REVIEW

Update on NHANES Dietary Data: Focus on Collection, Release, Analytical Considerations, and Uses to Inform Public Policy[1,2]

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ABSTRACT

NHANES is the cornerstone for national nutrition monitoring to inform nutrition and health policy. Nutritional assessment in NHANES is described with a focus on dietary data collection, analysis, and uses in nutrition monitoring. NHANES has been collecting thorough data on diet, nutritional status, and chronic disease in cross-sectional surveys with nationally representative samples since the early 1970s. Continuous data collection began in 1999 with public data release in 2-y cycles on ~10,000 participants. In 2002, the Continuing Survey of Food Intakes by Individuals and the NHANES dietary component were merged, forming a consolidated dietary data collection known as What We Eat in America; since then, 24-h recalls have been collected on 2 d using the USDA's Automated Multiple-Pass Method. Detailed and targeted food-frequency questionnaires have been collected in some NHANES cycles. Dietary supplement use data have been collected (in detail since 2007) so that total nutrient intakes can be described for the population. The continuous NHANES can adapt its content to address emerging public health needs and reflect federal priorities. Changes in data collection methods are made after expert input and validation/crossover studies. NHANES dietary data are used to describe intake of foods, nutrients, food groups, and dietary patterns by the US population and large sociodemographic groups to plan and evaluate nutrition programs and policies. Usual dietary intake distributions can be estimated after adjusting for day-to-day variation. NHANES remains open and flexible to incorporate improvements while maintaining data quality and providing timely data to track the nation's nutrition and health status. In summary, NHANES collects dietary data in the context of its broad, multipurpose goals; the strengths and limitations of these data are also discussed in this review. *Adv Nutr* 2016;7:121–34.

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Introduction

Dietary assessment and other nutrition surveillance techniques such as anthropometric measurements, biochemical tests, and evaluation of clinical signs and symptoms of malnutrition are used for population monitoring and to develop nutrition policies and programs toward improving nutrition and health. Wright et al. (1) described NHANES methods and dietary data collection until the mid-2000s, and others have described various uses of NHANES data (2). Statistical approaches for improving precision in estimating dietary intakes and for assessing usual intakes have been developed over the past 2 decades (3–5) and can be incorporated into analyses using NHANES data (6–8). This article provides an updated description of NHANES methods since it became a continuous survey in 1999. It describes analytical considerations and the uses of NHANES dietary data. The strengths, limitations, and potential improvements in dietary data collection and analysis are also highlighted.

Current Status of Knowledge: NHANES and Its Dietary Data

The NHANES is conducted by the National Center for Health Statistics of the CDC. It consists of ongoing, comprehensive, cross-sectional, population-based surveys designed to collect data on the diet, nutritional status, health, and health behaviors of the noninstitutionalized US civilian population. NHANES is unique because it combines personal interviews with standardized physical examinations and laboratory tests administered by a specially trained staff that travels to selected survey sites to collect data on a nationally representative sample of the US population (9). Nutritional

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status is examined via the combined assessment of dietary intake, anthropometric measurements, laboratory tests, and clinical findings.

Overview of NHANES History

NHANES has a long history, beginning in the early 1960s as the National Health Examination Survey that collected limited data on nutrition status. The findings of the Ten State Nutrition Survey emphasized the need for greater nutrition surveillance at the national level (10) and led to the expansion of the National Health Examination Survey in 1971 to become NHANES, with a major focus on health as well as nutrition. NHANES conducted a series of cross-sectional surveys on a periodic basis until the mid-1990s as NHANES I, NHANES II, Hispanic Health and Nutrition Examination Survey, and NHANES III. In 1999, NHANES became a continuous survey conducted in 2-y cycles with planning, data collection, and public release of data and key reports of findings for each 2-y survey cycle. In the same year, the USDA and US Department of Health and Human Services implemented plans to merge the USDA's Continuing Survey of Food Intakes by Individuals and NHANES into a single continuous survey. In 2002, the Continuing Survey of Food Intakes by Individuals and the dietary assessment component of the NHANES were implemented as "What We Eat in America" (WWEIA)[6]—the dietary component of NHANES. The WWEIA is jointly administered as a partnership between the USDA and National Center for Health Statistics (9, 11).

The continuous NHANES maintains a national probability sample of baseline information on the health and nutritional status of the resident noninstitutionalized civilian US population (9). It provides data to describe dietary intakes as well as prevalence estimates for risk factors and selected diet-related and other diseases in the US population to better monitor trends in nutritional health, certain diet-related diseases, diet-related behaviors, and environmental exposures. These data are critical for exploring emerging public health needs and nutrition surveillance of the nation.

NHANES: Design, Operations, and Dietary Data Collection and Release

NHANES has a complex, multistage, probability sampling design. It examines a nationally representative sample of ~5000 persons each year selected from 15 different locations that are chosen from a sampling frame of all US counties (9). NHANES is designed to examine between 200 and 400 participants in each of the 60–80 sampling domains (age, sex, race-ethnicity, and income based) over a 4-y survey period (12).

Over the years, various groups have been oversampled across different NHANES cycles to produce more reliable estimates for various population subgroups (**Table 1**). For example, non-Hispanic blacks, Mexican Americans, low-income whites, adolescents 12–19 y of age, and older persons (aged ≥70 y) were oversampled in 1999–2006. In addition, a supplemental sample of pregnant women was included. From 2007 to 2010, Hispanics, non-Hispanic blacks, low-income whites, and older persons (aged ≥80 y) were oversampled (9). In more recent surveys (2011–2014 and 2015–2018), Asian Americans are also being oversampled (Table 1) (12). The examination response rates in NHANES generally vary from 70–80% (13, 14). Sampling weights are created to account for differential probabilities of selection and nonresponse; applying appropriate sampling weights is necessary to obtain nationally representative estimates (9, 12, 13).

