Development of a Glycemic Index Database for Food Frequency Questionnaires Used in Epidemiologic Studies[1–3]

Marian L. Neuhouser,*[4] Lesley F. Tinker,* Cynthia Thomson,† Bette Caan,**
Linda Van Horn,‡ Linda Snetselaar,†† Linda M. Parker,‡‡ Ruth E. Patterson,*
Ramona Robinson-O'Brien,¶ Shirley A. A. Beresford,*§ and James M. Shikany#

*Division of Public Health Sciences, Fred Hutchinson Cancer Research Center, Seattle WA; †Department of Nutritional Sciences, University of Arizona, Tucson, AZ; **Kaiser Permanente Medical Research Program, Oakland, CA; ‡Department of Preventive Medicine, Northwestern University, Evanston, IL; ††Department of Epidemiology, University of Iowa, Iowa City, IA; ‡‡Department of Obstetrics and Gynecology, University of Miami, Miami, FL; §Berman Center for Outcomes and Clinical Research, Minneapolis, MN; ¶Department of Epidemiology, University of Washington, Seattle, WA; and #Division of Preventive Medicine, University of Alabama, Birmingham, AL

ABSTRACT Consumption of foods with a high glycemic index (GI) or glycemic load (GL) is hypothesized to contribute to insulin resistance, which is associated with increased risk of diabetes mellitus, obesity, cardiovascular disease, and some cancers. However, dietary assessment of GI and GL is difficult because values are not included in standard food composition databases. Our objective was to develop a database of GI and GL values that could be integrated into an existing dietary database used for the analysis of FFQ. Food GI values were obtained from published human experimental studies or imputed from foods with a similar carbohydrate and fiber content. We then applied the values to the Women's Health Initiative (WHI) FFQ database and tested the output in a random sample of previously completed WHI FFQs. Of the 122 FFQ line items (disaggregated into 350 foods), 83% had sufficient carbohydrate (>5 g/serving) for receipt of GI and GL values. The foods on the FFQ food list with the highest GL were fried breads, potatoes, pastries, pasta, and soft drinks. The fiber content of foods had very little influence on calculated GI or GL estimates. The augmentation of this FFQ database with GI and GL values will enable etiologic investigations of GI and GL with numerous disease outcomes in the WHI and other epidemiologic studies that utilize this FFQ. J. Nutr. 136: 1604–1609, 2006.

KEY WORDS: • *glycemic index* • *glycemic load* • *dietary assessment* • *nutrient database*

There is considerable interest in the association of carbohydrate intake with human nutritional status, energy balance, and chronic disease risk (1–4). Despite the fact that carbohydrates are typically the primary energy source for most humans, there is controversy surrounding the optimal quantity and quality of carbohydrates that should be recommended for consumption (5). Developing appropriate dietary assessment methods for research studies that address these issues is challenging because carbohydrates differ in their ability to influence immediate and long-term metabolic responses (i.e., postprandial glucose and insulin, and signaling molecules such as insulin-like growth factors). Yet, it is these physiologic responses that have important implications for energy balance, cardiovascular disease, and cancer (1,2,6–8). Thus, nutrient analyses that examine exposure only in terms of daily grams of carbohydrates or percentage of energy from carbohydrate, but do not include measures of carbohydrate quality and physiological effect, may obscure important associations of this macronutrient with disease risk or prevention.

One approach to evaluating carbohydrate quality is to classify foods and dietary patterns by their glycemic index (GI)[5] or glycemic load (GL) (See **Appendix 1**). The GI of an individual food is defined as 100 times the ratio of the glycemic response (the area under the blood glucose response curve for a

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[1] Presented in part at Experimental Biology 06, April 1–5, 2006, San Francisco, CA [Shikany JM. Tinker LF, Thomson C, Caan B, Van Horn L, Snetselaar L, Parker LM, Patterson RE, Robinson O'Brien R, Beresford SAA, Neuhouser ML. Development of a glycemic index database for a food frequency questionnaire used in epidemiologic studies (Abstract)] 2035 FASEB J 2006:20:A180.

[2] Supported by grants R01HL073114 and N01WH22110 from the National Heart Lung Blood Institute and P30CA15794 from the National Cancer Institute, NIH.

[3] Supplemental Table 1 is available with the online posting of this paper at www.nutrition.org.

[4] To whom correspondence should be addressed. Email: mneuhous@fhcrc.org.

