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NUTRITIONAL APPLICATIONS OF THE HEALTH AND NUTRITION EXAMINATION SURVEYS (HANES)[1]

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BACKGROUND

The Health and Nutrition Examination Surveys (HANES) are a series of successive surveys that measure and monitor aspects of the health and nutritional status of the US population and subgroups. Each survey has the capability of gathering relevant information that can be obtained best, or only, by direct medical examinations and clinical tests and measurements, including biochemical analyses of blood and body tissues. Data from the surveys are used for several purposes: (*a*) estimating prevalences of health and nutritional characteristics of the US population or subgroups, including previously undiagnosed conditions; (*b*) producing normative values for nutrition and health status measures in population groups; (*c*) evaluating interrelationships among health and nutritional variables; and (*d*) monitoring changes over time. These data and results are essential for identifying public health problems and for program design and evaluation. Data are also used to generate and evaluate hypotheses on the role of nutrition in health and disease.

The use of the HANES data bases is expanding rapidly. This growth has generated a number of analyses and publications, but it has not always occurred without growing pains. The purpose of this chapter, therefore, is to provide useful information to novice analysts and to users of published results who need to evaluate results critically and appreciate limits of interpretation. Thus, the content focuses primarily on (*a*) a basic description of the network of surveys in the HANES series, from both historical and current perspectives, (*b*) a brief discussion of the complex factors affecting interpretation and use, and (*c*) a summary of the wide range of reference and support materials available. In discussing summary results, the primary emphasis is on prevalence estimates of nutritional status and nutritional risk factors as reviewed by several recent expert panels. A brief summary of use of the data as a research tool for evaluating diet/health relationships is also given, but this latter use of the data bases needs further evaluation and critical review.

National Health Examination Surveys

The health examination portion of HANES originated with the conduct of Cycle I of the National Health Examination Survey (NHES I) during 1960–1962 (38). A major purpose of this survey was to provide information on the prevalence of selected chronic diseases and health conditions in the adult US population ages 18–79 yr. This survey focused particularly on certain cardiovascular diseases, arthritis and rheumatism, and diabetes through selected physical and physiological measurements, including blood pressure, serum cholesterol, skinfolds, various heights and weights, and electrocardiographic tracings. Two subsequent cycles of this survey series (NHES II and III) were conducted from 1963 to 1965 and from 1966 to 1970 (39, 40). Sampling was limited to children (6–11 yr) and adolescents (12–17 yr), respectively. Measures of growth and development and related health factors were one of the major focuses of these surveys. Longitudinal measurements for 2271 children were obtained, since the samples for both surveys were selected from the same sampling areas and segments. In the three NHES, the numbers of examined persons were 6672, 7119, and 6773, respectively (37).

National Health and Nutrition Examination Surveys

In 1969, dietary, biochemical, hematological, and clinical measures appropriate for the assessment of nutritional status were merged with a number of the health, demographic and socioeconomic, and anthropometric measurements in the NHES. The name of the survey was changed to reflect its broader purpose; and the first National Health and Nutrition Examination Survey (NHANES I) was conducted from 1971 to 1974 (37). The examined sample of 20,749 persons ages 1–74 yr was given the nutrition-related interview and examination. This included questionnaires on medical history and dietary intakes, general medical examinations, anthropometric measurements, and a number of laboratory determinations (see Table 1). A subsample of 3854 adults 25–74 yr old received a more detailed examination focused on other aspects of health and health care needs.

From July 1974 to September 1975, the Augmentation Survey was added to increase the size of the subsample of adults and, consequently, the usefulness of the data obtained (12). In this extension of NHANES I, an additional national sample of 3059 adults aged 25–74 yr participated in the anthropometric, medical history, and physician's examination portions of the NHANES I. The greatest number of nutritional biochemistries and hematological variables were scheduled for the 20,749 persons in the NHANES I examined sample. Serum calcium and phosphorus were planned for the 3854 persons in the detailed sample and for the 3059 persons in the augmentation sample. Serum folate, sodium, and potassium were limited to the 3059 persons in the augmentation sample. Several measurements, however, were obtained for persons from all three survey samples: serum magnesium and cholesterol, hemoglobin, and hematocrit.

A second national survey (NHANES II) was conducted from 1976 through 1980; 20,322 persons (ages 6 months to 74 years) were examined (36). For the nutritional assessments, the program continued to use essentially the same format as NHANES I with some modification. A major focus of the nutritional component in NHANES II was the assessment of iron status. In both NHANES I and II, groups assumed to be at greatest nutritional risk were intentionally oversampled: people with low incomes, preschool children, and the elderly (36, 37). In addition, in NHANES I women of child-bearing age were oversampled.