NHANES operations and content

The major components of NHANES over various cycles are described in **Table 2**. NHANES data collection occurs throughout the year, including weekdays and weekend days, and includes a household interview, mobile examination center (MEC) visit, and post-MEC follow-ups. During the household screening interview, eligible household members are identified by using a computer-assisted personal interview tool (9). Potential participants are provided a global list of topics and categories (e.g., health examination, blood- and urine-based tests, dietary intake) that would be assessed. After obtaining informed consent, a detailed in-person interview is carried out in the home of consenting persons. It includes questions on demographic, socioeconomic, dietary (including supplement use), and health-related domains. As part of this personal interview, data on food security at the household and/or individual level have been collected in certain survey years (9). Information on nutrition knowledge, attitudes, and behaviors has been collected in varying detail in some NHANES cycles in a module called the Flexible Consumer Behavior Survey. The Flexible Consumer Behavior Survey, conducted in partnership with the Economic Research Service (ERS) of the USDA, includes topics such as participation in food and nutrition assistance programs, as well as family food expenditures at home and away from home. Data on nutritional knowledge, use of food labels and nutritional information, and importance of factors such as price, convenience, and taste while shopping for groceries or dining out have also been collected. Information on infant-feeding practices, eating away from home, and consumption of certain food groups (e.g. milk and dark green leafy vegetables) is collected as part of the dietary behavior questionnaire (1, 15). Participants aged ≥16 y also report on weight history, perceived weight status, and methods used for weight control (1, 16). In addition, data are collected on consumption of various types of dietary supplements (quantity, frequency, duration, name, and manufacturer) over the past month, including vitamins, minerals, and non–vitamin-mineral supplements (e.g., botanical supplements and amino acids). A unique aspect of NHANES is that during the interview, the interviewer sees the supplement containers, lessening chances for recording errors.

[6] Abbreviations used: AMPM, Automated Multiple-Pass Method; DGA, Dietary Guidelines for Americans; ERS, Economic Research Service; FNDDS, Food and Nutrient Database for Dietary Studies; HEI, Healthy Eating Index; ISU, Iowa State University; MEC, mobile examination center; NCI, National Cancer Institute; WWEIA, What We Eat in America.

TABLE 1 NHANES sample design

Characteristic	NHANES I: 1971–1974	NHANES II: 1976–1980	Hispanic NHANES: 1982–1984	NHANES III: 1988–1994	Continuous NHANES		
					1999–2006	2007–2010	2011–2014
Ages examined	1–74 y	6 mo–74 y	6 mo–74 y	≥2 mo	All ages	All ages	All ages
Mean number of sample persons per eligible household	1	1	2.71	2.03	2.02	2	2
Geographic areas covered	United States (excluding Alaska and Hawaii)	United States	Mexican American persons, Southwestern United States; Puerto Rican persons, New York, New Jersey, Connecticut; Cuban persons, Dade County, Florida	United States	United States	United States	United States
Study locations, *n*	100	64	17 in Southwest; 9 in New York, New Jersey, Connecticut; 4 in Dade County, Florida	89	117	60	60
Domains oversampled	Low income (at or below 100% of federal poverty level): children aged 1–5 y; women aged 20–44 y; persons aged 65–74 y	Low income (at or below 100% of federal poverty level): children aged 6 mo–5 y; persons aged 60–74 y	Persons aged 6 mo–19 y and 45–74 y	Mexican American persons; black persons; children aged <1 y; adults aged ≥60 y	Mexican American persons; black persons; low-income white and other persons (at or below 130% of federal poverty level); adolescents aged 12–19 y; adults aged ≥70 y; supplemental sample of pregnant women	Hispanic persons; non-Hispanic black persons; low-income non-Hispanic white and other persons (at or below 130% of federal poverty level); non-Hispanic white and other persons aged ≥80 y	Hispanic persons; non-Hispanic black persons; non-Hispanic nonblack Asian persons; low-income non-Hispanic nonblack non-Asian white and other persons (at or below 130% of federal poverty level); adults aged ≥80 y
Selected persons, *n*	28,043	27,801	15,924	39,695	50,939	26,215	27,631
Persons interviewed in the household, *n* (%)	27,758 (99)	25,286 (91)	13,689 (86)	33,994 (86)	41,474 (81)	20,686 (79)	20,491 (74%)

TABLE 2 Major components that have been measured in various cycles of the continuous NHANES[1]

Component	Household interview	MEC visit	Post-MEC interview
Sociodemographic status	x		
Medical history	x		
Medication use	x		
Nutrition knowledge and behaviors	x		x
Infant feeding practices	x		
Eating away from home	x	x	
Weight history and weight control practices	x	x	
Clinical examination on selected conditions (hypertension, cardiovascular disease, hearing, vision, oral health, taste and smell, etc.)		x	
Anthropometric measurements		x	
Body composition		x	
Biological specimen collection and laboratory testing (nutrient status, hormones, health conditions, chemical exposures, etc.).		x	
Physical activity (questionnaire, monitor)		x	
24-h dietary recall		x	x
Dietary supplements use	Past 30 d	X (after 24-h dietary recall)	x (after 24-h dietary recall)

[1] Empty cells indicate that data on the corresponding component were not collected at that interview or examination. MEC, Mobile Examination Center.

After the in-home interview, participants are scheduled for a MEC visit. The MEC examination provides a mechanism for standardized and automated data collection across survey sites and over time. It comprises medical, dental, and physiologic measurements, as well as laboratory tests that are administered by trained staff, including medical personnel. Dietary data are collected by trained interviewers using standardized methods that are described below.

Anthropometric measurements are a mainstay of the NHANES program. They involve data collection on weight, recumbent length (for children aged <4 y), and standing height for participants aged ≥2 y. In addition, various body circumferences and skinfold thickness measurements are taken based on the participant's age in most NHANES cycles, with some variation across cycles (14).

In certain NHANES cycles, body composition data have been measured using bioelectric impedance and DXA on selected age groups and nonpregnant women. NHANES incorporates these and other novel assessment techniques when newer assessment methods are validated and become available on issues of public health importance. For example, data on sagittal abdominal diameter were collected in 2011–2014 as an indicator of abdominal obesity (17).