[5] Abbreviations used: CHO, carbohydrate; GI, glycemic index; GL, glycemic load; HA, heterocyclic amines; NDS-R, Nutrition Data System for Research; NFNAP, National Food and Nutrient Analysis Program; WHI, Women's Health Initiative; WHI-DM, Women's Health Initiative Dietary Modification Trial; WHI-OS, Women's Health Initiative Observational Study.

0022-3166/06 $8.00
Manuscript received 15 December 2005. Initial review completed 20 February 2006. Revision accepted 27 March 2006.

given time post consumption) of a test food to the glycemic response of an equal portion (e.g., 50 g) of reference carbohydrate, usually white bread or glucose (9,10). Thus, the lower the GI, the lower the overall rise in postprandial glucose and insulin concentrations. In general, most refined high-starch carbohydrates have a high GI, whereas low-starch vegetables, legumes, and dairy have low GI values. GI is a qualitative measure and is not related to portion size or the grams of carbohydrate per serving. Therefore, the glycemic load (GL) measure was introduced to capture information on the overall glycemic effect of the diet, which is believed to be the biologically relevant exposure in epidemiologic studies that examine associations of carbohydrate with disease risk (11,12). GL incorporates both the quantity and quality of dietary carbohydrates and is computed by multiplying the grams of carbohydrate per serving by the food's GI value and dividing by 100 (Appendix 1). By taking into account the gram amount of a particular carbohydrate consumed, GL may more accurately portray the minimal glycemic effect of a high-GI carbohydrate in situations in which only a small food portion is consumed (11).

The GI and GL concepts are used previously in epidemiologic studies to test hypotheses that persons with lower dietary GI or GL, compared with those with a higher dietary GI or GL have an increased risk of cardiovascular disease, obesity, diabetes, and several cancers (4,11,13–16). However, neither GI nor GL are components of standard food composition databases, and despite the large number of publications on this topic, there is scant information on the methods employed to generate these measures for use with standard dietary assessment instruments. To address this need, we developed a GI and GL database for use with the FFQ used in the Women's Health Initiative (WHI), a study of health among 165,000 postmenopausal women (17). The overall goal of this report is to provide an overview of the methodology used to construct the database and to present distributions for these measures from a random sample of FFQs completed by WHI study participants. The data presented in this report may be applied to other epidemiologic investigations that collect dietary assessment data using FFQs.

SUBJECTS AND METHODS

Overview of the WHI FFQ. The WHI FFQ was developed and validated for use in this large study of the health of postmenopausal women (17,18) and used subsequently in >100 NIH-supported research studies nationwide. The WHI FFQ is a self-administered questionnaire that inquires about usual food intake over the previous 3 mo. The FFQ is divided into 3 sections: *1*) adjustment questions; *2*) foods and food groups; and *3*) summary questions. The 19 adjustment questions relate to food purchasing and preparation (e.g., fat added at the table and in cooking) and are used in the analysis software to adjust the calculations of the nutrient content of specific food line items. The main section of the questionnaire includes 122 line items of foods or food groups with questions on the usual frequency of intake (ranging from "never or <1 time/mo" to "2+/d" for food and "6+/d" for beverages) and portion size (small, medium, or large compared with the stated medium portion size). The 4 summary questions ask about usual intake of fruits and vegetables and of fat added to foods in cooking (18). These questions are used to reduce the measurement bias of overreporting food consumption when there are long lists of foods (e.g., 22 vegetables and 10 fruits) within food groups.

Our general approach to constructing a dietary database for FFQ was published in detail (19). Briefly, we developed a self-documenting spreadsheet that includes the foods that correspond to each line item on the FFQ. For line items that are grouped foods (e.g., "white breads, including bagels, rolls, pita bread, and English muffins"), we assigned a weight based on food consumption data (when available) or expert judgment. We then added the gram weight of a medium portion size. Custom nutrient analysis software designed at the Fred Hutchinson Cancer Research Center links the spreadsheet to the University of Minnesota Nutrition Coordinating Center (NCC) Nutrition Data System for Research nutrient database (NDS-R, version 2005). The principal sources of data for the NCC database are the USDA Standard Reference Releases and information from manufacturers. To calculate nutrient intake, the software multiplies usual frequency of use by portion size by a vector of nutrient values for each FFQ line item. The sum of these results across all line items is then computed as the total usual nutrient intake for each study participant (20). To add the GI and GL to the database, we constructed a separate spreadsheet that assigned GI values to the FFQ line items. These data were then merged into the primary food and nutrient database so that GI and GL became part of the nutrient string for each individual food.

