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Nutrient Database Development: An Historical Perspective from the Framingham Nutrition Studies

Abstract

Food frequency questionnaires (FFQs) are commonly used in nutritional epidemiology to assess habitual eating habits. Development of an appropriate food and nutrient database is required for translating information derived from FFQs into estimates of nutrient intake, dietary quality or for absolute or rank-ordered nutritional risk assessment. We discuss the procedures used recently in designing an historical nutrient database to analyze an FFQ administered in 1984–1988 to Framingham Offspring-Spouse Study (FOS) members. This systematic approach should inform other research in the field. The self-administered 145-item Framingham FFQ is semi-quantitative with seven non-overlapping response categories to determine annual consumption frequency. The database development process included: 1) selection of the United States Department of Agriculture's Nutrient Database for Standard Reference as the primary raw data source; 2) expansion of the 145 FFQ line-items to code individual foods to assign nutrient values; 3) a selection process to match foods to appropriate nutrition codes for nutrient information; and 4) a statistical model to calculate nutrient intakes. The historical database contains 449 foods and nutrient data for all 29 nutrients available in 1985. The adequacy with which an FFQ can provide reliable diet assessment data depends on the integrity of the underlying database. We outlined a systematic protocol to derive usual dietary intake from an FFQ, using a robust nutrient database that is appropriate for the FOS FFQ and its assessment time-frame. The database can be updated to accommodate changes in the food supply and eating behaviors and creates a foundation for future nutrition research.

Keywords

nutrient database; food frequency questionnaire

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INTRODUCTION

Food frequency questionnaires (FFQs) facilitate dietary data collection in large cohort studies and are the most frequently used diet assessment method in nutritional epidemiology to assess habitual eating habits and rank individuals' energy and nutrient intake (1,2). Development of an appropriate food and nutrient database is required to translate information derived from FFQs into estimates of nutrient intake, dietary quality or for absolute or rank-ordered nutritional risk assessment (3). Experts use a variety of approaches in database development for FFQ analysis, including reliance on expert opinion (1), population-specific data-driven methods (2), or a combination of the two (4). To our knowledge, detailed methods of constructing a retrospective/historical nutrient database have not been published.

This paper discusses procedures to consider when developing an historical FFQ nutrient database designed to profile nutrient intakes of the Framingham Offspring-Spouse Study (FOS) cohort. The systematic approach is relevant to help investigators evaluate and/or construct nutrient databases for use in their own research.

METHODS

Research Program and Participants

A nutrient database was created recently to analyze an FFQ administered in 1984–1988 to members of the FOS who are offspring and their spouses of the original Framingham Heart Study cohort. Detailed study methods have been described previously (5). Briefly, the Framingham Study was initiated in 1948 to identify factors contributing to cardiovascular disease development and to study its progression among a random sample of approximately 5200 Framingham, MA residents, aged 28–62 years. The FOS began in 1971 and this cohort of 5124 adults is examined every four years. Following standardized protocols, participants provide an updated, detailed medical history and undergo a complete physical exam, including laboratory and non-invasive diagnostic testing at each clinic visit. At Exam 3 (1984–1988) extensive baseline dietary information was collected using published methodologies (1,6–8). Of participants who attended Exam 3, 97% completed a self-administered FFQ and 24-hour recall and 70% completed a 3-day dietary record (6). Currently, nutrient calculations are performed using the Minnesota Nutrition Data System software (version 2.6; Food Database 6A; Nutrient Database 23; Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN; 9, 10), specifically designed for research purposes (9,11).

The 145-item Framingham FFQ was adapted from the original Willett (1) prototype to include seven, rather than nine, non-overlapping response categories ranging from “never or <1/month” to “4 or more/day” to determine annual consumption frequency. The FFQ is semi-quantitative, listing standard portions of foods with participants reporting how often they consume a standard portion (e.g. “how often do you usually consume 1 cup of coffee”). Development of a nutrient database was necessary to compute nutrient values from the Framingham FFQ at Exam 3. Previously, this FFQ has been used to characterize dietary patterns of men and women with nutrient estimates derived from 24-hour recalls (8) and 3-day dietary records (10,12).

All participants provided written informed consent. All protocols were approved by the Human Subjects Institutional Review Board of the Boston University Medical Campus and Boston Medical Center.

Nutrient Database Development

Development of the database required multiple steps, including selection of a nutrient database for raw data, expansion of FFQ line-items to code individual foods, a selection process to match

foods to appropriate nutrition codes for nutrient information, and a statistical model to calculate nutrient intakes (Figure 1).

