is completed postcollection in WWEIA. The design of the AMPM for use in the continuous

NHANES was optimized to maximize time efficiency in conducting the dietary recall. This priority and the computer operational capacity at the time limited the AMPM program design to automatically apply nutrient values to reported foods and their amounts. Thus, programs were developed to code and apply nutrient values from the FNDDS to intake data collected in the AMPM; these programs are detailed in **Figure 1** within the data processing and review tasks.

3.3. Data Processing and Review

Linkage of food consumption data as collected in the AMPM to FNDDS data is performed outside of data collection with the AMPM. This linkage uses external software programs for automated (Post Interview Processing System) and manual coding (SurveyNet) developed specifically for use with the AMPM.

Automated coding of food data is accomplished as a data matching process between the food questions and response values reported in the AMPM and data in an autocode pathways database. A program applies the autocode pathways to food intake records (5). If an exact match is found, then the food is automatically assigned the FNDDS code. Automated coding was initiated with WWEIA, NHANES 2004, yielding automatic coding of approximately 45% of foods and amounts reported by respondents. The percentage has increased over time, with approximately 60% of foods and amounts automatically coded in WWEIA, NHANES 2017–2018.

Foods and amounts that are not automatically coded are manually matched to a food code that requires review and manual entry by trained staff. The manual coding system includes numerous automated food lookup features to enhance efficiency. Manual coding of WWEIA data is estimated to take approximately 1 h per dietary recall, significantly less time than that reported by other research (18).

Many computer-assisted 24-h dietary recall programs have incorporated this linkage capability within the collection program (28), and such linkage within the AMPM instrument is desirable. Koroušić Seljak et al. (44) reported detailed food descriptions in the food composition database as the most relevant requirement for efficient computer-based food matching. The FNDDS already meets that requirement, and many AMPM questions are designed to match a food in the FNDDS. The task that remains is to incorporate matching the food data in the FNDDS with reported intake data within the AMPM. However, the ability to collect unknown foods is a key component of the AMPM. Development of machine learning algorithms or other automated technology that applies predictive modeling needs to be evaluated for systematically handling unknown or unfound foods during dietary data collection. The challenge will be addressing the diversity of data from unknown food reports and establishing a proper learning algorithm that will produce expected outcomes with accuracy (16, 70).

4. FOOD AND NUTRIENT DATABASE FOR DIETARY STUDIES

Nutrient databases also provide critical tools for developing effective government policies to promote healthy diets and a nutritionally healthy food supply. Combined with national dietary surveys, nutrient databases provide estimates of the nutrients consumed by populations. Additionally, nutrient databases support the development and monitoring of policies addressing the nutrient composition of the food supply (47). The FNDDS is an application database created for analyzing dietary intakes from WWEIA, NHANES. It contains data to convert foods and their amounts reported in the AMPM into gram amounts and determine their nutrient values, as highlighted in **Figure 1**. FNDDS 2017–2018 (86), developed specifically for use with WWEIA, NHANES 2017–2018, contains food codes and their descriptions as well as portion weights and nutrient profiles.

4.1. Source of Nutrient Values

Each FNDDS food code contains nutrient values per 100 g of edible portion for 65 nutrients; there are no missing values. For FNDDS 2017–2018, the source for most nutrient values is the USDA FoodData Central (FDC) system, launched in April 2019 (85). The FDC is an integrated data system that presently provides—in one place—five distinct types of data containing information on food and nutrient profiles. Each data type has a unique purpose. The most current version of the FNDDS is part of FDC. The other two well-established data types are Standard Reference (SR) Legacy and the USDA Global Branded Food Products Database (Branded Foods). SR Legacy provides nutrient values derived from analyses, calculations, and published literature for 7,793 foods. Released in April 2018, it is the final release of this data type and will not be updated. Branded Foods is a public-private partnership whose goal is to enhance the open sharing of nutrient data that appear on branded and private-label foods. Updated monthly, Branded Foods contains almost 370,000 items.

The FDC also includes two new data types—Foundation Foods (FF) and Experimental Foods. The FF data type concentrates on the variability of the raw foods in the US food supply; the emphasis is on the analysis of individual samples of foods rather than composites. The result is a focus on fewer foods but a dramatic increase in the amount of data for each food (27). The Experimental Foods data type contains foods produced, acquired, or studied under unique conditions.

Data for approximately 2,300 items in SR Legacy and 45 items in FF were used to determine the nutrient values for the 7,083 foods and beverages in FNDDS 2017–2018. Approximately one-third of the FNDDS codes are a direct match to a single FDC code from either data set. The nutrient profiles for most foods and beverages in the FNDDS were generated using a recipe calculation process (62). In addition to selecting the appropriate ingredients and proportions for each recipe, nutrient retention and moisture change factors may be applied. The retention factor (88) adjusts the levels of 16 vitamins and eight minerals because of cooking preparation method. Moisture change factor accounts for how much moisture a food will lose or gain during cooking.

4.2. Strengths of the Food and Nutrient Database for Dietary Studies

The current strengths, limitations, and applications of technology of the FNDDS, the application database for the AMPM, are highlighted in **Table 3**.

4.2.1. Database to support the Automated Multiple-Pass Method. The AMPM and FNDDS are interrelated; both are critical components of national surveillance. AMPM questions and response options are the basis for the foods and their portion weights in the FNDDS. Since FNDDS codes are linked to pathways in the AMPM, updates to both are coordinated. The nutrient values reflect an average value for a generic representation of foods, as consumed by the US population. Food codes, when applicable, consider salt and fat used in preparation or processing.

Accurate estimation of food amount consumed is important. During the 24-h dietary recall, respondents in WWEIA, NHANES estimate the amount consumed using three-dimensional measuring guides on Day 1 and the USDA Food Model Booklet on Day 2. Respondents also report common amounts such as a medium-sized chicken breast, two slices of bread, or one piece of candy. The measuring guides and common amounts reported in the AMPM necessitate approximately 33,000 portion weights for converting foods collected in the AMPM into grams. This wide variety of weights in the AMPM and FNDDS allows for efficient collection and coding of food amounts reported in WWEIA. In addition, a criterion necessary for national surveillance is the ability to quickly code both food items and portions when specific details are not available. The FNDDS includes defaults of "Not Further Specified" for foods and "Quantity Not Specified" for portions.

4.2.2. Transparent public availability. One important purpose of the FNDDS is to provide transparent and easy access to the information used to determine the nutrient profiles for foods that are consumed by respondents in WWEIA, NHANES. A new version of the FNDDS is developed for each 2-year survey cycle and made publicly available on the Food Surveys Research Group website (86). The complete FNDDS is available in both SAS® and Microsoft Access® formats for download; selected variables provide quick viewing in Microsoft Excel file format.