Biochemical measures are also helpful in determining nutritional status. Blood samples are collected for consenting persons ≥1 y of age. Other biological specimens collected include urine, saliva, hair, and certain tissues (e.g., nasal swabs, vaginal swabs, oral rinses), based on age and sex of participants (18). Samples are processed on site in the MEC and shipped to collaborating laboratories across the United States for analysis using state-of-the-art methods. Some of the analytes include nutrients (e.g., vitamins, minerals), phytoestrogens, metabolites (e.g., related to nutrients, bioactives such as caffeine), biomarkers of environmental exposure (e.g., polyaromatic hydrocarbons, lead, cotinine), and clinical and biochemical tests spanning cardiovascular, lung, and liver function (e.g., blood pressure, heart rate, lipids, liver enzymes).

Physical activity data have been collected using questionnaires. In addition, physical activity monitors have been used in several recent NHANES cycles. Cardiovascular fitness has been assessed for 12- to 49-y-olds using submaximal treadmill tests and isometric grip strength in certain cycles (1).

The post-MEC data collection components vary across survey cycles. They have included a physical activity monitor, telephone-based 24-h dietary recall and consumer behavior questionnaire, and home-collected urine sample (14).

NHANES dietary data collection

NHANES has been collecting dietary intake data in various forms since the early 1970s. The mainstay of dietary data collection has been a 24-h recall beginning with NHANES I; a food-frequency questionnaire (FFQ) varying in the number of questions has also been included, with its focus varying over the survey cycles (**Table 3**). The 24-h recall method is most often used for determining dietary intake in large-scale surveys (19–22). The decision to continue with this method over the years in NHANES has been based on consensus of expert groups during workshops held periodically to evaluate data collection methods in NHANES (19, 23). Its use is supported by expert panel discussions in a recent symposium on "Strategies to Optimize the Impact of Nutrition Surveys and Epidemiological Studies" (24).

The use of a single 24-h recall administered by trained interviewers continued with the continuous NHANES; the larger FFQ used in NHANES III was converted to a targeted FFQ aimed at specific nutrition-health issues over varying cycles of the survey (e.g., fish/seafood and mercury, dairy and calcium, alcohol) (Table 3). An expanded version of the FFQ was again used during 2003–2006. NHANES staff, along with external federal and nonfederal experts, periodically assess revision of data collection methods to improve quality while weighing in factors such as cost, respondent burden, and overall feasibility within the multidisciplinary scope of NHANES (19, 23).

Dietary data collection methods in NHANES have evolved over time to reflect these recommendations and emerging data needs over the years. Some examples include the use of the USDA's Automated Multiple-Pass Method (AMPM) and collection of a second dietary recall since 2002 to account for day-to-day variation. In addition, targeted questions related to frequency of consumption of certain foods and beverages are also included in most cycles of NHANES. Together, these developments aimed at improving assessment methods for dietary data collection are in line with the recommendations

TABLE 3 Methods used for collection of food and nutrient intakes in NHANES[1]

Characteristic	NHANES I: 1971–1974	NHANES II: 1976–1980	Hispanic NHANES: 1982–1984	NHANES III: 1988–1994	Continuous NHANES		
					1999–2006	2007–2010	2011–2014
Dietary assessment method							
24-h recall, d	1	1	1	1[2]	1 (1999–2002); 2 (2003–2006)	2	2
FFQ	Yes	Yes	Yes	Yes (expanded version)	Yes (expanded version in 2003–2006)	Yes	Yes
Dietary recalls publicly available, *n*	1	1	1	1[2]	1 in 1999–2002; 2 in 2003–2006	2	2
Database used for 24-h dietary recall	In-house	In-house	In-house	In-house	In-house (1999–2001); FNDDS version 1.0 (2001–2002); FNDDS version 2.0 (2003–2004); FNDDS version 3.0 (2005–2006)	FNDDS version 4.1 (2007–2008); FNDDS version 5.0 (2009–2010)	FNDDS 2011–2012
Dietary supplements during home interview[3]	Vitamin and mineral use; no question on duration; "regular" or "irregular" use reported	Vitamin and mineral use; no question on duration; "regular" or "irregular" use reported	Not collected	Vitamin and mineral use over the past month; name, manufacturer, duration, frequency, and amount taken	Vitamins, minerals, herbals, other types of dietary supplements; prescription and over the counter; use over past 30 d; full name, strength, manufacturer, duration, frequency, and amount taken	Vitamins, minerals, herbals, other types of dietary supplements; prescription and over the counter; use over past 30 d and past 24 h; full name, strength, manufacturer, duration, frequency, and amount taken in past 24 h; reason for taking product	Vitamins, minerals, herbals, other types of dietary supplements; prescription and over the counter; use over past 30 d and past 24 h; full name, strength, manufacturer, duration, frequency, and amount taken in past 24 h; reason for taking product
Dietary supplements database	NA	NA	NA	Database contracted out	NHANES Dietary Supplement Database	NHANES Dietary Supplement Database	NHANES Dietary Supplement Database

[1] FFQ, food-frequency questionnaire; FNDDS, Food and Nutrient Database for Dietary Studies; NA, not applicable.
[2] The Supplemental Nutrition Survey for Older Americans was conducted on persons aged ≥50 y who provided 24-h recall in 1988–1991 as part of NHANES III. These individuals provided up to 2 additional 24-h recalls over the telephone to trained dietary interviewers ~8 and 6 mo after their first recall at the Mobile Examination Center. These data are publicly available on the NHANES website (14).
[3] Since the 1980s, dietary supplement use information has been collected during the household interview. Since 2007, information on dietary supplements consumed during the 24-h recall period also has been assessed during the dietary interviews.

summarized by Webb et al. (24). Furthermore, since 2007, detailed information on dietary supplement use has also been collected during the household interview for the past 30 d as well as during the two 24-h recalls. The latter change permits estimating total nutrient intake from diet and supplements for the US population and specific demographic subgroups.