Table 1 Nutritional biochemistries and hematological measures available[a] from the HANES

Measure	Survey		
	NHANES I	NHANES II	HHANES
Hemoglobin[b]	Yes	Yes	Yes
Hematocrit[b,c]	Yes	Yes	Yes
MCV, MCH, MCHC	No	Yes	Yes
Serum iron	Yes	Yes	Yes
Serum iron binding capacity	Yes	Yes	Yes
Transferrin saturation	Yes	Yes	Yes
Erythrocyte protoporphyrin	No	Yes	Yes
Serum ferritin	No	Subsample	Yes
Serum cholesterol[b,c]	Yes	Adult subsample	Adult subsample
Serum triglycerides	No	Adult subsample	Adult subsample
Serum glucose (GTT)[c]	No	Adult subsample	Adult subsample
Serum albumin	Yes	Yes	No
Serum folate	No	Subsample	Subsample
RBC folate	No	Subsample	Subsample
Serum vitamin A	Yes	Children	Yes
Serum vitamin C	No	Yes	No
Serum vitamin E	No	No	Yes
Serum calcium	Adult subsample	No	Adults
Serum phosphorus	Adult subsample	No	Adults
Serum zinc	No	Yes	No
Serum copper	No	Yes	No
Urinary protein	Yes	Yes	Yes
Urinary sugar	Yes	Yes	Yes

[a] Available data means data that are available or soon to be available through public release data tapes. A "no" refers to data either not collected or collected but not released because of unresolved quality control problems.
[b] Also done in NHES III.
[c] Also done in NHES I.

The use of NHANES as a research data base was enhanced by the implementation of the NHANES I Epidemiological Follow-up Survey from 1982 to 1984 (10, 31, 32). The purpose was to investigate the relationship of baseline physiological, nutritional, social, psychological, and demographic factors to subsequent morbidity or mortality from specific diseases and conditions. In this survey, participants 25–74 yr old at the time of the NHANES I were reinterviewed, weight and blood pressure measures were taken, and diagnostic information was obtained from hospital records. For decedents, causes of death were determined from death certificates. Because the followup study provides cohort data on a large sample of the US population, it presents a unique research data base for epidemiologists.

Hispanic HANES

One limitation of national surveys is their inability to sample some minority groups in large enough numbers to evaluate their health and nutritional status. To meet this need, a survey targeted toward Hispanics (the Hispanic HANES: HHANES) was conducted from 1982 to 1984 (47). Three separate Hispanic subgroups ages 6 months to 74 years were surveyed: (*a*) Mexican Americans in selected areas of five southwestern states (Arizona, California, Colorado, New Mexico, and Texas); (*b*) Cuban Americans in parts of Dade County, Florida; and (*c*) Puerto Ricans in selected areas of New York, New Jersey, and Connecticut. Oversampling was done for persons 6 months to 19 years and 45–74 years. Generally, the nutritional status assessments were similar to those done in NHANES II (Table 1). In the three respective subgroups, 7462, 1357, and 2834 people were examined (personal communication, National Center for Health Statistics).

Future NHANES

Plans for the third NHANES are currently underway, with field testing scheduled for 1987 and the survey scheduled to begin in 1988. As for previous surveys, a number of federal agencies and health professionals have been involved in planning phases and in requesting measures for inclusion. One set of recommendations that has been published is based on a review of requested topics by an ad hoc expert panel (27). Of the 22 nutrients and conditions reviewed by the panel, the following nutritional assessments were recommended for consideration in NHANES III: vitamins A, B_6, C, and D; folacin, riboflavin, thiamin; copper, iron, selenium; cholesterol and blood lipids. In addition, medical history questions on cancer, measures of blood pressure and risk factors associated with hypertension, and measures related to osteoporosis were also recommended. Conversely, because indicators of status appropriate for a national survey were not available at this time, the following were not recommended for inclusion: vitamin E, niacin, calcium, chromium, magnesium, manganese, and zinc. These recommendations, and many other recommendations from other sources, are being considered by the staff at the National Center for Health Statistics as planning is nearing completion for NHANES III.

Survey Characteristics

Detailed descriptions of the basic survey characteristics and assessment measures in each of the completed surveys are available (12, 19, 20, 36–41, 45, 47). A number of factors are common among the surveys. Each survey consists of two components: (*a*) household interviews and (*b*) physical examinations and interviews in mobile examination centers. The household interviews are done first and are used to obtain demographic and socioeconomic data on the family and to complete the medical history questionnaire for the sample persons.

The physician's examination, collection of blood and urine samples, special diagnostic tests, and dietary interviews are conducted in mobile examination centers. Specially equipped trailers, which are moved from one geographic location to another, are linked to form the examination centers. This approach has the advantage of providing a standardized environment and equipment and a relatively stable team of physicians and health professionals across a number of different geographic locations.

All past NHES and NHANES have been limited to the civilian, noninstitutionalized population of the US, with exclusion of any persons residing on reservation lands set aside for use by American Indians. All surveys have used complex, multistage, stratified, clustered samples of defined populations. The target populations for NHES and NHANES I were based on a probability sample of persons in the coterminous United States; with NHANES II, Alaska and Hawaii were included for the first time. The HHANES was restricted to those counties and neighborhoods in the three target areas of the country that had a sufficient number or proportion of Hispanics to render it economically feasible to screen households and to operate an examination center for a 4–7-week period. All past surveys have had upper and lower age limits. Thus the very young infant and the elderly above 74 to 79 yr have not been included. These limits, however, are likely to be extended or dropped for NHANES III.