Identification of glycemic index values for foods and completion of the database. Our primary data sources for GI values from food were the "International Table of Glycemic Index and Glycemic Load Values: 2002" (21) and a web site created and maintained by the University of Sidney (22). A Medline search using the search terms "glycemic index" and "glycemic load" through March 2005 did not identify any GI food values beyond that provided by our primary sources. One GI value (for the line item, beer) was obtained via personal communication (Simin Liu, University of California, Los Angeles, CA).

The international tables list GI and GL data for ~800 foods generated by numerous human experimental studies. For each food, Foster-Powell et al. (21) presented the GI using both glucose and white bread as the test reference food. For this report, we used the glucose-based values to maintain consistency with published epidemiologic literature (4,23,24), but it is notable that GI values for bread vs. glucose are highly correlated ($r^2 = 0.98$) (10) and interchangeable using a conversion factor (21). The international tables also provide information from the original studies about the types of subjects (healthy vs. diabetic) and the number of hours over which the postprandial glucose response was measured. Because between-subject variability is relatively small when the glycemic response to a test food is presented relative to a standard food (12,25), we did not restrict GI values to those obtained only from nondiabetic subjects. Similarly, GI values were applied without regard to the reference time period or geographical locale of the original studies.

To assign values to each FFQ line item, we disaggregated the 122 line items and 19 adjustment questions into 350 distinct foods. A priori we assigned GI values only to foods on the FFQ with ≥5 g of total carbohydrate per medium portion size because carbohydrate values below this cut-off point do not contribute significantly to the glycemic response. Thus, foods such as nonstarchy vegetables, oils, and plain meats did not receive a GI. We also excluded any foods for which the carbohydrate content was in the form of very small amounts of ingredients used as preservatives or stabilizers, e.g., cornstarch or maltodextrins. Using these criteria, 39 (31.9%) of the WHI FFQ line items did not receive a GI value.

We evaluated the international tables for exact matches with respect to characteristics such as food manufacturer and cooking method for foods on the WHI FFQ food list. If the identical food was not available, we chose a similar food with equivalent carbohydrate and fiber content and comparable preparation method (e.g., added fat, cooking time) because these variables strongly influence the glycemic response (12,21). For foods without any brand, such as fresh bakery items or produce, we selected the mean GI value for multiple sources of the same food. In the case of foods with no published GI data available, we imputed from a closely related food with an equivalent macronutrient and fiber content and similar cooking method (if known). For example, there were no experimental GI values for some mixed foods and casserole dishes such as lasagna; thus, GI was imputed from spaghetti with meatballs and cheese. Finally, for those FFQ line items that are a composite of >1 food per line (e.g., "biscuits, muffins, scones, croissants") we assigned GI values for the line that were proportionally weighted according to the overall contribution of the food to the total line item in our database.

Application of the database to the WHI FFQ. After each eligible food frequency line item was assigned a GI value, a structured query language server query was run to calculate the GL for both total and available carbohydrate (total carbohydrate minus total fiber) (11,26). The GL values were then calculated for each line item and the data were merged with the main nutrient database. Hand calculations confirmed that the test code implemented the specified calculation. Distributions of GL and GI were made using a random sample of 200 baseline FFQs from the WHI. The GL was estimated for both total carbohydrate and for available carbohydrate (total carbohydrate minus fiber) because fiber can modulate the glycemic response (11).

RESULTS

The GI and GL values for the WHI FFQ line items are provided in Supplemental Table 1. Of the 122 FFQ line items, 83 (68.0%) were eligible to receive a GI and GL value. We give GL per medium portion size, calculated using both total carbohydrate and available carbohydrate. Seven line items in Supplemental Table 1 are adjusted by one of the 19 adjustment questions on the WHI FFQ. For example, adjustment question number eight asks, "did you eat cold cereals during the last three months?" If yes, the participant is permitted to mark up to 2 of the following response options: granola; high-fiber, or bran cereals such as Fiber One (General Mills) or raisin bran types; whole-grain cereals such as Cheerios (General Mills) or Shredded Wheat (Post Cereals); fortified cereals such as Total (General Mills) or Product 19 (Kellogg's); or other cereals such as corn flakes, Frosted Flakes (Kellogg's). If a participant marked only "whole-grain cereals" such as Cheerios or Shredded Wheat, then 100% of the nutrients (including GI and GL) for the line item "cold cereal" would come from the nutrient strings for these 2 cereals. If a participant marked 2 cereal response options, then half of the nutrient string would come from each respective choice. This methodology is used for all of the adjusted line items. For these line items, the range of possible GI and GL values are presented; the values vary depending on the line item adjustment.