To increase the transparency of the development of nutrient profiles, characterization of each ingredient nutrient value obtained from FDC was added. This includes the source of each nutrient value, how the value was derived, and the year of determination. Some FDC items were modified or corrected for inclusion in the FNDDS; the source for the modified nutrient value is provided.

4.2.3. Linkage to additional variables. The FNDDS can readily be linked to variables beyond traditional nutrients useful in evaluating adherence with dietary guidance messages and in studying associations between diet and health (55). The USDA's Food Patterns Equivalents Database (FPED) (87), a unique research tool to evaluate food and beverage intakes of Americans compared with recommendations of the DGA, converts foods and beverages in the FNDDS to 37 food pattern components. Analysis of foods and beverages as consumed in the American diet is enhanced with the WWEIA Food Categories (65), which link each FNDDS code to one WWEIA Food Category. The focus of this categorization system is on grouping together foods and beverages that have similar usage and nutrient content, with the emphasis on how foods and beverages are commonly consumed in the American diet. The WWEIA Food Category number and description are included as variables in the FNDDS to support search capabilities.

Both the FPED and the WWEIA Food Categories have been applied in a wide variety of analyses of dietary intake by researchers and by the DGA (91). Additionally, the process used to create the Thrifty Food Plan, 2021 relied on WWEIA Food Categories and FPED components (90). Although the FNDDS does not contain data on bioactive compounds or potentially harmful food components such as pesticides or contaminants, it is possible to link FNDDS codes to external databases. A flavonoid database (83) provides values for 29 flavonoids for USDA survey foods and beverages for 2007–2010.

4.3. Limitations of the Food and Nutrient Database for Dietary Studies

The current limitations of the FNDDS indicate challenges in advancing national dietary surveillance. Technology applications provide opportunities for advancement.

4.3.1. Generic food information. Since the AMPM and FNDDS are designed for national surveillance of the US population, the FNDDS was developed to generate approximations of the likely nutrient composition of foods and beverages as consumed by respondents in WWEIA, NHANES. The considerable increase in the number of commercial foods available at supermarkets, the rapid and frequent changes in formulations, and the wide range of restaurant foods do not allow for a quick estimate of the comprehensive intake of a population. To limit participant burden and to account for potential knowledge gaps in the ability to provide specific details about foods, the FNDDS reflects average values for a generic representation of foods and beverages as consumed by the US population.

4.3.2. Limited updates. Although a new version of the FNDDS is released for every 2-year survey cycle of the NHANES, the continuous nature of the NHANES and the resources needed to plan for future survey cycles while collecting data for present cycles and disseminating data for completed cycles have limited extensive updates. Beginning with the 2013–2014 survey cycle, selected pathways in the AMPM along with the corresponding FNDDS codes were completely revised. This modernization increased for successive cycles and included strategies for timely development for updating the FNDDS. The process involved minimizing specific food descriptions and consolidating foods into more generic codes that reflect likely products. This update increased efficiency by expanding the number of foods collected in the AMPM that were coded by an automated program.

Progress has also been made in reducing the number of food codes reported no more than one time in a 2-year survey cycle. In FNDDS 2007–2008 there were 3,200 codes reported no more than one time. For FNDDS 2017–2018 this decreased to 2,700 codes, with an additional 1,000 codes dropped for FNDDS 2019–2020. A resource file details every discontinued code, the rationale for discontinuation, and, if appropriate, a link to a new FNDDS code (1). This file supports researchers conducting trend analysis. Plans are to accelerate the process to delete rarely reported foods and concentrate resources on reviewing highly reported foods.

4.3.3. Availability of composition values. National nutrient intake data are constrained by the completeness and accuracy of the food composition values available. Reference databases include analyses of representative foods and provide values that are correct at one point in time. The massive increase in the number of prepared and proprietary food products available as well as rapid and frequent changes in formulations or recipes have made it impossible to analytically determine the composition of all, or even the most important, foods in the food system. Cost is also an issue when analysis for a complete set of nutrients for one food can exceed $50,000 (27). Even when nutrient values are determined by calculation or imputed from similar foods, the maintenance and continual updating of food composition information within a national database is an expensive process (73).

As FDC, the new USDA data system, continues to develop and the amount of FF data increases, it is necessary to rely on SR Legacy for nutrient values. Although the FNDDS utilizes approximately 2,300 SR Legacy codes and 45 FF codes to develop nutrient profiles, only 600 account for 95% of dietary intake reports in WWEIA, NHANES 2017–2018. These top FDC codes include items such as water, milk, oils, butter, margarines, cheese, eggs, flour, onion, and tomato, items linked to both a single FNDDS code and utilized as ingredients for recipe calculations. A review of the currency of the nutrient values of the top 600 codes for two nutrients of public health concern—saturated fat and calcium—indicate that 50% and 41% of the values for saturated fat and calcium, respectively, list values from the years 2010–2019. Approximately 22% of the values for both nutrients were from the year 1999 or earlier. FF provides the date the item was acquired for analysis; SR Legacy, retired in 2018, indicates the date each nutrient value was added or last modified. These dates are also included in the FNDDS files.

Every food code in the FNDDS includes a value for each of the 65 nutrients included in the dietary data release of WWEIA, NHANES. Since the beginning of the continuous NHANES, four additional nutrients have been released: vitamin E, added; vitamin D; vitamin B_{12}, added; and choline. Limitations and gaps in FDC need to be considered for coverage of all nutrients. Each of the data types in FDC has unique characteristics and a range of nutrient values. For updating FNDDS 2017–2018, assumptions were made to estimate missing values in FF or to update SR Legacy values. Addressing these limitations and gaps will be critical for future updates to the FNDDS; therefore, populating missing or outdated nutrient values using algorithms and model calculations must be considered. Given that resources are always limited, more creative efforts to enhance our nutrition databases are needed (47). However, as databases become more complex and data continue to become more available, the focus must be on technology.

The availability of food composition data and the projected cost lead to consideration of critical nutrients for national surveillance. It is unclear if data for all nutrients reported in WWEIA are necessary for nutrition monitoring and what other nutrients might be important. Looking to the future, selections must be made considering specific nutrients for which there are identified needs on the basis of policy and research priorities. Accuracy and reliability of analytic procedures for the nutrient must also be considered.

5. EMERGING TECHNOLOGY APPLICATIONS IN DIETARY ASSESSMENT

Technology applications incorporated within the AMPM and FNDDS have been elaborated. The development and application of new technologies for dietary assessment both nationally and internationally have been reviewed and summarized (4, 11, 13, 16, 19, 22, 28, 30, 36, 78). There are several new technologies that can be categorized according to technology type, including web-based assessment tools and apps, cameras or image-based tools, and other technologies such as wearable sensors (22). This section focuses on these innovations as they relate to US dietary surveillance and specifically the ability to meet the foremost objectives essential for national dietary surveillance as detailed in **Table 2**.