A number of biochemical and hematological measures of nutritional status were included in the three HANES, either in all examined persons or in subgroups. The majority of these are summarized in Table 1. Dietary intake data were also collected in all of the HANES through use of a single 24-hour recall and a food frequency questionnaire. In addition, all NHES and HANES included measures of blood pressure and numerous anthropometric measures such as height, weight, several skinfolds, and circumference or girth measures.

FACTORS INFLUENCING USE AND INTERPRETATION

The HANES have many uses but, as is the case with all surveys, they also have the potential for a number of different types of errors and biases. Numerous quality control procedures are incorporated into the survey design to minimize sources of error (12, 19, 20, 36–41, 45, 47). These procedures include standardization of questionnaires and probes; training, retraining, and monitoring of staff; regular calibration and maintenance of equipment; automated recording of results; replicate measurements; and checking of unusual results by stand location or by individual observers. Central laboratory facilities were used for the nutritional biochemistries to standardize analytical procedures. Laboratory quality control procedures included use of "bench" quality control pools inserted by the analyst and "blind" quality control samples indistinguishable from regular field samples (19, 20, 41). However, despite numerous quality control measures, the data should be carefully examined by users before specific analyses are done to identify any problems that could affect the interpretation and use of the data.

Nonresponse Bias

One type of error that can occur in voluntary surveys such as HANES is the bias introduced by nonresponse if the nonrespondents differ from the respondents with respect to the measurements being made. In any HANES, there exists the potential for three levels of nonresponse: initial household interview, examination nonresponse when sample persons do not come to the examination center, and missing data for some measures for examined persons (36–40, 47).

The potential for nonresponse bias is greater when interview and examination response rates are low. Therefore a number of steps have been taken to maximize response. These include use of smaller sampling areas to decrease travel time and logistical problems for persons coming to the mobile examination centers, advance publicity, extra personal contacts to schedule appointments and arrange transportation, and a small remuneration (7). Response rates were 86, 96, and 90% for the three NHES and 74 and 73% for NHANES I and II. For HHANES, a response rate of 75% was obtained for the Southwest and Puerto Rican samples, but only 61% for the Cuban-American sample (personal communication, National Center for Health Statistics).

Several studies have been conducted to evaluate the potential effect of nonresponse on survey results by comparing demographic and medical history variables for responders and nonresponders at both the household and examination levels (15, 37–40, 47). No apparent biases were observed in any of the surveys. This was particularly true for NHANES II after application of sample weighting factors that included adjustments for nonresponse based on income, age, geographic region, and metropolitan area (15). This, however, does not rule out the possibility that some crucial variable or combination of variables exists but was either not measured or not analyzed in evaluating the potential for bias.

The third type of potential nonresponse bias is that of item-missing data. All measures are subject to missing data and should be evaluated on an item-by-item basis. For nutritional assessments, missing values for the nutritional biochemistries are often of primary concern. In NHANES II the percentage of missing laboratory data varied considerably by type of assessment: hemoglobin, hematocrit, and mean corpuscular volume, (6.6–7.5%); erythrocyte protoporphyrin (10.3%); serum iron (13.6%); serum vitamin C (14.8%); serum zinc (20.4%); transferrin saturation (22.9%); and serum vitamin A and red blood cell folate (38%) (16, 49, 59). The missing data also varied by age; rates were higher for infants and young children than for other age groups (16). For example, in NHANES II, values for erythrocyte protoporphyrin were lacking for 60% of examined children 6 to 11 months vs 3 to 4% of adults; comparable values for transferrin saturation were 93.5% and approximately 12%.

Several examples can be given of critical evaluations of missing data problems and documented approaches for dealing with them. Losses of red blood cell (RBC) folate data from 10 of the 64 stands (locations) in NHANES II were deemed to have relatively little effect on sampling bias after similarities were found among descriptive variables and other nutritional biochemistries for persons from stands with and without the RBC folate data (59). A relatively high percentage of missing values for transferrin saturation (TS) (23% overall; 90% in infants and 13% in adults) was compensated, in part, by using multiple regression to derive an algorithm for predicting TS values from serum iron data (51). Imputed values for missing systolic and diastolic blood pressures were assigned from the records of matched examinees with the same age, sex, and race, and with similar arm girth, weight, and height (55). In NHANES II, if either hemoglobin or hematocrit value was missing, but not both, a value was imputed using formulas derived from an analysis of the relationship of hemoglobin and hematocrit for sampled persons with known results (16). A "hot deck" procedure, using the variables age, sex, and use of hormone/birth control pills, was used to impute missing serum cholesterol values in NHANES II (17).

These specific examples, plus the discussion on other types of potential nonresponse bias, illustrate the need for individual users of the data to evaluate carefully the potential for nonresponse bias for their specific applications. In addition, when problems are encountered and imputations are made, adequate documentation should be provided for users of the data bases and readers of the published results.