Dietary recall data for WWEIA-NHANES are collected on both weekdays and weekend days. Dietary intakes can vary by day of the week. Thus, special dietary weights are computed for each survey cycle that adjust for the differences in the proportion of recalls on weekdays compared with weekend days, and these weights should be used in analysis of the WWEIA-NHANES data (9, 12, 13). Dietary interviews are not unannounced. NHANES participants are told they will be asked questions about what they eat (14). Thus, the possibility of self-reporting bias on reported intake of foods, beverages, and dietary supplements remains as in other large-scale epidemiologic studies and surveys. For children aged ≤5 y, interviews are obtained through a proxy familiar with the child's intake, generally a parent; proxies also assist with children aged 6–11 y. Dietary intakes are self-reported by participants aged ≥12 y. Bilingual dietary interviewers administer an in-person interview at the MEC by using the AMPM. The AMPM is a computer-assisted multiple-pass format interview system with standardized probes, developed by the USDA to estimate current dietary intake and to minimize misreporting (25). Its 5-step multiple-pass process is designed to enhance complete and accurate data collection while reducing respondent burden by prompting the respondent to recall foods and beverages consumed throughout the 24-h period with probes using 3-dimensional food models and the USDA Food Model Booklet to better estimate portion size (25, 26).

Additional dietary data collected in NHANES have varied over cycles. They include questions on salt use at the table and during cooking, as well as questions on alcohol and seafood and fish consumption that were targeted in certain cycles of NHANES. Also included are questions on supplement use, starting with a few generic questions in NHANES I to much more detailed information (e.g., nature, dose, frequency, duration, motivations of dietary supplement use) collected during the household interview in later surveys and to date (Table 3). A major milestone in 2007 was the move to collecting detailed information on dietary supplement use in the two 24-h recalls as well. This allows researchers to compute the total nutrient intake from diet and dietary supplements and nonprescription antacids containing calcium and/or magnesium, as well as to better estimate usual nutrient intakes. NHANES is the only national survey that currently provides complete nutrient intake from foods, beverages, and dietary supplements at the national level for US persons of all ages.

Coding and release of dietary data: foods and nutrient intake and related databases

Since 2001, the USDA's Food and Nutrient Database for Dietary Studies (FNDDS) has been used as the food composition database to assign codes to all foods and beverages and amounts reported by participants during their 24-h dietary interviews (27) (Table 3). Descriptions of the >7600 foods and beverages in the FNDDS are primarily generic, with some exceptions for brand-name items, including ready-to-eat cereals, infant formulas, candies, and nutrition bars. In this database, the nutrient and dietary constituents (including caffeine) from foods and beverages are based on the USDA National Nutrient Database for Standard Reference (28). Data sources for the National Nutrient Database for Standard Reference include scientific literature, data provided by food companies and trade associations, and chemical analyses contracted for by the USDA. The nutrient data for ~3200 items from the National Nutrient Database for Standard Reference are used to determine the nutrient values for the >7600 foods and beverages in the FNDDS. Details about how nutrient values are determined for the foods and beverages are described in the FNDDS documentation (27). For each NHANES 2-y survey period, an updated FNDDS version is produced that reflects the foods and beverages reported by participants and their nutrient content during that specific timeframe. The FNDDS is updated on an ongoing basis by the USDA, and new foods and beverages are added to reflect changes in consumption and the marketplace for each survey period. For example, the FNDDS 2011–2012, developed for the WWEIA-NHANES 2011–2012, included 1156 new foods and beverages. On the USDA website, other specialized databases further characterize foods and beverages found in the FNDDS. They include the USDA's Food Patterns Equivalents Database for various NHANES cycles since 2005. The Food Patterns Equivalents Database disaggregates foods and beverages reported in 37 USDA Food Patterns components and provides a unique research tool to evaluate food and beverage intakes compared with recommendations of the Dietary Guidelines for Americans (29).

Dietary data are released, on the NHANES website (14), in collaboration with the USDA for each 2-y survey period of NHANES. Data release usually occurs ~6–9 mo after the initial release of other NHANES component data corresponding to that same 2-y period (Table 3). This lag is because the dietary data are checked for quality in an ongoing manner over the 2-y collection period and at the end of the 2-y cycle and the time it takes for the nutrient composition for foods and beverages to be determined for all items reported in the survey.

NHANES has been collecting dietary supplement use data since it began. The dietary supplement use information collected during the household interview (since the 1980s) and in the two 24-h recalls (since 2007) is coded using in-house databases (Table 3). The NHANES Dietary Label Supplement Database includes all (~11,000) dietary supplements or nonprescription antacids containing calcium and/or magnesium reported by participants since 1999. It synthesizes information obtained from various sources, including the manufacturer or retailer, Internet, company catalogs, and the Physician's Desk Reference, and is available on the NHANES website.

In summary, the continuous NHANES survey has been operating since 1999, sampling persons of all ages, with fully automated data collection that allows more timely release of data on the health and nutritional status of the US population. Expanded documentation and tutorials for use of NHANES data have been compiled and made available publicly online. The survey is constantly evolving, considering recent advances in the fields of health and nutrition and adapting its methods accordingly. For example, since the continuous NHANES began, a dietary intake assessment method has evolved to fully automate this data collection by computer-assisted means via the AMPM (25). Other changes include using state-of-the-art methods for biochemical tests and collection of novel data providing national estimates on emerging conditions and the provision of population-based reference data on newer laboratory tests and measurements. As methods evolve or change over the years, after conducting crossover and validation studies and incorporating expert input, accompanying documentation is provided online on the NHANES website (14) for consideration during analyses. The release of data and accompanying documentation online allows efficient and free access to these files and the ability to link them to a growing number of external data files and databases (e.g., food environment, environmental exposure, market data, health records, medication use), as well as the National Death Index. The USDA and NHANES are continually updating the food and nutrient databases as well as dietary supplement databases to capture market trends and items reported consumed by the NHANES participants. Today's databases are far more complete in terms of foods and beverages, nutrients, and bioactives of public health concern than those before the continuous NHANES, reflecting the positive impact of the partnership between these federal agencies. In addition, growing public-private partnerships such as the Agricultural Technology Innovation Partnership on Branded Food Products Database for Public Health will allow the NHANES-related dietary databases to be more comprehensive and improve the quality of these critical data even further. Keeping research methods updated to reflect consensus in the scientific community as well keeping databases current and complete is a priority identified by the federal Inter-agency Committee on Human Nutrition, and NHANES is committed to meet this challenge.