5.1. Web-Based Dietary Assessment

In recent years, expanded use of computers and the internet has prompted the adaptation of automated dietary data collection software to web-based collection versions. The web-based dietary assessment tools developed for use in research have typically been tailored to closely match methods used in interviewer-led automated dietary data collection and are available in the United States as well as other countries such as Canada, the United Kingdom, and Germany (26, 43, 46, 77). The United Kingdom conducts a continuous cross-sectional national dietary survey and is currently evaluating the use of a self-administered web-based dietary assessment tool with data collection that started in 2019 (67). Self-administered web-based dietary assessment tools offer advantages such as reduction in costs associated with interviewers, flexibility in the time and location of data collection, and potential for expedited data collection over a large geographic area (77, 78).

A prominent self-administered web-based dietary assessment tool in the United States is the Automated Self-Administered 24-Hour (ASA24) tool. Developed by the National Cancer Institute in 2009, ASA24 is publicly available and has been used by nutrition researchers to collect 630,000 dietary intakes (57). ASA24 has been validated with biomarkers and evaluated against other dietary measures (42, 58). It is indicated as being most appropriate for those 12 years and older with at least a fifth-grade reading level and who are comfortable using computers, tablets, or mobile devices (57). ASA24 also provides optional modules to capture information related to dietary intake such as supplement intake and activities during eating.

ASA24 was designed on the basis of aspects of the AMPM including the multipass approach and food pathway questions and the FNDDS database for nutrient content of foods. The current ASA24-2020 uses AMPM 2015–2016 food pathway questions and FNDDS 2015–2016 (57). The upcoming version, ASA24-2022, will incorporate FNDDS 2017–2018.

ASA24 is a fully autocoded tool; that is, all food entries are automatically coded, and nutrient calculation is performed within the software. ASA24 allows for the entry of an unfound food; however, the system then assigns a default code to this item on the basis of a series of follow-up questions (101). The researcher can review files to check whether the resulting matches are appropriate. Although burdensome for the researcher, this aspect of data collection is valuable and indicates the challenges of achieving total automation in dietary assessment.

One challenge in the adoption of self-administered web-based dietary assessment tools for national dietary surveillance is usability among a diverse population. Determining how to create a self-administered web-based program that can be used by all populations and age ranges remains problematic (28, 78). Web-based assessment methods are better suited for study populations with higher technological literacy and reliable access to internet service (23). Segments of the population, such as older adults, may be less likely to participate or more likely to have difficulty with web-based dietary data collection (14, 23, 79, 98). Levels of income and education are also related to the usability of self-administered web-based dietary assessment tools (41, 45, 68).

Overall usability of self-administered web-based dietary assessment tools is of great importance to compel respondent participation and has not been widely assessed. A review that looked at the usability of a selection of self-administered web-based tools indicated some common issues including difficulties in identifying the correct food, issues with navigation within the tool, and difficulties logging in (28).

Challenges similar to those experienced with the AMPM and FNDDS also exist in the adoption of self-administered web-based dietary assessment tools for national dietary surveillance, specifically the continuous maintenance of the program to reflect changes in food supply and food behaviors and a background food and nutrient database that is transparent. Although automation of dietary intake data collection and food coding may be desirable, certain aspects such as the ability to incorporate foods and portions reported that do not have matches within the database are desirable to capture eating behaviors of a diverse population.

5.2. Mobile- or App-Based Dietary Assessment

A recent assessment indicated that 30,000 diet and physical activity mobile apps are available on Google Play and the Apple App Store (40). Selected popular examples include MyFitnessPal and WW (Weight Watchers Reimagined)®, which have 1.3 and 1.7 million ratings in the Apple App Store, respectively. These consumer-based apps are very popular for real-time self-tracking with easy access due to the advantage of portability. Interactive features, such as goal setting, provide the user with the ability to monitor progress along with dietary intake and may possibly prompt healthy behavior change (16). Some apps have incorporated additional features including the ability to scan a product barcode, add in personal recipes or nutrient profiles of unique foods, or link to fitness-monitoring devices. Basic versions of consumer-based apps are often free to download, with the option to purchase additional features.

In addition to consumer-based apps, there have also been apps developed for use in nutrition and health research. These apps have often been developed for use in a specific study or study population, such as for weight loss, although there are also apps being developed for general assessment of dietary intake (12, 15, 63). Apps developed for nutrition research may provide additional benefits from a researcher standpoint including identifiable scientific input and validation, a higher quality background food and nutrient database, and better access to data (40).

Although consumer-based apps are very useful for tracking self-intake and related health information, they are not appropriate for national dietary surveillance due to the lack of standardized methodology and the lack of transparency in associated food and nutrient databases. Chen et al. (17) compared 24-h dietary recall data collected on the basis of the AMPM with data from individuals logging intake in MyFitnessPal and found 18% of food items omitted on average and significant underestimation of mean energy and macronutrient intake when entered using

MyFitnessPal. Consumer-based apps may have tens of thousands of foods available for coding; however, the ability of the user to enter in their own recipes or nutrient profile means there is a lack of scientific vetting of the assigned nutrient profiles. There are also concerns about the accuracy of the nutrient values within the apps, including missing values (33). In addition, there may be limited access to background nutrient values as well as resulting dietary intake data files (48).

Apps specifically developed for nutrition research may have advantages for use in national dietary surveillance, as they have been developed for research purposes. However, challenges still exist related to compelling respondent participation. Although data entry via apps is flexible in relation to location and time, when compared with the time needed for traditional dietary recall interviews, a user will require additional time to learn how to use the specific app and familiarize themselves with the process of entering foods and navigating the database (12). It also must be recognized that the amount of time a participant is willing to spend entering dietary data in general is limited and may vary by age and other characteristics. For example, adults may be willing to spend slightly more time entering an assessment than adolescents (14). Apps developed for research purposes require more time for data entry due to the incorporation of prompts and probes for detailed food data collection, and this additional time is less desirable from a user standpoint.

5.3. Image-Based Dietary Assessment

Cameras, as a component of smartphones, allow an individual to create a dynamic representation of food consumption via pictures. Approximately 85% of adults aged 18 years or older in the United States owned a smartphone in 2020, a large increase from the approximately 35% of adults who owned one in 2011 (60). Digital images have been used in recent years to either assist or replace data collected for dietary records and 24-h dietary recalls (11). Capturing images can be either active or passive and can vary in the amount of participation required from the user.