Measurement Bias

In addition to the potential for bias from missing data, systematic biases inherent in the laboratory methodologies are also possible. Biases that would not be apparent with small studies or clinical laboratory conditions can be magnified with the large sample sizes available in NHANES and can affect estimates of prevalence rates and other distributional analyses. Changes in methodologies can raise questions as to whether differences in population values are due to differences in methodologies or to "true" differences in nutritional status over time.

Recently, thorough evaluations were undertaken of the methodologies used to evaluate the iron (13, 51), zinc (52, 53), folate (59, 60), and vitamin A (49, 50) status of the US population. Vitamin A represents a particularly graphic example of the problems that may arise in evaluating methodological issues. In the three completed HANES, different laboratory methods were used in each survey: the colorimetric procedure used in NHANES I was modified for use in NHANES II, and a high-pressure liquid chromotography (HPLC) method was used in HHANES. Changing from the colorimetric methods, which measured total serum vitamin A (retinol + retinyl esters) to the HPLC method used in HHANES (retinol only) meant that not only did methodologies change but that the serum vitamin A component being measured also changed. Furthermore, discrepantly high values for vitamin A results and quality control pools over a 6-month period in NHANES I, probably due to a contaminated reagent, resulted in the recommendation that a constant multiplier adjustment factor be applied to the problem data. Finally, a comparison study of the colorimetric method used in NHANES II and the HPLC method in HHANES for vitamin A suggested that comparability of results was closest for values in the low range, but became divergent for values above the median. Thus, differences in serum vitamin A values among the three surveys cannot necessarily be interpreted as differences in vitamin A status, since results are confounded by concurrent methodological changes and problems. Nonetheless, the analyses conducted provided valuable insights for improving assessment of vitamin A status in future NHANES and useful estimates of the prevalence of low levels of serum vitamin A in US population subgroups.

Other potential sources of systematic bias may come from the logistical constraints imposed by the survey itself. For example, dietary interviews were conducted on Tuesdays through Saturdays; thus the 24-hour recall information did not capture weekend food patterns (36, 37). Because of practical problems of operating the mobile examination centers in northern states in the middle of winter, the scheduling of stands (locations) was deliberately arranged so the North was avoided in winter and the South in summer. Thus any characteristic under study that may have a seasonal variation will be difficult to interpret by geographic region. In summary, analysts should carefully evaluate the methodologies used and their potential impact on analysis and interpretation of the results when using the HANES data tapes.

Weighting Factors and Design Effects

The analysis of data from large complex sample surveys is not a straightforward task, and the use of statistical software programs that assume simple random sampling is seldom appropriate (1, 28–30, 36–40, 47). Because the HANES used a stratified, multistage design that provided for the selection of samples at each stage with a known probability, national estimates are derived through a multistage estimation procedure. For the NHANES, the procedure has three basic components: (*a*) inflation by the reciprocals of the probability of the selection; (*b*) adjustment for nonresponse taking into account income, age, geographic region, and metropolitan area; and (*c*) poststratification by age, sex, and race to bring the population estimates into close agreement with the US Bureau of Census estimates at approximately midpoint in the surveys (36, 37). Several modifications in these procedures were necessary for the HHANES (47).

Two aspects of the HANES design must be taken into account in analyses: the sample weights and the complex sample design (1, 28–30, 36, 37). Sample weights are needed to estimate means, medians, and other descriptive statistics. Weights and the strata and the primary sampling units are needed to estimate variances and to test for statistical significance. In some cases, analyses with weights and design effects vs analyses without these factors result in quite different conclusions (1, 28–30).

Examples of the effects of weighting factors and complex design effects on results and interpretations have been evaluated and discussed by Landis et al (30), Abraham (1), and Kovar (28). In particular, they show that the effects of incorporating the complex sample design can be quite dramatic as compared to procedures for simple random samples, often resulting in greater difficulty in achieving statistical significance. Recently, the finding that design effects from HHANES are unstable prompted reevaluation of data from NHANES I and II and consideration of a strategy for using average design effects in analyses (29). Currently, additional research is being done in this area.

Interpretative Criteria

A major concern in estimating prevalences of nutritional problems or health conditions in populations or in identifying individuals at nutritional risk is in arriving at a definition of impaired or at-risk nutritional status. Measures are often evaluated according to whether they are above or below a criterion "cut-off" value. The limitations of cut-off points for assessing dietary or health status are discussed in the recent report of the Joint Nutrition Monitoring Evaluation Committee (61). A comprehensive discussion of recommendations for specific cut-offs and interpretative guidelines for the iron, zinc, folate, and vitamin A nutritional status indices has been recently completed by expert panels (13, 49–53, 59, 60). A general question addressed by these panels was the need to evaluate the appropriateness of literature-derived cut-offs for the NHANES populations. To do this, supporting evidence from other related physiological measures in the NHANES was examined. For example, in the evaluation of iron status, the appropriateness of using results from clinical studies to define cut-off values for adults was supported by the observation that mean hemoglobin levels for adults falling in the normal range differed from those of adults falling in the "at-risk" range (13, 51). The absence of this relationship in children younger than 11 years necessitated a more empirical approach for arriving at interpretative criteria.