Nutrient Database Selection

The United States Department of Agriculture (USDA) has been creating food composition databases for over a century and the staff involved is comprised of dietitians, food technologists and computer specialists. Therefore, in Step 1, the USDA Nutrient Database for Standard Reference (SR) was selected as the primary raw data source because it is the foundation for most public, commercial, foreign and domestic nutrient databases (13–15) and has a primary role in nutritional status assessment, nutrition and food policy development, as well as human nutrition research and is the source of monitoring US population nutrient intakes (13–15). It is updated annually and is reasonably comprehensive with the current version, SR 21 (13), containing 7,412 foods and 140 nutrients and food components (14).

Our database was created to analyze an FFQ completed in the mid-1980s. An historical nutrient dataset from 1985 was obtained from USDA. This first version of USDA's Survey Nutrient Database for Trends Analysis, based on the SR, includes nutrient values, food descriptions, and food weights appropriate to the time period of interest (16). The trends analysis system is continually updated to reflect changes in the food supply and revisions of nutrient and food composition values due to improvements in analytical or sampling procedures (16). This was the first opportunity to use the 1985 USDA trends database in the FOS.

Expansion of FFQ

In Step 2, because many line items on the FFQ contain multiple foods on one line (e.g. pizza and lasagna), the 145-item FFQ was disaggregated into 295 lines with a single food to match each food to all reasonable USDA database choices commonly consumed in the mid-1980s.

Food Code Selection/Confirmation Algorithm

In Step 3, an algorithm was created to select USDA food codes to match to FFQ line-items. All matching was performed in duplicate by two registered dietitians (RDs) who independently matched each food to all appropriate items in the 1985 USDA database. Each RD noted their rationale for choosing the food code(s) assigned to food line-items. To avoid systematic error, a calculated average was determined from all food codes identified for a particular line-item (e.g. "chicken with skin" was matched to stewed, fried, and roasted listings). Bias was also avoided by choosing generic food items whenever possible (e.g. canned chicken soup), rather than a brand-specific food.

At each stage in Step 3, food technology and composition journals, as well as manufacturer and food consumption data (17) were researched to determine whether all potential matches in the USDA database had been selected for each food and to confirm that matches were appropriate for inclusion in the final nutrient profile. Further research identified several foods listed in the 1985 USDA database under another name (e.g. kasha is also known as buckwheat in the US). It was also determined that several foods in the USDA database were listed because of product development research, but were not available for consumer consumption. For example, fat-free potato chips were not marketed until FDA approval of Olestra® in 1996 and were omitted from our historical database.

In Step 3A, foods with only one appropriate USDA match were verified and finalized. Foods with only one match (e.g. honey, olive oil, and sherbet) or with a generic choice representing a variety of foods in the same category (e.g. composite choices for crackers and margarine) in the 1985 USDA database were identified. For line-items with multiple choices in the USDA database, if only one choice represented the form most likely consumed or most widely

available at that time, it was confirmed for inclusion (e.g. cooked versus uncooked legumes, reconstituted versus unprepared, dry mix cocoa and aspartame-sweetened versus saccharine-sweetened diet soda [aspartame dominated the market after its introduction in the early 1980's]).

In Step 3B, composite nutrient profiles (i.e. average nutrient content from >1 food) were created for line-items with multiple potential matches in the USDA database. All potential matches were considered. Items in the USDA database not consumed in large quantities during this time period due to availability were excluded from the composite. For example, unsalted potato chips and low-fat (not low-calorie) salad dressings were not consumed by most individuals in the mid-1980s and were not included in our database.

The composite nutrient profile included commonly consumed varieties of a food that were not nutritionally equivalent, though a respondent could have consumed any reasonable form of the food. For example, the line-item “coffee” contains brewed and instant coffee. Both were commonly consumed in the mid-1980s and the caffeine content was dissimilar so that a composite was required. Equal weighting was applied to all USDA matches within the composite in absence of population-specific consumption data.

In Step 3C, foods with no match in the 1985 USDA database were identified and matched to a like-item, when possible (e.g. cornbread was matched to corn muffin). Alternate sources were identified to match line-items with no match and no like-item match in the USDA database (~10% of line-items) to collect nutrient information on these foods. The 1985 version of *Bowes and Church's Food Values of Portions Commonly Used* (18) was consulted, as this was the professional reference for nutrient values of foods during the time period the FFQ was administered. Nutrient values from SR 19 (19,20) were used for a line-item when 1) a match was not in Bowes and Church (18), such as lemonade and coleslaw or 2) Bowes and Church (18) contained some missing nutrient values for the line-item but listed nutrient values matched those in SR 19. SR 19 values were not used if foods were substantially different than those available in 1985 (e.g. folate-fortified foods). If a food did not have a match, yet was grouped on a line-item with similar foods of comparable nutrient values, the food was excluded from the nutrient profile of the line-item. For example, bluefish and swordfish do not have a match in the 1985 USDA database but are on the same line with other dark-meat fish on the FFQ; hence, they were not included in calculating the nutrient profile for the line-item. Bowes and Church (18) was used to validate that nutrient values were comparable.