Of the 83 line items in Supplemental Table 1, 29 (34.9%) received identical GL values, regardless of whether total carbohydrate or available carbohydrate was used to create the estimates. These results suggest that for most foods on the WHI FFQ food list, the quantity of dietary fiber would have a negligible effect on the glycemic response. The major exception for these GL estimates, calculated using available vs. total carbohydrate, were high-fiber cereals; whole grain cereals; refried beans; and all other beans such as baked beans, lima beans, black-eyed peas, and chili without meat, for which the GL ranged from 12 to 33% lower based on available carbohydrate values vs. total carbohydrate values.

The FFQ foods and food groups with the highest GL (GL ≥19 calculated using total carbohydrate) are presented in **Table 1**. Two line items in Table 1 represent adjusted line items; thus, a range of GL values is given. Because informative FFQ food lists include those foods that are consumed frequently by a substantial proportion of the population (27), this ranking of high GL foods provides information that may be useful for the design of intervention studies targeted at lowering total GL. It is important to note, however, that the contribution of these and other foods to the total variance in GL in a study sample is likely to vary across study samples.

The distributions of dietary GI and GL values for baseline FFQ data from women enrolled in the WHI-Observational Study (WHI-OS) as well as the WHI-Dietary Modification Clinical Trial (WHI-DM) are shown in **Table 2** (17). Women were eligible for the DM trial only if their baseline percentage of energy from fat was >32.0%, as measured with the WHI FFQ, whereas in the OS, there were no eligibility restrictions based on dietary fat intake (28). Therefore, due to these potential differences in dietary patterns at baseline, both study samples were used for this analysis. Although 100 women from each sample is an insufficient sample size for any disease-related analyses, it is satisfactory for the purpose of testing the function of the GI database. Future analyses that include larger subpopulations within WHI will examine associations of GL with various disease endpoints in the WHI. These analyses will also identify which high-GL foods explain the most between-person variance in GL that will allow investigators to discriminate between individuals in a particular study sample.

TABLE 1

WHI FFQ food groups and food items with the highest GL

Food line item	Glycemic load (total carbohydrate)	Glycemic load (available carbohydrate)
Indian fry bread	29	30
Plantains, fried	29	27
All other pies, fried pastries, pastelitos, and fruit empanadas	28	27
Spaghetti or other noodles with tomato sauce (no meat)	27	29
Spaghetti or other noodles with meat sauce	26	24
Soft drinks	25	25
Pumpkin and sweet potato pie	24	23
Doughnuts, cakes, pastries, PopTarts,[1] and pan dulce[2]	24–28	24–27
Pizza	23	22
Saltines,[3] SnackWells,[3] fat-free tortilla chips, and fat-free potato chips	22	21
Cornbread, corn muffins and corn meal mush	21	20
French fries, fried potatoes, fried rice, fried cassava, and fritters	20	18
Cold cereal[1]	20–26	17–24
Pancakes and waffles	20	19
Biscuits, muffins, scones, and croissants	19	18
Tamales, with or without meat	19	17
Chilaquiles	19	16

[1] Kellogg's.

[2] The range is given; pastry and cold cereal line item responses are linked to participant response to adjustment question about types of pastries/cakes and cereals commonly consumed. For the purpose of this table, the range of pastries/cakes and cold cereals in the database is given.

[3] NabiscoWorld.

The results from this test set of FFQ data showed that the 90th percentile of the dietary GI distribution was slightly higher in the WHI Dietary Modification group, but there were no other remarkable differences between values estimated from the WHI-OS vs. the WHI-DM. GL values were slightly lower when available carbohydrate rather than total carbohydrate was used in the calculations and the entire GL distribution was slightly higher for FFQs from the DM trial. Finally, we conducted analyses to examine correlations of GI with potentially collinear variables such as total carbohydrate and sugars. In the absence of a definitive biomarker to validate our assumptions about GI and GL, we undertook these analyses to ensure that measurement of GI was a distinct dietary exposure and not simply a measure of a closely related nutrient. The GI

TABLE 2

Distributions of glycemic index and glycemic load (using total and available carbohydrate) from FFQs completed by a sample of postmenopausal women enrolled in the WHI[1]