A prominent active image-capturing technique is the Technology Assisted Dietary Assessment (TADA) system, which includes a mobile food record (mFR) app for collection of the food record that is then connected to an image-based food and nutrient database system (3). The system design has been validated using both controlled feeding and community-dwelling studies, and energy accuracy was assessed via doubly labeled water (3, 10). The user captures images of foods via the camera in a smartphone before and after eating. A critical component for image capture and analysis is a fiducial marker placed in the image that is a reference for the spatial and color calibration of the camera and enables both identification of the foods and portion size estimation. The image must also be captured from a specific angle, and the user is assisted in complying with this requirement by a colored border in the camera display. Along with other metadata, captured images are then sent to the server, processed, and returned to the user for review and confirmation. The user can either confirm or change the food identification to a suggested food or search for another food via a food list. TADA incorporates an expanded version of the FNDDS with the addition of visual descriptions and other information such as barcode data.

Passive image capturing uses a device that is worn and triggered by human or external sensors. An example of a passive image-capturing device used in dietary data collection is the SenseCam, which is a camera worn around the neck that can operate continuously to capture images approximately every 20 s and is triggered via sensors that detect movement, heat, and light (29). A study using another automated passive image-capturing system that captured an image every 10 s found that this frequency captured foods at regular meals but that a higher frequency would be needed to capture items quickly consumed such as snacks or beverages (6). Battery life and data storage capacity are considerations with passive image capturing as well, when it is necessary to capture high-quality images consistently throughout the day. Whether an image is taken with a smartphone or via a sensor-triggered device, there is still an element of active participation by the user. Training and the use of a device are required.

The use of image capturing for national dietary surveillance presents multiple challenges related to the lack of available standardized methodologies, the process of linking images to a food and nutrient database, and the need to compel respondent participation. Previous studies incorporating image-based dietary assessment have typically used smaller samples of select population groups, and standardized validated methods for this emerging technology are still being developed (11, 30, 36). For example, Boushey et al. (10) found that energy intake accuracy results for the TADA mFR were comparable with traditional dietary records and other image-based methods for a group of 45 adults aged 21–65 years. However, with a mean age of 33 years and a majority non-Hispanic sample, it is unknown how these results may translate to use by the broader national population. Although promising, more research is needed in this area on larger and more diverse populations.

The number of images received in a large-scale survey, particularly if passive image-taking methods were used, would be overwhelming to attempt to manually code and analyze (36). The example of an image captured every 10 s corresponds to 8,640 images during a 24-h time frame. Although images would not need to be captured during sleep, this still corresponds to thousands of images per user on a given day. To address the burden of image review, technologies such as automatic image recognition and estimates of volume are being developed, but enhanced algorithms will be required to further this technology to the point where it can be used for large studies of populations with varied eating behaviors (25, 35, 96). In addition to automatic image recognition, an extensive database of food images along with portion data and nutrient profiles is required to code and analyze reported foods and would need to be continually updated as new products enter the marketplace (3).

Challenges beyond those traditionally associated with collection of dietary intake data may also arise with the capturing of images. Although smartphone users would likely be familiar with use of the camera, time would be needed for training or familiarization with the data collection method. Depending on the device and mode of image capture, users may have the additional burden of taking the image and then reviewing the image to ensure that privacy concerns are met, that is, there is no sensitive material within the image such as other people or objects, before uploading the image (36). If needed, the user must also remember to carry with them and use a fiduciary marker when the image is captured. After the image is uploaded and processed, there may be additional review required by the user to verify and confirm the food matched either automatically or by research staff. There may be other unique concerns in addition to the collection of images such as altering of behavior due to the use or wearing of an image-capturing device. There may also be technical issues or the prohibition of cameras in some environments such as schools, all of which would affect respondent participation and the collection of accurate dietary information (39, 59, 100).

5.4. Other Technologies

Along with the web-, app-, and image-based technologies that have been highlighted and discussed, a variety of other technologies are available. Select examples include sensors, direct measures of diet quality, and biomarkers.

Use of sensors as a direct measure of eating behavior is an emerging area. Surface pressure sensors placed on a table can automatically weigh food before, during, and after the eating occasion (34). Wearable sensors have been developed that detect the movements associated with chewing and swallowing (97). Multiple aspects of intake can be assessed using sensors; however, no input regarding type of food consumed is tracked.

An example of a technology that has incorporated diet quality metrics within a 24-h dietary recall collection is the Global Diet Quality Score (GDQS) application (54). GDQS uses a 24-h dietary recall to collect a list of all foods consumed, automatically classify them into the corresponding GDQS food group, and assess the quantity consumed on the basis of a set of 10 cubes in a range of predetermined sizes per GDQS food group. The metric is entirely food based, does not require the use of a food composition table for analysis, and allows for an automated assessment of healthy diets. However, characteristics of food intake including time, eating occasion, and source are not assessed.

Dietary biomarkers provide an objective measure of dietary intake. Currently, only a few reliable intake biomarkers are known, and these include doubly labeled water for total energy expenditure, 24-h urinary nitrogen for protein, and 24-h urinary sodium for sodium and potassium. Numerous other biomarkers have been used in research that assess nutrient, food, or food group intakes (61). Mainly, dietary biomarkers are currently used to assess single nutrients and foods and do not provide an understanding of eating behaviors in dietary surveillance such as time of eating and source of food. While biomarkers do overcome inherent limitations in self-reported dietary intake, they are costly and invasive. There is extensive ongoing work in this field utilizing multidisciplinary approaches in biomarker development that support precision nutrition (49).

6. APPLICATION OF NUTRIENT DATABASES

The supporting database of foods and beverages and their nutritional composition is integral to monitoring dietary intake. The nutrient profiles incorporated into the FNDDS have been sourced from existing USDA food composition databases; supporting documentation is provided for the source of each nutrient value. However, changes to the development of these databases along with the expanded availability of branded food data necessitate an evaluation of how food composition data will be reviewed and included in future national dietary surveillance of the US population.

6.1. Commercial Databases

Nutrient databases, produced outside the federal government, are available in the United States for analyzing dietary intakes. For example, the University of Minnesota's Nutrition Coordinating Center (82) provides databases, software, training, and services for the collection and analysis of dietary data. The food and nutrient database contains approximately 19,000 foods, including brand-name products and menu items from leading restaurants. Commercial databases do not meet the guiding principle that data need to be transparent and publicly available; therefore, commercial databases are not applicable for national dietary surveillance.

6.2. Branded Foods

Food and beverage companies already provide a significant amount of nutrition information in the form of the Nutrition Facts panel and can transmit this information electronically to their customers or retail stores (7). Compilation of data provided by manufacturers into a retail product database may be faster and cheaper than construction of standard food composition databases and may provide opportunities to enhance our capacity for capturing the nutritional information of foods. However, there is still a long way to go if we are to ensure the transparency and accuracy of such information (81). Even though the data are available, accessing and combining data from different data sets is not an easy task. Development of tools and software to assist in data compilation is a challenge (38).