Attempts to correlate physiological variables to measures of folate, zinc, or vitamin A status were also made, but were not particularly useful in confirming literature-derived interpretative criteria (49, 50, 52, 53, 59, 60). For serum and RBC folate, expected correlations of low folate values with hemoglobin and mean corpuscular volume (MCV) were not observed. Low serum zinc values were not associated with growth retardation in children. For vitamin A in NHANES I, there were almost no reports of clinical symptoms normally associated with vitamin A deficiency (conjunctival xerosis, Bitot's spots, keratomalacia, xerophthalmia). Given the lack of physiological correlates, the relatively low prevalences of "at-risk" biochemical levels, and the lack of sensitivity and specificity of some available measures, caution in interpreting results as characterizing nutritional deficiency states was recommended. Despite such cautions, these results were particularly useful in identifying subgroups at relatively greater risk for whom future public health programs and/or surveys should be targeted.

In summary, we have identified the major types of potential problems when using survey data bases such as HANES. These problems included the potential for nonresponse and measurement bias, use of weighting factors and complex design effects, and development of interpretative criteria. Individuals who use the data for primary analysis or who depend on published results should carefully consider these issues as they plan analyses and interpret results. Analysis methods must be appropriate not only for the hypothesis or objective of the particular study, but also for the study design and methodologies available in the HANES. Interpretation of results should be linked to survey methodologies and designs as well as to study objectives. Procedures for checking for potential problems should be carefully thought out and documented. Numerous data manuals and program descriptions were referenced and are available to guide users as they review these issues in light of their specific interests.

ANALYSES AND RESULTS

Distributional Analyses

The availability of data for large numbers of persons in the NHES and HANES allows for distributional analysis of results; thus tables of means, variances, percentile distributions, and cumulative percentage distributions for the nutrition and health variables in a number of subgroups can be examined. The need for this type of data was an early purpose and remains a key element of these surveys. It is from these data that prevalence estimates and normative values are derived. When enough data bases are available with comparable measures, time trends in prevalence estimates and population distributions can also be monitored. A number of publications are available (48) that present reference tables for age, sex, income, and racial subgroups for anthropometric indices (4, 22, 23, 61), dietary intakes (2, 3, 9), nutritional biochemistries (16, 42, 49, 51, 52, 59, 61, 62), and chronic diseases and risk factors (11, 17, 21, 54–57, 61). Data tapes and supporting documentation also are available for direct use by researchers (43, 44).

Distributional analyses are frequently presented by categories of demographic, socioeconomic, or physiological subgroups, but may also be warranted when methodological differences result in shifts in the distribution of values. For NHANES II, separate reference tables have been published for serum and RBC folate values determined by microbiological vs bioassay methodologies (59). Results showed comparable distributions of values below the median, but above the median values from the two methods diverge. For serum zinc values, differences in distributions of values due to fasting status and diurnal variation prompted publication of separate tables by time and conditions of blood collection (52).

NORMATIVE DATA Perhaps the best known and used examples of NHES and HANES data for development of normative data are the growth charts for infants and children (22, 23). The charts, which are used to provide standards for clinicians to track and evaluate whether a child's height and weight are appropriate for his age, were developed by the National Center for Health Statistics and the Centers for Disease Control using data from the NHES, the NHANES I, and the Fels Institute. These charts represent the distribution of heights and weights one would expect to find in a healthy, or reference, population.

PREVALENCES OF NUTRITIONAL STATUS Using NHANES I, II, and data from the Southwest portion of HHANES, several ad hoc groups of experts have recently evaluated the prevalence of persons at risk of nutritional deficiencies for iron, zinc, folate, vitamin A, vitamin C, and protein. Risk of nutritional overages is more difficult to assess, but was attempted for iron.

Iron The wealth of iron status indices in NHANES II allowed, for the first time in a national survey, the luxury of assessing iron status with a combination of measures rather than the usual dependence of presenting results based on the percentage of persons falling outside a cut-off for a single variable (13, 51). A major advantage of using several variables in combination is that it minimizes the potential for bias in prevalence estimates due to the influence of factors unrelated to iron nutritional status. For example, low mean corpuscular volume (MCV) values are also associated with α-thalassemia; hemoglobin distributions vary between blacks and other races; smoking is associated with shifts in distributions of hemoglobin and erythrocyte protoporphyrin; and values for some variables (e.g. transferrin saturation) vary by the time of day in which blood samples are collected. Since nonnutritional factors tend to be associated with one or two but not all variables in a model, a model approach is generally more resistant to possible confounding factors than is a prevalence estimating procedure based on single variables.