NHANES Dietary Data: Analytical Considerations

There is no single perfect method for assessing dietary intake information in surveys. Different methods may be appropriate for specific purposes (19–23, 30). Since 2002, NHANES has been collecting food and nutrient intake data via two 24-h recalls obtained with standardized AMPM method in conjunction with databases that are updated to correspond to each 2-y survey cycle (Table 3). The 24-h recall technique requires short-term memory, is less burdensome and less likely to alter eating behavior than food records, and can be used with diverse populations because it does not require a high level of literacy (22, 30). It has been recommended as the dietary method of choice for quantifying "actual" intakes (rather than perceived intakes collected retrospectively via the FFQ) in large population studies (22, 30), is less-biased than FFQs that rely on longer-term recall, and is less burdensome for the respondents (20). In addition, because trained staff obtains the 24-h recalls by the standardized AMPM method, measurement error is further reduced (26).

It has long been recognized that self-reported dietary intakes (via food records or 24-h dietary recalls) are associated with underreporting of energy intake (22, 26, 31, 32) and, to differing extents, several macro- and micronutrients (33). This has been demonstrated with NHANES data as well (33, 34). Moreover, the underreporting bias in energy intake is proportionally related to total energy intake (35) and is higher in overweight and obese persons as well as in women (26, 32–34). In one study (26) that evaluated the AMPM 24-h recall method that is used in NHANES, using doubly labeled water as the reference method, mean energy intake was underreported compared with total energy expenditure by 10% in males, 12% in females, and 3% in normal-weight subjects. This degree of underreporting was substantially lower than that achieved by other dietary intake instruments evaluated using doubly labeled water (32, 34, 36). However, differences in study methods, including reference methods as well as the fact that NHANES data were used for individual-level assessment (34) that they are generally not intended for, could partly explain these differential findings (37, 38). In addition, periodic dieting or undereating is a common practice among Americans, particularly those who are overweight and obese (39). These factors could explain the discrepancy between 1-d estimates of reported energy intake and expected energy intake observed among studies. On the other hand, additional evidence for the accuracy of the AMPM has been provided by analysis of the 24-h urinary sodium data from the AMPM Validation Study. Mean dietary sodium estimates derived from the AMPM reflected >90% of the biomarker-based estimates from 24-h urine collections (40). Lankester et al. (41) recently presented 2 statistical simulation models that were developed by using data from an observational study (i.e., Observing Protein and Energy Nutrition (OPEN) study; doubly labeled water served as the reference method to estimate energy expenditure) and applied to NHANES data to adjust for underreporting in energy intake. After adjustment with the models, dietary recall bias was drastically reduced to <3% with the regression model and between 4% and 9% with the intake shift model. The findings of this study suggest that underreporting error can be corrected using external data sets on a similar population when available. Another way to correct for the underreporting of intakes of specific nutrients is by use of biomarkers. For instance, urinary nitrogen has been used to correct for underreporting in protein intake (32, 42). However, it must be recognized that biomarkers also have errors in their measurement, and biomarkers for many nutrients of interest do not exist (38).

Hébert et al. (43) discuss the underreporting associated with self-reports and other issues related to bias and measurement error in their recent article on the value of dietary assessment data in informing nutrition-related policies. Overall, there is always some error associated with self-reported dietary intakes, as is the case for self-reported data on any variable (44). This error can attenuate correlations between diet and health/disease in epidemiologic surveys and large studies, where self-reported data offer the most feasible and reasonably accurate means to examine group-level intakes and associations among diverse populations. As Hébert et al. (43) and Satija and colleagues (38) point out, although existing methods are not perfect and further studies are needed to quantify the magnitude of error and identify the sources of biases, they still provide much useful information. Nevertheless, it is important to examine how the measurement error relates to potential confounders and effect modifiers, as well as to describe how to adjust for those errors under "real-world" conditions to adjust estimates of health effects (42, 43).

One goal of NHANES is to describe population and population subgroup-level distributions of food and nutrient intake and to relate these to health and disease biomarkers and outcomes. A single 24-h recall has historically been considered sufficient to describe the mean (21). This is because the effects of random errors associated with dietary recall, including the day-to-day variability, are generally assumed to cancel out if days of the week are evenly represented (21). The smaller magnitudes of systematic errors (compared with a FFQ) allow a 24-h recall to produce reasonable estimates of mean usual dietary intake of population subgroups or for examining trends over time, after the effects of random errors are averaged out (22, 35, 38). To describe the tail ends of the distribution of the population, a single 24-h recall may not be reliably sufficient. For this, usual intake estimates may be needed, either by obtaining multiple days of dietary information per individual or by statistical approaches using at least 2 d of dietary information per individual (described in the next section).

In addition, a single 24-h recall is also an unreliable indicator of habitual dietary intake at an individual level because of the large day-to-day variations in dietary intake (24, 45, 46). To overcome the "random error" associated with this day-to-day fluctuation in intakes at an individual level, multiple 24-h recalls are needed to estimate the variance across days and to estimate the usual intake by individuals (22, 35, 38). The number of 24-h recalls needed to precisely estimate a single individual's usual intake (i.e., ameliorate the effects of random within-person variability) varies by nutrients, foods, and food groups of interest (45, 46). However, obtaining large numbers of repeated 24-h recalls to estimate individual-level intakes poses practical challenges within the scope of NHANES—a large multidisciplinary survey on a nationally representative sample aimed at producing population and large subgroup-level national estimates. This approach would be impractical because of the associated heavy burden on respondents that could affect response rates adversely, increase attrition, and result in data with limited external validity in obtaining national estimates, as well as increasing costs. Techniques involving web-based technology to obtain repeated 24-h recalls are being tested and are promising for use in large survey settings with participants who are computer literate (47, 48).