Branded Foods is the result of a public-private partnership, whose goal is to enhance public health and the open sharing of the nutrient composition of branded and private-label foods provided by the food industry (85). Branded Foods, containing almost 370,000 items, is part of the USDA FDC and, therefore, is publicly available for download. The food market is constantly evolving, with products within a single food category having varied nutrient profiles. Use of branded product data may help to capture this variety of nutrients (76). A UK study identified that changes in the diet may be more attributable to product reformulation than to changes in consumer behaviors (32). Thus, it is important to capture dynamic trends in product reformulation.

Incorporating data from a very large source of branded product data may pose unique challenges as well when a search for a specific product type or name may yield hundreds to thousands of results (21). An attempt to demonstrate the process of linking FNDDS codes to a private-label database indicated that considerable manual review was required to link approximately 5,000 cookies to 111 food codes (76). The researcher burden to link data from a private-label database is extensive, and machine learning algorithms are required to deliver a practical number of food items.

Another critical issue for the incorporation of branded product data into the FNDDS is that label data are generally only inclusive of those nutrients legally required to be present. These nutrients are not as comprehensive as the list of 65 nutrients and food components incorporated into each nutrient profile for the approximately 7,000 FNDDS foods and beverages. Label data provided to Branded Foods often report nutrition information for products as purchased; the FNDDS calculates nutrition information for foods as consumed. In addition, Branded Foods does not provide information on the wide range of restaurant foods available in the United States.

While it is increasingly easy to store and transfer large data sets and make them available online, it is usually necessary to do a large amount of work to clean and standardize the data before the data sets can be accurately and usefully combined (38). With large data sets such as Branded Foods, there is also the risk of overwhelming the respondent. When faced with extensive lists of products, there is the potential for the user to select the first option that resembles a reported food, rather than reviewing all the options to select the best match, resulting in user bias.

7. CONCLUSION

National dietary surveillance, the foundation for informing federal nutrition policies and programs, demands accurate and timely data reflective of a population's food choices and eating behavior. Over the past two decades, the USDA's AMPM and FNDDS have been effective components in monitoring dietary intakes of the US population. The application of technology has played critical roles both within the AMPM's traditional 24-h dietary data collection and in the translation of collected dietary data to public data release. Emerging technology applications for dietary assessment are numerous and well established in society. The development of such new dietary assessment technologies is also a fast-developing field in health research and application. Moving forward, national dietary surveillance must take advantage of these new technologies for their potential in enhanced efficiency and objectivity in data operations. For any new technology to be valuable in dietary surveillance of the diverse US population, it must compel respondents to collect accurate dietary information. Furthermore, any new dietary assessment technology must also be standardized, validated, and publicly transparent.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

LITERATURE CITED

1. Adler ME, Rhodes DG, Moshfegh AJ. 2017. Discontinued codes in the USDA Food and Nutrient Database for Dietary Studies. *J. Food Compos. Anal.* 64:104–6
2. Ahluwalia N, Dwyer J, Terry A, Moshfegh A, Johnson C. 2016. Update on NHANES dietary data: focus on collection, release, analytical considerations, and uses to inform public policy. *Adv. Nutr.* 7(1):121–34
3. Ahmad Z, Kerr DA, Bosch M, Boushey CJ, Delp EJ, et al. 2016. A mobile food record for integrated dietary assessment. In *MADiMa'16: Proceedings of the 2nd International Workshop on Multimedia Assisted Dietary Management*, *Amsterdam*, *The Netherlands*, pp. 53–62. New York: ACM
4. Amoutzopoulos B, Steer T, Roberts C, Cade JE, Boushey CJ, et al. 2018. Traditional methods *v.* new technologies – dilemmas for dietary assessment in large-scale nutrition surveys and studies: a report following an international panel discussion at the 9th International Conference on Diet and Activity Methods (ICDAM9), Brisbane, 3 September 2015. *J. Nutr. Sci.* 7:e11
5. Anderson E, Steinfeldt L. 2004. Blaise instrument design for automated food coding. In *Proceedings of the 9th International Blaise Users' Conference*, *IBUC 2004*, *Gatineau*, *Quebec*, *September 22–24*, *2004*, pp. 129–36. Ottawa, Canada: Statistics Canada
6. Arab L, Winter A. 2010. Automated camera-phone experience with the frequency of imaging necessary to capture diet. *J. Am. Diet Assoc.* 110(8):1238–41
7. Black R. 2017. Begin to imagine: thoughts and considerations following the 39th NNDC. *J. Food Compos. Anal.* 64:143–44
8. Blanton CA, Moshfegh AJ, Baer DJ, Kretsch MJ. 2006. The USDA Automated Multiple-Pass Method accurately estimates group total energy and nutrient intake. *J. Nutr.* 136(10):2594–99
9. Bliss R. 2004. Researchers produce innovation in dietary recall. *Agric. Res.* 52(6):10–12
10. Boushey CJ, Spoden M, Delp EJ, Zhu F, Bosch M, et al. 2017. Reported energy intake accuracy compared to doubly labeled water and usability of the Mobile Food Record among community dwelling adults. *Nutrients* 9(3):312
11. Boushey CJ, Spoden M, Zhu FM, Delp EJ, Kerr DA. 2017. New mobile methods for dietary assessment: review of image-assisted and image-based dietary assessment methods. *Proc. Nutr. Soc.* 76(3):283–94
12. Bucher Della Torre S, Carrard I, Farina E, Danuser B, Kruseman M. 2017. Development and evaluation of e-CA, an electronic mobile-based food record. *Nutrients* 9(1):76
13. Cade JE. 2017. Measuring diet in the 21st century: use of new technologies. *Proc. Nutr. Soc.* 76(3):276–82
14. Carter MC, Albar SA, Morris MA, Mulla UZ, Hancock N, et al. 2015. Development of a UK online 24-h dietary assessment tool: myfood24. *Nutrients* 7(6):4016–32
15. Carter MC, Burley VJ, Nykjaer C, Cade JE. 2013. 'My Meal Mate' (MMM): validation of the diet measures captured on a smartphone application to facilitate weight loss. *Br. J. Nutr.* 109(3):539–46
16. Chaves LO, Domingos ALG, Fernances DL, Cerqueira FR, Siequeira-Batista R, Bressan J. 2021. Applicability of machine learning techniques in food intake assessment: a systematic review. *Crit. Rev. Food Sci. Nutr.* **https://doi.org/10.1080/10408398.2021.1956425**
17. Chen JC, Berkman W, Bardouh M, Kammy CY, Allman-Farinelli M. 2019. The use of a food logging app in the naturalistic setting fails to provide accurate measurements of nutrients and poses usability challenges. *Nutrition* 57:208–16
18. Chin EL, Simmons G, Bouzid YY, Kan A, Burnett DJ, et al. 2019. Nutrient estimation from 24-hour food recalls using machine learning and database mapping: a case study with lactose. *Nutrients* 11(12):3045
19. Conrad J, Nöthlings U. 2017. Innovative approaches to estimate individual usual dietary intake in large-scale epidemiological studies. *Proc. Nutr. Soc.* 76(3):213–19
20. DiGrande L, Pedrazzani S, Kinyara E, Hymes M, Karns S, et al. 2021. *Field interviewer-administered dietary recalls in participants' homes: a feasibility study using the US Department of Agriculture's Automated Multiple-Pass Method*. RTI Press Publ. MR-0045-2105, RTI Press, Research Triangle Park, NC
21. Drewnowski A. 2021. Perspective: identifying ultra-processed plant-based milk alternatives in the USDA Branded Food Products Database. *Adv. Nutr.* 12(6):2068–75
22. Eldridge AL, Piernas C, Illner AK, Gibney MJ, Gurinovic MA, et al. 2018. Evaluation of new technology-based tools for dietary intake assessment—an ILSI Europe Dietary Intake and Exposure Task Force evaluation. *Nutrients* 11(1):55