Glycemic index characteristics	WHI-OS, *n* = 100	WHI-DM, *n* = 100
Dietary glycemic index		
Mean ± SD	50 ± 5	51 ± 4
Percentile		
10th	45	47
50th	50	51
90th	55	61
Glycemic load[2]		
Mean ± SD	98 ± 55	102 ± 42
Percentile		
10th	36	51
50th	94	101
90th	154	163
Glycemic load[3]		
Mean ± SD	91 ± 53	95 ± 40
Percentile		
10th	33	48
50th	87	93
90th	141	152

[1] Baseline FFQs.
[2] Calculated using total carbohydrate.
[3] Calculated using available carbohydrate.

was correlated with total carbohydrate ($r = 0.47$, $P < 0.001$) and total sugars ($r = 0.38$, $P < 0.001$). Although statistically significant, we interpret these modest correlations as evidence that measurement of GI is not merely a proxy for either carbohydrate or sugar intake.

DISCUSSION

Improvements in the quality and complexity of food composition databases enable nutrition scientists to investigate novel questions about diet and health. This methodological report describes the development of a GI and GL database for use with FFQs used in epidemiologic studies. Because GI and GL are neither components of the standard output provided in nutrient analysis software programs nor among the specialty components currently under development by the USDA's National Food and Nutrient Analysis Program (NFNAP), this database development will be useful for diet-disease association studies using the WHI and similar FFQs.

Other research groups published epidemiologic studies that examined associations of GI or GL via an FFQ with disease outcomes (1,7,23), but we are aware of only one other description of the methods used to add GI to an FFQ database (29). One unique aspect of the present report is our presentation of GL values using both total and available carbohydrate. It has often been presumed that fiber will substantially reduce the glycemic response, although this supposition was not supported consistently by the experimental data (8). Our results showed very little difference in the FFQ GL values for those estimated using available carbohydrate vs. total carbohydrate, even for foods with modest fiber content such as whole-wheat breads and select fruits. One possible reason for this unexpected lack of influence of fiber is that in general, soluble fibers have greater effects on the glycemic response than do insoluble fibers, but the predominant sources of fiber in the FFQ-listed foods are insoluble (10,26). Although the GI of a food is generally not related to its insoluble fiber content, soluble fiber reduces the rate of gastric emptying and intestinal absorption, resulting in a flattened blood glucose response and lower GI (10,26). Nonetheless, other investigators testing hypotheses relating GI and GL to various metabolic biomarker or disease outcomes should consider carefully whether it is necessary to restrict calculation to available carbohydrate only.

The estimated distributions of GI and GL in the sample of WHI study participants compare favorably to those from the Nurse's Health Study and the Health Professionals Follow-Up Study (4,7,23), although the ranges and quartile cut-off points differ slightly. Some of this variance may be attributed to a different food list for the Harvard FFQ as well as decisions with regard to imputing GI from similar foods in cases in which no published GI values exist. In addition, portion sizes listed on an FFQ may vary across studies. Because the GL calculations incorporate grams of carbohydrate, which is a function of portion size (Appendix 1), variations in defined portion sizes across studies may influence GL calculations. Detailed discussions about the benefits and limitations of portion size estimates for FFQs may be found in references (27) and (30).

We acknowledge that controversy exists concerning the utility of GI and GL in dietary assessment. Pi-Sunyer (8) stated that there are a substantial number of unresolved questions related both to the ability to measure GI from the diet and to the clinical interpretation of GI as it relates to disease risk. For example, he suggests that person-specific variables such as individual variation in postprandial glucose response, as well as food-specific variables including the influence of food processing and preparation, and the lack of data on GI of mixed meals raise important questions about the validity of GI and its public health relevance (8). Conversely, other investigators support the reduced consumption of high-GI foods as an effective prevention strategy for lowering the risk of obesity and obesity-related diseases (13). These latter views are supported by data from human experimental studies of single test foods (12), but receive only modest support from meal patterns of low- or high-GL (31). Almost no data exist on the glycemic response to habitual consumption of standard mixed meals or whether there is heterogeneity of glycemic response among persons who are obese vs. lean. In addition, although there is no universally recognized objective measure of total carbohydrate intake or carbohydrate quality (e.g., GI), several biomarkers have provided useful information about GI, including C-peptide, plasma lipids, and various glycated proteins (32). Our objective was not to provide resolution to the controversies surrounding GI, but rather to provide a method to enable nutritional epidemiologists who use FFQs to test hypotheses related to GI and GL and its association with important public health outcomes such as obesity, metabolic syndrome, cardiovascular disease, and cancer (1).