Cross-sectional data from NHANES are often used to examine population and large subgroup-level trends in intakes over time and to inform policy (38, 49). When conducting trends over time analyses, researchers need to be aware of change in dietary data collection methods (e.g., shift to using the AMPM method since 2002) and that the databases accompanying each survey cycle in the continuous NHANES are updated to reflect foods reported consumed in that cycle. Users should consult online documentation for changes in collection methods and relevant food composition and supplements databases such as the FNDDS to ensure that no major changes occurred over the survey years being examined—all of which could affect interpretation of findings.

Statistical approaches for estimating usual intake distributions

Researchers are often interested in capturing habitual or usual intakes when assessing dietary intake among populations or individuals (50). Although a 24-h dietary recall can provide rich details about mean dietary intake for a given day on the population or large-group level, it does not reflect the usual intake over time due to the large intra-individual variation in dietary intakes described in preceding sections. As discussed previously, collecting more than two 24-h recalls per participant is usually impractical in large survey settings. Recognizing this fact, statistical methods have been developed that can assist in accounting for within-individual variation (3–5, 51). A key component to these methodologic advances is a shift in focus; rather than attempting to estimate usual intake at the individual level, the goal is to estimate distributions of usual intake or regression parameters relating usual intake to health outcomes, where statistical modeling can be performed with substantially fewer repeated 24-h recalls (as few as 2 per person on a subset of the entire sample) (3, 52). Various methods have become available over the past few decades to estimate usual intake distributions (53), of which the Iowa State University (ISU) method (4) and the National Cancer Institute (NCI) method (3) are more well known.

Researchers at ISU developed the ISU method (4) that corrects for the intraindividual variation in 24-h recall data to reduce bias in estimates of usual intake distributions. The usual intake distributions of foods and nutrients consumed daily or episodically can be estimated, along with fractions of the population with the usual intakes falling above or below reference cutoffs such as the DRIs. The use of the relatively "user-friendly" ISU method requires special software called "PC-Side" (4). The ISU method requires at least 2 d of nonzero intake for at least some participants to estimate the intraindividual variation to obtain estimates of usual intake distributions. Researchers at the

NCI have made further advances in the ISU approach and provided SAS macros that implement their procedure. The macros are less user-friendly than the PC-Side software but allow more advanced analyses. The NCI method is particularly useful for describing the habitual intakes of foods and nutrients that are not routinely eaten ("episodically consumed") (3, 6, 50, 54), because it allows the probability to consume an episodic food to be related to the amount consumed when it is consumed. Furthermore, the NCI method (in contrast to the ISU method) can explicitly model covariate effects, which facilitates subgroup and other advanced analyses, including an implementation of the regression calibration approach to correct for bias in estimated diet-health outcome relations (55). In addition, if 24-h recall data are augmented with FFQ-type information, when available, the NCI method has the capacity to include such FFQ information as a covariate to help estimate the usual intake distributions of foods that are rarely consumed or where a large proportion of the population never consumes that food (54). NHANES has the capacity to amend its protocol and incorporate targeted FFQs and "propensity questionnaire(s)" to address public health needs. In fact, targeted FFQs have already been used in NHANES (seafood, dairy). Researchers can submit proposals for consideration to amend NHANES methods such as inclusion of a targeted FFQ to address specific research and public health priorities.

It is important to note that these statistical methods typically assume that 24-h recalls are unbiased for usual intake and then proceed to adjust for intraindividual variation, thus correcting for only that part of the measurement error. Biases such as underreporting inherent to self-reported dietary data or any other systematic bias are not removed when usual intake estimates are obtained. Although these approaches do not completely ameliorate all bias, they do lead to improved estimates of distributions and regression parameters relative to the use of other self-report assessments "as is" (56). The consensus from a symposium on optimizing the impact of nutritional surveys and epidemiologic studies is that adjusting for measurement error, with an imperfect but better reference instrument, is preferable to ignoring the bias introduced due to measurement error (24, 54).

In summary, dietary data from NHANES can be used to describe food and nutrient intakes on a given day, and they are also useful for descriptive and analytical epidemiologic purposes. Results based on a single 24-h recall are sufficient to estimate population means (38) because the effects of random errors associated with dietary recall, including day-to-day variability, are generally assumed to cancel out if days of the week are evenly represented (21). The mean of 1-d intakes from the weighted study population has been shown to be a reasonably accurate estimate of the mean of the usual intake distribution of the population (6, 22, 35). However, for foods, beverages, nutrients, and bioactives that are episodically consumed, findings based on a single 24-h recall (day 1 data only) or even using both days of dietary recall data from NHANES may not be sufficiently precise to satisfactorily model the usual intake estimates due to high intra- and interindividual variation in intake (21, 45). In such a case, special programs designed to estimate usual intake for episodically consumed foods could be used. Such programs use correlated models incorporating information on the frequency of consumption of the episodically consumed food in the population and subgroups, along with amounts consumed. These require thorough knowledge of such analytical approaches and some level of statistical analysis programming experience to implement them effectively. The tutorials on the NHANES as well as the NCI websites are excellent starting points for learning about these approaches (57). Work continues in this important area for better understanding the sources of measurement error and accounting for it in analyses.

Uses of NHANES Dietary Data

NHANES is the nation's primary survey that provides data collected using standardized collection methods that allow dietary and health surveillance over time. NHANES is the only source of data that provides national estimates of food and beverage consumption and nutrient intakes from diet and supplements for persons of all ages. NHANES data are used globally by researchers, policy makers, and private industry as well as diverse federal agencies for many purposes. They have been used for descriptive and analytical epidemiologic scientific research, such as the association of diet, dietary factors, foods, and nutrients with health, disease, biomarkers, and functional outcomes (2, 14). Other key uses include nutrition monitoring research, assessing dietary intakes, the contribution of dietary supplements to the intakes of Americans, and development of biomarkers of dietary intakes (e.g., caffeine and flavonoid metabolites) (2, 10, 11, 14).