23. Ettienne-Gittens R, Boushey CJ, Au D, Murphy SP, Lim U, Wilkens L. 2013. Evaluating the feasibility of utilizing the Automated Self-administered 24-hour (ASA24) dietary recall in a sample of multiethnic older adults. *Procedia Food Sci.* 2:134–44
24. Evans K, Hennessy A, Walton J, Timon C, Gibney E, Flynn A. 2017. Development and evaluation of a concise food list for use in a web-based 24-h dietary recall tool. *J. Nutr. Sci.* 6:e46
25. Fang S, Liu C, Zhu F, Delp EJ, Boushey CJ. 2015. Single-view food portion estimation based on geometric models. *ISM* 2015:385–90
26. Foster E, Lee C, Imamura F, Hollidge SE, Westgate KL, et al. 2019. Validity and reliability of an online self-report 24-h dietary recall method (Intake24): a doubly labelled water study and repeated-measures analysis. *J. Nutr. Sci.* 8:e29
27. Fukagawa NK, McKillop K, Pehrsson PR, Moshfegh A, Harnly J, Finley J. 2022. USDA's FoodData Central: what is it and why is it needed today? *Am. J. Clin. Nutr.* 115(3):619–24
28. Gazan R, Vieux F, Mora S, Havard S, Dubuisson C. 2021. Potential of existing online 24-h dietary recall tools for national dietary surveys. *Public Health Nutr.* 24(16):5361–86
29. Gemming L, Rush E, Maddison R, Doherty A, Gant N, et al. 2015. Wearable cameras can reduce dietary under-reporting: doubly labelled water validation of a camera-assisted 24 h recall. *Br. J. Nutr.* 113(2):284–91
30. Gemming L, Utter J, Ni Mhurchu C. 2015. Image-assisted dietary assessment: a systematic review of the evidence. *J. Acad. Nutr. Diet.* 115(1):64–77
31. Grandjean AC. 2012. Dietary intake data collection: challenges and limitations. *Nutr. Rev.* 70(Suppl. 2):S101–4
32. Griffith R, O'Connell M, Smith K. 2017. The importance of product reformulation versus consumer choice in improving diet quality. *Economica* 84:34–53
33. Griffiths C, Harnack L, Pereira MA. 2018. Assessment of the accuracy of nutrient calculations of five popular nutrition tracking applications. *Public Health Nutr.* 21(8):1495–502
34. Haarman JAM, de Vries RAJ, Harmsen EC, Hermens HJ, Heylen DKJ. 2020. Sensory Interactive Table (SIT)—development of a measurement instrument to support healthy eating in a social dining setting. *Sensors* 20(9):2636
35. Herzig D, Nakas CT, Stalder J, Kosinski C, Laesser C, et al. 2020. Volumetric food quantification using computer vision on a depth-sensing smartphone: preclinical study. *JMIR Mhealth Uhealth* 8(3):e15294
36. Höchsmann C, Martin CK. 2020. Review of the validity and feasibility of image-assisted methods for dietary assessment. *Int. J. Obes.* 44(12):2358–71
37. Inst. Med. 2000. *Dietary Reference Intakes: Applications in Dietary Assessment*. Washington, DC: National Academy Press
38. Kapsokefalou M, Roe M, Turrini A, Costa HS, Martinez-Victoria E, et al. 2019. Food composition at present: new challenges. *Nutrients* 11(18):1714
39. Kelly P, Marshall SJ, Badland H, Kerr J, Oliver M, et al. 2013. An ethical framework for automated, wearable cameras in health behavior research. *Am. J. Prev. Med.* 44(3):314–19
40. Khazen W, Jeanne JF, Demaretz L, Schafer F, Fagherazzi G. 2020. Rethinking the use of mobile apps for dietary assessment in medical research. *J. Med. Internet Res.* 22(6):e15619
41. Kirkpatrick SI, Guenther PM, Douglass D, Zimmerman T, Kahle LL, et al. 2019. The provision of assistance does not substantially impact the accuracy of 24-hour dietary recalls completed using the automated self-administered 24-h dietary assessment tool among women with low incomes. *J. Nutr.* 149(1):114–22
42. Kirkpatrick SI, Subar AF, Douglass D, Zimmerman TP, Thompson FE, et al. 2014. Performance of the Automated Self-Administered 24-hour Recall relative to a measure of true intakes and to an interviewer-administered 24-h recall. *Am. J. Clin. Nutr.* 100(1):233–40
43. Koch SAJ, Conrad J, Cade JE, Weinhold L, Alexy U, Nöthlings U. 2021. Validation of the web-based self-administered 24-h dietary recall myfood24-Germany: comparison with a weighed dietary record and biomarkers. *Eur. J. Nutr.* 60(7):4069–82
44. Koroušić Seljak B, Korošec P, Eftimov T, Ocke M, van der Laan J, et al. 2018. Identification of requirements for computer-supported matching of food consumption data with food composition data. *Nutrients* 10(4):433