In assessing the prevalence of impaired iron status from NHANES II, five measures of iron status were used: MCV, transferrin saturation, erythrocyte protoporphyrin, serum ferritin, and hemoglobin (13, 51). Age-specific interpretative criteria were used to define impaired iron status. Different combinations of variables were used in three different models, yielding a range of estimates that were fairly low for most groups. For males aged 15–64 yr, the highest estimates did not exceed 2%. Similar values were <6.2% for children 3–10 yr, females 11–14 and 45–74 yr, and males 65–74 yr. Several groups, however, exhibited relatively higher prevalences of impaired iron status: children 1–2 yr (9.2–9.4%), males 11–14 yr (3.5–12.1%), and females 15–44 yr (2.5–14.2%). Since the models did not differentiate between impaired iron status due to iron deficiency or inflammation, serum ferritin values (which measure body stores of iron) were examined for adults defined as having abnormal iron status. The results suggested that many of the abnormal values for iron status indicators in older persons may have resulted from inflammatory disease.

The prevalence of impaired iron status tended to be associated with poverty and race (51, 61). Blacks and persons below the poverty level tended to have higher prevalences than whites or nonpoor. The greatest discrepancy was for children 1 to 2 yr, with 20.6% below the poverty level versus 6.7% of the nonpoor with impaired iron status. For some children, low iron status was associated with high blood lead levels (32a).

The potential for assessing iron overload was also evaluated, although data from NHANES II are limited for this purpose (51). Five of 3540 adults had biochemical and clinical values consistent with a diagnosis of uncomplicated idiopathic hemochromatosis. From data unadjusted for sampling inequalities, the gene frequency of the hemochromatosis allele was estimated to be 0.038, a frequency similar to that reported for other populations.

Zinc The criteria to identify low serum zinc values were chosen to accommodate differences in the time of sample collection and fasting status of sampled persons: <70 μg/dl for the AM "fasting" sample, <65 μg/dl for the AM "other" sample, and <60 μg/dl for the "PM" sample. Using these criteria, the prevalence of low serum zinc values was low for all sex/age groups (0.8–3.9%) and was not associated with other physiological and environmental variables often observed in zinc deficiency (i.e. stunted growth, vitamin A deficiency, or poverty status) (52, 53, 61, 62). The well-documented lack of specificity of low serum zinc values and the lack of correlation with other physiological correlates of zinc deficiency in the NHANES II data were interpreted to mean that low serum zinc values in the NHANES II population are only suggestive of poor zinc nutriture.

Folate Serum and red blood cell (RBC) folate data were scheduled for a subsample of 3909 persons in NHANES II. Cutoff values to estimate the prevalence of low serum folate and low RBC folate levels were somewhat arbitrarily selected as <3.0 ng/ml and <140 ng/ml, respectively. With these criteria, the prevalence of low serum and RBC folate values was lowest in children 6 months to 9 years old (2 and 2%, respectively), males 10–19 yr (3 and 5% respectively), and females 45–74 yr (9 and 4% respectively) (59, 60). The prevalence of low folate values was greatest in females (including pregnant women) ages 20–44 yr (15% low serum folate, 13% low RBC folate, 6% both low) and in males of the same age (18, 8, and 5% respectively). However, the lack of association of low folate values with low hemoglobin levels or enlarged red blood cells suggested that either the number of persons with a folate deficiency was too small to affect results, or low folate values did not represent a deficiency of sufficient severity to produce abnormal values.

Vitamin A Data on serum vitamin A were available from all three HANES: for all persons in NHANES I, for children 3–11 yr in NHANES II, and for persons 4–74 yr in the Southwest portion of HHANES. Serum vitamin A levels of <20 μg/dl were relatively rare (0–6.1%) for all age groups in all three surveys (49, 50). The prevalences of serum vitamin A levels in the range 20 to 24 μg/dl were generally higher (0–23.5%), especially in children. A multivariate analysis of some of the factors that may influence the prevalence of low serum vitamin A levels indicated (*a*) that regardless of poverty status, blacks had higher prevalences of low serum vitamin A levels for all age groups except adolescents; and (*b*) that regardless of race, poor persons had higher prevalences of low serum vitamin A levels for all age groups, except adolescents (49, 50, 61).

Vitamin C The prevalence of low plasma vitamin C data from NHANES II was 3% overall for the total US population. Very few young children had low vitamin C values (61, 62). Males 25 yr of age and over had a higher proportion of low values than did females. Black males 55–74 yr had the highest proportion of low values (16%). Low values were more commonly found among poor than nonpoor, particularly in adults. Thus, although the overall percentage of persons with low vitamin C in the US population (3–74 yr) was not large (3%), there were selected subpopulations for which this was not true, particularly for those with low dietary intakes, cigarette smokers, and the poor.

Protein Protein was assessed by serum albumin. The overall prevalence of low serum albumin was 0.1% (61).

SURVEILLANCE OF RISK FACTORS In addition to providing data to assess the prevalence of nutritional problems in the US, the NHANES provide valuable data on prevalences of diseases (such as diabetes) and risk factors (including dietary and nutritional factors) associated with the occurrence of chronic diseases.

Overweight Using NHANES II data and defining overweight by a body mass index (weight/height^2) above the 85th percentile for men and women 20–29 yr old, 28% of the population 25–74 yr were classified as overweight (61). Approximately 60% of black females 45 yr and over compared with 30–36% of white women were overweight. Problems of overweight were more common in adult women below the poverty level (~45%) than in those above the poverty level (~29%). Among adults in NHANES II, overweight was associated with higher prevalences of diabetes, high-risk serum cholesterol levels, and hypertension. This relationship tended to be more pronounced in adults 25–44 yr than in older adults (45–74 yr).