In Step 3D, recipes were developed for mixed-dish line-items with no match in the 1985 USDA database (e.g. pizza and lasagna). Recipes came from the *Joy of Cooking* (21) cookbook. This source was chosen as it has been in continuous publication from a major publisher since 1936 (22) and represents mixed-dishes available during the diet assessment time-frame. To reflect ingredients in mixed-dish line-items, each recipe ingredient was matched individually to items in the 1985 USDA database. This expanded the 295 line-items to 499 to include ingredient foods. Since participants were asked how often they consumed these mixed-dishes, the nutrient profile was created based on cooked values. The total yield of the mixed-dish/recipe was divided by the number of servings using the information from the recipe. The total gram weight for the serving was calculated and converted to a 100-gram portion (the standard used by USDA). Portion sizes, gram weights, and nutrient values were confirmed from Bowes and Church (18). The nutrient profile was created for each recipe by summing the nutrients in a 100-gram portion of the mixed-dish. The 499 line-items were then aggregated back to the 295 food line-items following creation of the nutrient profile for each mixed-dish.

In Step 3E, the principal investigator (PI) of the Framingham Nutrition Studies (BEM) reviewed the independent, duplicate matching of all line-items by each RD and compared them

against the original 1985 USDA database. The PI resolved any differences through discussion with the RDs and made the final decision as to whether each line-item was matched appropriately.

Data Management and Statistical Analysis

The nutrient database was generated using an Excel® spreadsheet (Excel® release 10.26142625, 2002, Microsoft Corporation, Redmond, WA). A self-documenting spreadsheet simplifies and automates the process of creating and updating the database as all information (e.g. variable names, data, and mathematical equations) are visible in one file. To minimize data entry error, each RD independently imported the nutrient information for each food code from the 1985 USDA dataset for the 295 disaggregated line-items into the spreadsheet and differences were reconciled. Using the mathematical functions in Excel®, the RDs independently averaged each food code contained in each line-item and differences were reconciled. Each food code received equal weighting in calculating the nutrient profile for each line-item as population-specific consumption data was unavailable.

The 295 line-items were then aggregated into the original 145 FFQ line-items. The RDs independently calculated the nutrient profile for the 145 line-items, again using the mathematical functions in Excel. For example, line one on the FFQ contains two food items, chicken with skin and turkey with skin. Three food codes were matched to chicken with skin and one food code was matched to turkey with skin. An average was calculated for the three chicken with skin options. The averaged nutrient profile for chicken with skin was added to the one nutrient profile for turkey with skin and divided by two, creating the nutrient profile for line one “chicken or turkey, with skin.”

Only two final line-items contained any missing values for nutrients in our database. These values were treated as missing values and not included in the final calculation of the nutrient profile.

Upon completion, the historical database contains 449 foods and nutrient data for all 29 nutrients available in 1985 (Table 1). The nutrient database was imported into SAS (release 9.1, 2003, SAS Institute, Inc, Cary, NC) and a statistical algorithm was created to estimate nutrient intakes from the FFQ. Values for each nutrient in 100 grams of each of the 145 FFQ line-items were converted into a commonly consumed portion, using a conversion factor specific to the gram weight of the portions identified on the FFQ or listed in the 1985 edition of Bowes and Church (18). To estimate usual daily nutrient intake, nutrient values for each portion per line-item were multiplied by the reported consumption frequencies using a weighting factor associated with the participant's response (the weighting factors used were 0.5/30 for Never or < 1/month, 2/30 for 1–3/month, 1/7 for 1/week, 3/7 for 2–4/week, 1 for 1/day, 2.5 for 2–3/day, and 4 for 4+/day) and then summed across all foods on the FFQ. A formal validation of the database can be found elsewhere (23).