45. Kupis J, Johnson S, Hallihan G, Olstad DL. 2019. Assessing the usability of the Automated Self-Administered Dietary Assessment Tool (ASA24) among low-income adults. *Nutrients* 11(1):132
46. Lafreniere J, Lamarche B, Laramee C, Robitaille J, Lemieux S. 2017. Validation of a newly automated web-based 24-hour dietary recall using fully controlled feeding studies. *BMC Nutr.* 3:34
47. Leighton J, Koehler KM, Kavanaugh C, Heintz K. 2013. Nutrient databases: critical tools for policy development. *Procedia Food Sci.* 2:187–94
48. Maringer M, van't Veer P, Klepacz N, Verain MCD, Norman A, et al. 2018. User-documented food consumption data from publicly available apps: an analysis of opportunities and challenges for nutrition research. *Nutr. J.* 17(1):59
49. Maruvada P, Lampe JW, Wishart DS, Barupal D, Chester DN, et al. 2020. Perspective: dietary biomarkers of intake and exposure—exploration with omics approaches. *Adv. Nutr.* 11(2):200–15
50. McBride J. 2001. Was it a slab, a slice, or a sliver? *Agric. Res.* 49:4–7
51. Morton S, Rhodes DG, Moshfegh AJ. 2020. *Convenience stores: source of food/beverages among adults: What We Eat in America, NHANES 2013–2016*. Dietary Data Brief 27, Food Surv. Res. Group, Beltsville, MD
52. Morton S, Rhodes DG, Moshfegh AJ. 2021. *Convenience stores: source of food/beverages among children: What We Eat in America, NHANES 2015–2018*. Dietary Data Brief 42, Food Surv. Res. Group, Beltsville, MD
53. Moshfegh AJ, Rhodes DG, Baer DJ, Murayi T, Clemens JC, et al. 2008. The US Department of Agriculture Automated Multiple-Pass Method reduces bias in the collection of energy intakes. *Am. J. Clin. Nutr.* 88(2):324–32
54. Moursi M, Bromage S, Fung TT, Isanaka S, Matsuzaki M, et al. 2021. There's an app for that: development of an application to operationalize the Global Diet Quality Score. *J. Nutr.* 151:176S–86S
55. Murphy SP. 2013. Aligning food composition tables with current dietary guidance for consumers. *Procedia Food Sci.* 2:12–19
56. Natl. Cent. Health Stat. 2015. *Measuring guides for the NHANES dietary recall interview*. Rep., Natl. Cent. Health Stat., Washington, DC. **https://www.cdc.gov/nchs/nhanes/measuring_guides_dri/measuringguides.htm**
57. Natl. Inst. Health, Natl. Cancer Inst. 2021. *Automated Self-Administered 24-Hour (ASA24®) dietary assessment tool*. Rep., Natl. Cancer Inst., Div. Cancer Control Popul. Sci., Epidemiol. Genom. Res. Progr., Bethesda, MD. **https://epi.grants.cancer.gov/asa24**
58. Park Y, Dodd KW, Kipnis V, Thompson FE, Potischman N, et al. 2018. Comparison of self-reported dietary intakes from the Automated Self-Administered 24-h recall, 4-d food records, and food-frequency questionnaires against recovery biomarkers. *Am. J. Clin. Nutr.* 107(1):80–93
59. Pettitt C, Liu J, Kwasnicki RM, Yang GZ, Preston T, Frost G. 2016. A pilot study to determine whether using a lightweight, wearable micro-camera improves dietary assessment accuracy and offers information on macronutrients and eating rate. *Br. J. Nutr.* 115(1):160–67
60. Pew Res. Cent. 2021. *Mobile fact sheet*. Fact Sheet, Pew Res. Cent., Washington, DC. **https://www.pewresearch.org/internet/fact-sheet/mobile/**
61. Picó C, Serra F, Rodríguez AM, Keijer J, Palou A. 2019. Biomarkers of nutrition and health: new tools for new approaches. *Nutrients* 11(5):1092
62. Powers PM, Hoover LW. 1989. Calculating the nutrient composition of recipes with computers. *J. Am. Diet. Assoc.* 89(2):224–32
63. Rangan AM, Tieleman L, Louie JC, Tang LM, Hebden L, et al. 2016. Electronic Dietary Intake Assessment (e-DIA): relative validity of a mobile phone application to measure intake of food groups. *Br. J. Nutr.* 115(12):2219–26
64. Raper N, Perloff B, Ingwersen L, Steinfeldt L, Anand J. 2004. An overview of USDA's Dietary Intake Data System. *J. Food Compos. Anal.* 17(3–4):545–55
65. Rhodes DG, Adler ME, Clemens JC, Moshfegh AJ. 2017. What We Eat in America Food Categories and changes between survey cycles. *J. Food Compos. Anal.* 64:107–11
66. Rhodes DG, Murayi T, Clemens JC, Baer DJ, Sebastian RS, Moshfegh AJ. 2013. The USDA Automated Multiple-Pass Method accurately assesses population sodium intakes. *Am. J. Clin. Nutr.* 97(5):958–64
67. Roberts C, Collins D, Amoutzopoulos B, Steer T, Page P. 2021. *Evaluation of changes in the dietary methodology in the National Diet and Nutrition Survey rolling programme from year 12 (2019 to 2020)*

stage 1. Rep., Public Health England and UK Food Standards Agency, London, UK. **https://www.gov.uk/government/publications/evaluation-of-change-in-dietary-methodology-in-ndns-rolling-programme-stage-1**