The availability of body measures on adults from the first NHES and the two completed NHANES means that time trends in the prevalences of overweight can be compared for 1960–1962, 1971–1974, and 1976–1980 (61). For men, no consistent trend was seen. For females 25–34 yr and 35–44 yr, the percentage overweight increased from 15.9 to 20.0% and 24.4 to 27.0%, respectively, from 1960–1962 to 1976–1980. Conversely, for women 55–64 yr and 65–74 yr, the percentage overweight declined (43.6 vs 37.0 and 43.3 vs 38.5%). The prevalence of severe overweight by age group was not significantly different over the three surveys for men and women.

Hypertension Several reports have estimated the prevalence of elevated blood pressures and hypertension in the US population and adult subgroups (11, 46, 55–57, 61). Although criteria for defining hypertension and age groups varied somewhat, so that prevalence estimates differed, conclusions were similar among the various reports. Under the traditional definition of hypertension as a systolic blood pressure (SBP) ≥160 mm Hg and diastolic blood pressure (DBP) ≥95 mm Hg and/or use of antihypertensive medications, 17.5% of adults 18–74 yr from NHANES II were defined as definite hypertensives, either diagnosed or undiagnosed (11). If the more recently published criteria from the Joint National Committee on Detection, Evaluation and Treatment of High Blood Pressures were applied, the estimated prevalence for hypertension would be considerably higher: 29.7%.

With traditional criteria, definite hypertension was more prevalent among black than white adults (25.7 vs 16.8%), respectively (11). About 26.4% of hypertensive adults had not been diagnosed prior to the survey. Mean DBP levels were generally higher among men than women. Both SBP and DBP levels were generally higher among black than white adults (11, 61). As overweight and obesity increased, so did the risk of hypertension (61).

For trend analyses, blood pressure and medical history data for adults were available from three surveys: NHES I (1960–1962), NHANES I (1971–1974), and NHANES II (1976–1980). Mean SBP decreased by 5 mm Hg among white adults and by 10 mm Hg among black adults over this time span (11). Improvements in mean SBP were greater among older than younger adults. The prevalence of elevated SBP decreased 5.3% among white adults and 12.6% among black adults. The prevalence of definite hypertension (elevated blood pressure and/or use of antihypertensive medications) decreased from 33.6 to 28.6% in black adults, but the differences did not reach statistical significance. No similar decline was observed among white adults. Over the 20-yr time span, the prevalence of diagnosed hypertensives taking antihypertensive medication increased from 30.3 to 45.4%, and the proportion of medicated hypertensives whose hypertension was controlled increased from 39.3 to 51.7%.

Serum cholesterol Reference values for serum cholesterol from several surveys have been published (17, 46, 56, 61). In NHANES II, overall means for men and women 20 to 74 years old were 211 and 215 mg/dl, respectively (17). Mean serum cholesterol levels were significantly higher in each succeeding age group until age 45–54 yr for men and 55–64 yr for women (17, 46). Using serum cholesterol levels of 220, 240, and 260 mg/dl to indicate high risk levels for adults 20–29, 30–39, and ≥40 yr, respectively, 21.8% of individuals 25–74 yr were so classified (61). The prevalence of elevated serum cholesterol did not differ significantly by race. Females aged 55 to 74 yr, regardless of race, showed highest prevalences of at-risk levels for serum cholesterol (about 35%). The prevalence of elevated serum cholesterol levels was greater for persons above the poverty level than for persons below it (21 vs 13% for males age ≥ 35 yr old and 36 vs 29% for females).

Time trend data for serum cholesterol are available from three national surveys over 20 yr (1960–1962, 1971–1974, 1976–1980). Results show a decrease in cholesterol levels for both men and women (61).

Diabetes Persons surveyed in NHANES II were classified as having diabetes if results of an oral glucose tolerance test indicated a diabetic condition (National Diabetes Data Group criteria) or if diabetes was indicated on the participant's medical history (21, 61). In NHANES II, approximately 7% of the total adult population was classified as having diabetes (61). Most of these were the non-insulin-dependent type: two thirds of adult diabetics under age 45 and 99% over this age. Prevalence was higher for females than males (8.2 vs 6.6%); blacks than whites (11.2 vs 7.0%); poor than nonpoor (12.9 vs 6.8%); overweight than nonoverweight (13.4 vs 4.9%); older males (65–74 yr) than younger (25–34 yr) (19.0 to 1.9%); and older females than younger (16.5 to 1.5%).

Diet, Nutrition, and Health Relationships

The newest use of NHANES data is in the evaluation of relationships among dietary, nutritional, and health factors. Landis et al (30) gave an extensive and detailed description of the statistical methodologies for using data from the complex NHANES for this purpose, along with numerous tables documenting the effect of weighting factors and incorporation of design effects on results.