Dietary data from NHANES are critical to nutrition monitoring and for informing nutrition policy in several ways. They are used to describe the nutritional and health status of Americans, including descriptions of food and nutrient intakes by the US noninstitutionalized population, development and evaluation of DRIs, and development of diet quality indexes such as the Healthy Eating Index (HEI), the MyPlate icon for healthy eating, and other tools (2, 10, 11, 14, 58, 59). Last, longitudinal passive follow-up has been possible with NHANES data from certain cycles that have been linked to the National Death Index. This allows researchers to examine the prospective association of diet as a whole, as well as intake of foods and nutrients, with overall and cause-specific mortality in US persons. Dietary data from NHANES can also be used to carry out time-trend analyses when they are appropriately adjusted (49) to examine the association of diet (as a whole, food groups, foods, nutrients, or other dietary components) with health, disease, and mortality (in certain cycles) and to inform nutrition and health policies (38).

Some of the key uses of the NHANES data in informing the nation's public health and nutrition policy are presented in **Table 4**. Because NHANES is deeply involved in and

TABLE 4 Chief uses of NHANES dietary data in nutrition monitoring, nutrition policy, and federal food and nutrition programs

Chief use
Nutrition monitoring
Identify groups at risk of nutrient deficiency or excess
Develop and update reference standards (e.g., Dietary Reference Intakes, Healthy Eating Index)
Track trends in dietary behaviors and food and nutrient intakes:
Relate to nutritional status and health
Relate to meeting nutrition and health objectives (Dietary Guidelines for Americans, Healthy People)
Inform policy development (e.g., nutrients of public health concern: sodium, added sugars, caffeine, *trans* fatty acids, saturated fat)
Meal consumption patterns of Americans (e.g., meals eaten at home or outside home)
Food safety and regulatory purposes
Develop and update food labeling policies
Develop and monitor food fortification policies (folic acid, vitamin D)
Establish food safety guidelines: assess exposure to potentially unsafe substances via food and beverage intake (caffeine, heavy metals, pesticides)
Federal nutrition programs: plan, evaluate, update
Assess diet quality of participants in federal nutrition programs
Develop and update meals provided in food assistance programs

works collaboratively with several agencies that inform and develop nutrition policy, the various ways that NHANES data serve as one of the critical pieces of information in the development of nutrition and health policy are described at greater length below.

Nutrition monitoring

NHANES dietary data are used to describe the distribution of usual intakes of the population and subgroups (age, sex, physiological status) for foods, food groups, and nutrients (60). The findings are used, in conjunction with other literature evidence, by federal agencies and expert panels to assist, establish, and evaluate DRIs (5, 51, 61).

One of the aims of dietary surveillance is to estimate the proportion of the population that meets the recommended level of food and nutrient intakes (51, 61). By estimating usual dietary intakes based on NHANES data, the percentage of the population and population subgroups with intakes below (or above) the estimated average requirements or upper limits of the DRIs can be estimated. Dietary supplement users and nonusers can be analyzed separately. In addition, data collected over various survey cycles, with appropriate adjustments, assist researchers and policy makers to evaluate how well the nation is doing in terms of meeting the DRIs over time.

HEI. The HEI was developed as a tool to quantify the quality of diet consumed by individuals in the United States (58, 59). Using NHANES data for 2001–2004, Freedman and colleagues (62) described statistical approaches to estimate population distribution of usual HEI 2005 component scores using 2-d dietary recall data. For example, recent analyses showed that an estimated 30% of the total US population scored low for total vegetable intake. WWEIA-NHANES survey data from more recent surveys can provide the continuum of data needed to compute the HEI scores and to help track the nation's quality of diet. Using NHANES data from 1999–2010, Wang et al. (49) reported that although the diet quality of Americans showed a steady improvement across the 12-y period examined, overall it remained poor.

Dietary Guidelines for Americans. The Dietary Guidelines for Americans (DGA) are federally mandated to be updated and released every 5 y. Dietary guidance helps Americans eat healthier diets toward better health and optimal function (63). NHANES data are used to develop and evaluate the population's progress in meeting the dietary guidelines. Krebs-Smith et al. (6) modeled usual intake distributions from 2001–2004 NHANES data and showed that most of the population did not meet recommendations for all of the nutrient-rich food groups, except total grains, meat, and beans. Overconsumption of energy from solid fats, added sugars, and alcoholic beverages was ubiquitous.

The Dietary Guidelines Advisory Committee 2015 (29) relied on NHANES dietary data to describe food and nutrient intakes and nutrients of concern, dietary patterns of Americans, food and menu label use, food access, and diets of persons participating in the federal nutrition assistance programs, as well as consumption of food items that could have potential safety concerns, such as caffeine and noncaloric sweeteners.

The Agricultural Act of 2014 directed the DGA to expand to include infants from birth to 2 y and pregnant women, beginning with the 2020 DGA (63). Data collected in NHANES have many potential uses in this regard (15). To provide data necessary to develop dietary guidance for infants and toddlers, NHANES could potentially oversample infants and toddlers in place of certain other groups it usually oversamples. Alternatively, NHANES can be expanded to address this specific subpopulation as has been done in the past with the NHANES National Youth Fitness Survey (64).

Healthy People 2020 Objectives. Healthy People Objectives, the plan from the US Department of Health and Human Services for promoting health and preventing disease, are one of the cornerstones of US health policy and include several nutrition-related objectives (65). NHANES data (including dietary data) provided baseline estimates for many of these objectives and are used to track their progress. Several Healthy People 2020 objectives, including those on intake of food (e.g., fruit, vegetables, grains, and alcohol) and nutrients (e.g., calcium, sodium, and total fat) or reducing calories (from solid fats and/or added sugars), rely on NHANES data from WWEIA to monitor progress toward better health.