DISCUSSION

We outlined a systematic protocol to design an historical nutrient database for use with the FOS FFQ. While standardized methods for database construction have been reported (1,2,4), none address historical issues as we present here. Ideally, appropriate referent population survey data are used to generate both the FFQ and its analytical software (corresponding nutrient database), as pioneered by Block (2). The premise of this approach is that the most valid, unbiased nutrient estimates are obtained through use of food consumption data derived from current population surveys to determine food items for inclusion and assignment of nutrient values for those foods. This strategy provides nutrient intake estimates that reflect

current food composition data and population consumption levels that do not rely alternatively on assumptions or expert opinions (24).

The Block approach was not strictly feasible here because the FOS FFQ was one of the first instruments of its type in the epidemiologic literature and representative study population data were not available for the time period. Thus, we developed the alternative approach we describe here using time-specific nutrient data for food items from USDA combined with industry food availability and consumption statistics.

Recently, the use of FFQs to measure diet and disease associations in nutritional epidemiology has been questioned (25–27). Kristal and colleagues (27) emphasize the inability of FFQs to detect a relationship between diet and cancer due to their “poor measurement characteristics”. The poor performance of FFQs may partially be related to limitations of their underlying nutrient databases. Since the fundamental purpose of FFQs is to characterize usual dietary intake and rank respondents nutrient intake relative to each other, the database used to generate intake data is of utmost importance. Substantial flaws in the nutrient database will affect nutrient intake estimation and the ability of the FFQ to provide accurate dietary assessment data.

Evaluation of the nature and impact of database measurement error in the FFQ’s estimation of nutrient intake is warranted. To fully demonstrate this, the same FFQ would need to be administered in the same population and analyzed using different nutrient databases, which could then be compared. Comparison studies to date have only investigated whether nutrient estimates differ between FFQs (28,29). McCann et al. (29) compared three FFQs from the same respondents and found that mean daily nutrient intakes differed for each questionnaire, while the ability to rank respondents according to nutrient intake was comparable for two out of the three. The authors acknowledged that nutrient composition data and the method of nutrient calculation, as well as other structural differences in the three questionnaires could have influenced the results.

Nutrient values in databases are subject to limitations such as 1) factors influencing the composition of foods due to their biological nature (e.g. agricultural region and nutrient stability); 2) analytical techniques; 3) manufacturing/processing methods; and 4) use of algorithms, factors, or other mathematical calculations to determine nutrient values. Many of these are generally not able to be corrected at the investigator level and a standardized strategy for nutrient database development offers a practical approach to minimizing sources of error in nutrient estimation. An advantage of our approach is use of the USDA trends database, as it incorporates historically more complete information about the composition of foods available in the mid-1980’s. Future research may aim to standardize nutrient databases within the US and/or with international food composition databases. Investigations comparing US databases to each other and to international databases to determine whether nutrient intake estimates are comparable/interchangeable would be a first step toward standardization.

Conclusion

We describe a systematic method to measure usual dietary intake from an historical FFQ, using a robust nutrient database that is appropriate for our diet assessment instrument and time-frame. The nutrient database is based on the USDA’s Nutrient Database for Standard Reference and was developed using a systematic approach for the compilation of foods, development of recipes/mixed-dishes and calculation of nutrient profiles. The database can be updated to accommodate changes in the food supply and eating behaviors for use with future FFQ applications and creates a foundation for future FOS nutrition research.

Documenting the process implemented to construct the nutrient database allows for improvement in assessing relationships regarding food and health/disease. It also facilitates exploration of discrepancies between diet-disease relationships due to limitations of the underlying nutrient database. Lastly, these systematic procedures inform other researchers in the field with particular emphasis on the process of selecting an appropriate nutrient database for diet analysis research.

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¹ FFQ = Food Frequency Questionnaire

Figure 1.
Nutrient Database Development Process

Table 1

29 nutrients available for inclusion in the 1985 nutrient database of the Framingham FFQ¹ from Exam 3 (1984–1988)

Energy (kcal)	Vitamin C (mg)
Protein (g)	Vitamin A (IU)
Carbohydrate (g)	Vitamin B-6 (mg)
Total Fiber (g)	Vitamin B-12 (µg)
Total Fat (g)	Total Folate (µg)
Saturated Fat (g)	Iron (mg)
Polyunsaturated Fat (g)	Magnesium (mg)
Monounsaturated Fat (g)	Phosphorous (mg)
Cholesterol (mg)	Potassium (mg)
Alcohol (g)	Zinc (mg)
Calcium (mg)	Copper (mg)
Sodium (mg)	Thiamin (mg)
Selenium (µg)	Riboflavin (mg)
Carotenes Not Otherwise Specified (µg/RE)	Niacin (mg)
Vitamin E (mg/ATE)	

¹ FFQ = Food Frequency Questionnaire