These statistical techniques were applied to NHANES I data in evaluating possible relationships of nutritional factors to dental health (8) and to cardiovascular risk factors (25, 26). Helpful discussions of a number of problems encountered are given: (*a*) the difficulty in cross-sectional research of relating measures of current dietary intakes to risk factors of diseases incurred over a long and earlier time period; and (*b*) the lack of a complete set of measures needed to test a relationship because the NHANES are not always designed in advance to test specific hypotheses. Also, many of those persons surveyed had been informed of their current medical conditions and therapy had been prescribed by their personal physicians. Thus, these persons may already have altered their eating behaviors and consequently also altered the levels of their clinical or biochemical measures. These people, then, must be excluded from relational analyses; yet if their prediagnostic dietary and physiological values were known, they would be the people most likely to show relationships that are "real."

As discussed in the studies referenced above, considerable care must be used in assessing diet/health relationships from the HANES. Consequently, critical evaluation of published results is often difficult since authors do not always adequately describe their analytical samples, interpretative criteria, or statistical models. Weighting factors and complex design effects are incorporated sometimes, but not in all cases. Results, then, can be conflicting. For example, a popular use of NHANES data in the past few years has been the investigation of a possible relationship of dietary calcium to blood pressure. Using the same data base (NHANES I), separate research groups have obtained quite different results. McCarron et al (34) concluded that a reduced consumption of dietary calcium and potassium is the primary marker of hypertension. These analyses and conclusions were challenged by leaders of several government agencies (14); and a rebuttal was offered by McCarron (35). At about the same time, Harlan et al (24, 25), using multiple regression analyses and fairly complex models, found that relationships of dietary calcium and blood pressure measures were inconsistent among sex or race subgroups. There was a positive association between systolic blood pressure and dietary calcium in males, while diastolic blood pressure in females and blacks showed a negative association. No relationship between these variables was observed in males or whites for diastolic blood pressure, or in females, whites or in blacks for systolic blood pressure. Gruchow et al (18), also using multiple regression, found that dietary calcium was significantly associated with systolic blood pressure only in the zero-order equation. When age was controlled, the calcium effect was no longer significant. Finally, Sempos et al (58), using quantile analysis and controlling for age and body mass index, found that only in one subgroup was there a relationship between dietary calcium and blood pressure: black males in NHANES I. This finding, however, was not confirmed for this or any other subgroup in NHANES II. These latter authors concluded that the data of NHANES I and II do not show an association between low calcium intakes and blood pressure.

CONCLUSIONS

The HANES data bases, along with their NHES predecessors, provide a wealth of measures for assessing nutritional status and risk factors associated with chronic diseases. The breadth and nature of the measures obtained, the generalizability to US population groups, and the succession of and linkages among surveys over time are invaluable for development and evaluation of public health policy at the national level. As such, they make a significant contribution to the implementation of the National Nutrition Monitoring System. For example, their use has been important in the areas of nutrient fortification for the national food supply, monitoring the use of vitamin/mineral supplements, design and evaluation of food programs and nutrition education initiatives, and information on infant feeding practices and growth

(47). A dramatic example of the potential for using HANES data in documenting the need for public health policies and in evaluating effectiveness of those policies was the data showing not only that blood lead levels in some young children were high, but also that declines in mean blood lead levels between 1976 and 1980 paralleled exactly the decline in use of leaded gasoline (5, 6, 33). In addition, comparison of blood lead and erythrocyte protoporphyrin levels provided valuable information for evaluation of the criteria used in lead screening programs (32a).

In this chapter, we have attempted to summarize the various surveys in the HANES system and to describe their characteristics. We focused our discussion on nutritional status assessments and results generated primarily for the purpose of assessing the prevalence of nutritional problems and nutritionally related risk factors for chronic diseases; and only superficially treated the significant body of analyses generated by researchers to examine diet/health relationships. This was not meant to imply that these latter uses are not important, but rather was necessitated by time and space limitations and the need to discuss the background factors so necessary for use and interpretation of these data bases. The increasing use of HANES by epidemiologists for hypothesis generation and evaluation is a growing and important area that also warrants critical examination.

Throughout this chapter, considerable attention was given to problem areas or potential problem areas. The complexities and cautions in using the surveys were identified and references for more detailed information provided. This was not meant to detract from the tremendous value and usefulness of the data; instead, it was presented to provide an awareness of the issues, the extensive documentation available, and the scope and depth of both internal and external analyses and evaluations of the data bases, particularly for prevalence estimates of nutritional status measures and nutritionally related risk factors in US population groups. The purpose of presenting this information was to give the reader a feel for the increasing breadth and degree of sophistication of the surveys over time, as experience was gained, as critical evaluations were made, and as state-of-the-art methodologies improved. An awareness of the complexities and potential problems is needed by users of published results as well as by analysts who are involved in direct number manipulation. The surveys are extremely powerful when used correctly and appropriately; however, their potential for misuse, either intentionally or naively, is also great. Only by understanding the complexities and potential pitfalls can we enhance the use of results in a scientific and responsible manner. Knowledge of problems encountered in the past is a prerequisite for improvement and should also minimize "reinvention of the wheel" by new users of the data bases.

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