There are strengths to this work. First, because of the considerable interest in the scientific community in the association of GI with chronic disease risk (1,23), the database described in this report will be useful for investigators using FFQs in large intervention and observational studies. Second, our underlying food and nutrient database based on the University of Minnesota NDS-R database provides sufficient detail on food descriptions to facilitate exact GI matches or close imputations for the foods in the FFQ food list. There are also limitations that must be mentioned. Most notably, variables such as cooking time for rice, pasta, and potatoes and the degree of ripeness of fruit influence GI (8,21). However, FFQs are not designed to capture such details; even if they were, the variability caused by cooking and physical manipulation of foods may complicate the reliability of estimates for a single GI value for a specific food. These issues are similar to the difficulties that arise when estimating heterocyclic amines (HA) from self-report because HA formation is strongly influenced by cooking time and temperature (33). Moreover, FFQs are not able to measure meal patterns; thus, we are unable to assess the effect of concurrently ingested foods and nutrients on GI, nor can we test the influence of meal frequency or timing. An additional limitation is that there is a critical need for additional experimental GI values from a variety of foods. This last point is particularly important for studies that utilize either 24-h recalls or multiple-day diet records as the primary assessment approach. FFQs rely on a fixed list of foods (~350 foods on the WHI FFQ), but recalls and records are open ended with potentially tens of thousands of foods in a dataset. The procedures for creation of the GI database are not automated, and each GI value must be individually assigned to a food after careful consideration of the food's composition. This task could not be accomplished realistically with the potentially thousands of different foods captured in a large study using diet records and recalls. Another limitation is the lack of a biomarker to confirm the validity of our assumptions. However, it is important to note that all of the original data included in the international tables were generated from studies measuring postprandial glycemic response in controlled experimental settings (21).

Food composition databases are the foundation for estimating dietary exposures and therefore play an important role in epidemiologic studies of diet and chronic disease risk. The obesity epidemic in the United States has necessitated a careful assessment of diet, dietary patterns, and the relative influence of macronutrients. The extent to which carbohydrate quality or GI and GL influence obesity and related metabolic disorders warrants further testing in a wide variety of research and clinical settings before verification. The approach described in this report will facilitate etiologic studies of GI and GL in relation to diet-related chronic disease risk and may help shape ensuing public health recommendations.

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APPENDIX

Terminology and definitions

Glycemic index (GI): An index of the postprandial glucose response of a food, compared with a reference, usually glucose or white bread.

$$\text{GI} = [\text{Blood glucose area under the curve (AUC) of test food/ blood glucose AUC of reference food}] \times 100.$$

Glycemic load (GL): A measure that incorporates both the quantity and quality of dietary carbohydrate. Each glycemic load unit is the equivalent of 1 g of carbohydrate from white bread of glucose.

$$\begin{aligned}\text{GL} &= [\text{GI of individual food}\\ &\quad \times \text{g carbohydrate CHO per serving of food}]/100.\end{aligned}$$

Dietary glycemic load: Dietary GL reflects the quantity and quality of carbohydrate in the overall diet (see references 11,22). It is estimated as the sum of the glycemic loads of all carbohydrate foods consumed during the dietary period of interest (e.g., meal, day, week, month).

GI_i = GI for food *i*.

CHO_i = Carbohydrate content (g) per serving; may be estimated using total or available carbohydrate.

FPD_i = average frequency per standard portion size of servings of food *i* per day during the dietary period of interest.

$$\text{Dietary GL} = \sum_{i=1}^{n}[(GI_i \times CHO_i \times FPD_i)/100].$$

Dietary glycemic index: Dietary GI gives an indication of the carbohydrate quality in the overall diet. Dietary GI is estimated as the weighted average (with weights based on the amount of each CHO consumed) if GI values of all carbohydrate foods consumed during the dietary period of interest (e.g., meal, day, week, month).

CHO_j = Carbohydrate content (g) per serving; may be estimated using total or available carbohydrate.

FPD_j = average frequency per standard portion size of servings of food *j* per day during the dietary reporting period. Food *j* refers to all carbohydrate-containing foods, including those with very small amounts of CHO and no GI value.

$$\text{Dietary GI} = [\text{Dietary GL}/\sum_{j=1}^{n}(CHO_j \times FPD_j)] \times 100.$$