68. Rowland MK, Adamson AJ, Poliakov I, Bradley J, Simpson E, et al. 2018. Field testing of the use of Intake24—an online 24-hour dietary recall system. *Nutrients* 10(11):1690
69. Saksena MJ, Okrent AM, Anekwe TD, Cho C, Dicken C, et al. 2018. *America's eating habits: food away from home*. EIB 196, U.S. Dep. Agric., Econ. Res. Serv., Washington, DC
70. Sarker IH. 2021. Machine learning: algorithms, real-world applications and research directions. *SN Comput. Sci.* 2(3):160
71. Sebastian RS, Wilkinson EC, Goldman JD, Hoy MK, Moshfegh AJ. 2015. Sandwich consumption by adults in the US: What We Eat in America, NHANES 2009–2012. Dietary Data Brief 14, Food Surv. Res. Group, Beltsville, MD
72. Sebastian RS, Wilkinson EC, Goldman JD, Murayi T, Moshfegh AJ. 2021. Late evening eating patterns among U.S. adults vary in their associations with, and impact on, energy intake and diet quality: Evidence from What We Eat In America, National Health and Nutrition Examination Survey 2013–2016. *J. Acad. Nutr. Diet.* 122(5):932–48
73. Sivakumaran S, Huffman L, Sivakumaran S. 2016. The New Zealand Food Composition Database: a useful tool for assessing New Zealanders' nutrient intake. *Food Chem.* 238:101–10
74. Stat. Neth. (CBS). 2020. About Blaise®. *Statistics Netherlands*. **https://blaise.com/blaise/about-blaise**
75. Steinfeldt LC, Martin CL, Clemens JC, Moshfegh AJ. 2021. Comparing two days of dietary intake in What We Eat in America (WWEIA), NHANES, 2013–2016. *Nutrients* 13(8):2621
76. Taylor CA, Watowicz RP, Spees CK, Hooker NH. 2018. Shelf to health: Does product innovation change national estimates of dietary impacts? *J. Food Sci.* 83(3):831–36
77. Thompson FE, Dixit-Joshi S, Potischman N, Dodd KW, Kirkpatrick SI, et al. 2015. Comparison of interviewer-administered and automated self-administered 24-hour dietary recalls in 3 diverse integrated health systems. *Am. J. Epidemiol.* 181(12):970–78
78. Timon CM, van den Barg R, Blain RJ, Kehoe L, Evans K, et al. 2016. A review of the design and validation of web- and computer-based 24-h dietary recall tools. *Nutr. Res. Rev.* 29(2):268–80
79. Timon CM, Walton J, Flynn A, Gibney ER. 2021. Respondent characteristics and dietary intake data collected using web-based and traditional nutrition surveillance approaches: comparison and usability study. *JMIR Public Health Surveill.* 7(4):e22759
80. Tippett KS, Enns CW, Moshfegh AJ. 1999. Food consumption surveys in the US Department of Agriculture. *Nutr. Today* 34(1):33–46
81. Traka MH, Plumb J, Berry R, Pichen H, Finglas PM. 2020. Maintaining and updating food composition datasets for multiple users and novel technologies: current challenges from a UK perspective. *Nutr. Bull.* 45(2):230–40
82. Univ. Minn. 2021. Database licensing. *University of Minnesota Nutrition Coordinating Center*. **http://www.ncc.umn.edu/food-and-nutrient-database/**
83. U.S. Dep. Agric. 2016. *Flavonoid values for USDA survey foods and beverages 2007–2010*. Rep., U.S. Dep. Agric., Agric. Res. Serv., Food Surv. Res. Group, Beltsville, MD. **https://www.ars.usda.gov/ARSUserFiles/80400530/pdf/fndds/Flav_factsheet_2007-10.pdf**
84. U.S. Dep. Agric. 2020. *All restaurants: percent reporting, mean amounts, and percent of selected nutrients from foods obtained from all restaurants, by gender and age, in the United States, 2017–2018. What We Eat in America, NHANES 2017–2018*. Rep., U.S. Dep. Agric., Agric. Res. Serv., Food Surv. Res. Group, Beltsville, MD. **https://www.ars.usda.gov/ARSUserFiles/80400530/pdf/1718/Table_53_RST_GEN_17.pdf**
85. U.S. Dep. Agric. 2019. *FoodData Central*. US Dep. Agric., Agric. Res. Serv., Beltsville, MD, accessed Nov. 8, 2021. **https://fdc.nal.usda.gov**
86. U.S. Dep. Agric. 2020. *Food and Nutrient Database for Dietary Studies 2017–2018*. Rep., U.S. Dep. Agric., Agric. Res. Serv., Food Surv. Res. Group, Beltsville, MD. **https://www.ars.usda.gov/ARSUserFiles/80400530/pdf/fndds/FNDDS_2017_2018_factsheet.pdf**

87. U.S. Dep. Agric. 2020. *USDA Food Patterns Equivalents Database 2017–2018*. Rep., U.S. Dep. Agric., Agric. Res. Serv., Food Surv. Res. Group, Beltsville, MD. **https://www.ars.usda.gov/northeast-area/beltsville-md-bhnrc/beltsville-human-nutrition-research-center/food-surveys-research-group/docs/fped-databases/**
88. U.S. Dep. Agric. 2007. *USDA table of nutrient retention factors, release 6*. Rep., U.S. Dep. Agric., Agric. Res. Serv., Nutrient Data Lab., Beltsville, MD. **https://www.ars.usda.gov/ARSUserFiles/80400535/Data/retn/retn06.pdf**
89. U.S. Dep. Agric. 2018. *Special Supplemental Nutrition Program for Woman, Infants and Children (WIC) food package policy and guidance*. Rep., U.S. Dep. Agric., Food Nutr. Serv., Washington, DC. **https://wicworks.fns.usda.gov/resources/wic-food-package-policy-and-guidance**
90. U.S. Dep. Agric. 2021. *Thrifty Food Plan, 2021*. FNS-916, U.S. Dep. Agric., Food Nutr. Serv., Washington, DC. **https://FNS.usda.gov/TFP**
91. U.S. Dep. Agric., US Dep. Health Hum. Serv. 2020. *Dietary Guidelines for Americans, 2020–2025*. 9th ed., U.S. Dep. Agric., U.S. Dep. Health Hum. Serv., Washington, DC. **https://dietaryguidelines.gov/**
92. U.S. Dep. Health Hum. Serv. 2021. *Healthy People 2030: nutrition and healthy eating objectives*. Rep., U.S. Dep. Health Hum. Serv., Off. Dis. Prev. Health Promot., Washington, DC. **https://health.gov/healthypeople/objectives-and-data/browse-objectives/nutrition-and-healthy-eating**
93. U.S. Environ. Prot. Agency. 2021. *General principles for performing aggregate exposure and risk assessments for pesticides*. Rep., U.S. Environ. Prot. Agency, Off. Pestic. Progr., Washington, DC. **https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/general-principles-performing-aggregate-exposure**
94. U.S. Food Drug Adm. 1996. Food standards: amendment of standards of identity for enriched grain products to require addition of folic acid. *Fed. Reg.* 61(44):8781–97
95. U.S. Food Drug Adm. 2016. Food labeling: revision of the Nutrition and Supplement Facts Labels. *Fed. Reg.* 81(103):33742–999
96. Van Asbroeck S, Matthys C. 2020. Use of different food image recognition platforms in dietary assessment: comparison study. *JMIR Form. Res.* 4(12):e15602
97. Vu T, Lin F, Alshurafa N, Xu W. 2017. Wearable food intake monitoring technologies: a comprehensive review. *Computers* 6(1):4
98. Ward HA, McLellan H, Udeh-Momoh C, Giannakopoulou P, Robb C, et al. 2019. Use of online dietary recalls among older UK adults: a feasibility study of an online dietary assessment tool. *Nutrients* 11(7):1451
99. Zhang L, Geelen A, Boshuizen HC, Ferriera J, Ocke MC. 2019. Importance of details in food descriptions in estimating population nutrient intake distributions. *Nutr. J.* 18(1):17
100. Ziesemer K, Konig LM, Boushey CJ, Villinger K, Wahl DR, et al. 2020. Occurrence of and reasons for "missing events" in mobile dietary assessments: results from three event-based ecological momentary assessment studies. *JMIR Mhealth Uhealth* 8(10):e15430
101. Zimmerman TP, Potischman N, Douglass D, Dixit-Johnson S, Kirkpatrick SI, et al. 2015. The effect of editing open-ended text responses on nutrient food group estimates from the Automated Self-Administered 24-hr dietary recall (ASA 24). *Procedia Food Sci.* 4:160–72