Monitoring intakes of foods and nutrients of public health concern. With the introduction of new foods and products in the market, NHANES dietary data are important in examining the intake of foods, food components, and nutrients of public health concern such as added sugars, sodas,

caffeine, *trans* fatty acids, saturated fat, and sodium (63). NHANES dietary data can be linked to blood concentrations and other biomarkers of disease collected in the survey to describe the diet-disease paradigm and to develop hypotheses for future research (14).

Assessing dietary behaviors. The USDA ERS has used the NHANES dietary data to examine diet quality by food source in relation to the DGA, to examine the impact of eating out on diet quality, and to simulate the nutritional and health outcomes of pricing strategies. Dietary intake data and the USDA's Food Patterns Equivalents Database have also been used to assess diet quality in relation to food preparation at or away from home (66).

Food Intakes Converted to Retail Commodities Databases and commodity consumption. The Food Intakes Converted to Retail Commodities Databases were jointly developed by the USDA's Agricultural Research Service and ERS and provide data for foods consumed in the national dietary intake surveys at the retail commodity level, whereby the survey foods are converted into retail-level commodities (67). The ERS has used NHANES 1999–2000 and 2001–2002 data to examine commodity consumption by household income, age and sex, body weight status, race and ethnicity, and education attainment as well as by the location where foods were eaten.

Food safety and regulatory purposes

NHANES dietary data are used by various agencies to develop and update food labeling and food fortification policies and to establish and monitor food safety issues related to exposures to heavy metals, pesticides, and so on via food and beverage consumption. Some of the specific ways dietary data from NHANES are used in these respects are described below.

Nutrition facts label. NHANES dietary data were used to determine the nutrients of public health concern in the US population for listing on the Nutrition Facts Label. NHANES 2003–2008 dietary data were also used to propose the updates for the "Reference Amounts Customarily Consumed" in the US FDA proposed rule for the revision of Serving Size on the Nutrition Facts label (68).

Monitoring food fortification policies. NHANES dietary data along with other data (e.g., biomarkers) from NHANES and other surveys have been instrumental in the development of food fortification policies that address nutrition gaps and deficiencies (e.g., folic acid, vitamin D). National dietary data have been used to simulate and forecast fortification strategies for specific nutrients for the population groups concerned and to assess associated risks (14, 69). They are also used for tracking the associated effects on nutrient intake and status in the US population and subgroups of interest who are at risk of lacking or having an excessive intake of such nutrients.

Exposure assessment. The NHANES dietary and nutritional data are critical for quantitative risk assessments of exposures, not only to food constituents but other sources of relevance to human health, by regulatory agencies such as the FDA for programmatic decisions and regulations development (8, 10). NHANES dietary data are also used to monitor the food and nutrient intakes of the US population to evaluate the dietary exposure and examine food safety issues (e.g., arsenic). Dietary data from NHANES are also useful for updating the food list (Market Basket) in the Total Diet Study to reflect the current food intake patterns of the US population (70).

Assessing diet quality in federal nutrition assistance programs

The USDA's Food and Nutrition Service and the Center for Nutrition Policy and Promotion use NHANES dietary data to assess the diet quality of program participants, set program benefits, and evaluate the content of benefit packages.

To assess the diet quality of participants in the Supplemental Nutritional Assistance Program (formerly the Food Stamp Program), the National School Lunch Program, and the Special Supplemental Nutrition Program for Women, Infants, and Children, the Food and Nutrition Service uses NHANES dietary data to compare nutrient intakes, food choices, and the diet quality of program participants with those of income-eligible nonparticipants and higher income individuals. In addition, nutrient intakes of participants are compared with the DRI to assess the adequacy of nutrient intakes. NHANES dietary data assist the Food and Nutrition Service in the review of nutritional content of packages from the Special Supplemental Nutrition Program for Women, Infants, and Children to meet the needs of the population served (71). NHANES food and nutrient intake data were used along with intake data collected through USDA's School Nutrition Dietary Assessment Study III to develop meal pattern changes in the National School Lunch Program and the School Breakfast Program.

Conclusions

NHANES has been a key source of comprehensive nutrition data at the national level for nearly half a century. It is a broad multipurpose survey on the nutrition and health of Americans. A major strength of NHANES over the years has been the use of a combination of different dietary methods, along with anthropometric measures and biomarkers to assess nutritional status and to lessen bias or measurement error in estimates.

NHANES planners strive to continuously evaluate and balance various NHANES components and assessment tools used to improve monitoring of nutrition and overall health. NHANES has a flexible design that allows changes to its components to address emerging public health issues, and the methods used in the survey are periodically evaluated to keep the survey updated with market trends, scientific advances, and to include new tools and techniques that become available while balancing respondent burden, feasibility, validity, and cost. Among the newer techniques are the AMPM method and measurements such as DXA and sagittal abdominal diameter. These changes were made taking into consideration the logistics of the complex design of NHANES

to gather national-level data that require a high response rate. Although NHANES is flexible enough to adapt to emerging needs and updated technologies and developments in assessment methods, it must evaluate and reach balanced decisions on when and how to incorporate such changes so that trends over time using NHANES data can continue to be obtained. Validation and crossover studies are conducted before initiating such changes in protocols; these are documented on the NHANES website (14).

NHANES data have been important for population-based nutrition surveillance, and NHANES dietary data have served many purposes in nutrition monitoring, informing nutrition policy, and assessing associations between nutrition and health. However, NHANES dietary data are neither intended nor suitable for all purposes, especially for assessment at the individual level. The issues related to individual-level dietary assessment compared with population-level estimates are critical, and their understanding is essential to the use and correct interpretation of dietary intake findings from NHANES.

In conclusion, NHANES is a large multipurpose cross-sectional survey that provides comprehensive data on various aspects \of nutrition and health. Like any other broad epidemiologic survey, NHANES data have their strengths and limitations. The survey's design must be kept in mind when analyzing the data, including an understanding of its strengths and limitations, so that appropriate conclusions are reached. NHANES data have served as and remain an important cornerstone for nutrition monitoring in the United States.

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