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Original Article

Compiling glycemic index and glycemic load values for addition to a food composition database

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ABSTRACT

The glycemic index (GI) provides an indication of a food's carbohydrate quality by measuring the blood glucose response to consuming the food. The glycemic load (GL) is calculated as the GI times the available carbohydrate in a fixed amount of the food. GI and GL are currently of interest for the study of associations of diet and chronic disease including diabetes, cardiovascular disease, cancer and obesity. An international table of GI values is available and provides a compilation of currently available data. The purpose of this project was to use these data, as well as other available references, to expand the Cancer Research Center of Hawaii Food Composition Table (FCT) to include GI and GL values. All of the individual foods in the FCT ($n = 1592$) were assigned GI values as a direct match ($n = 181$), imputation ($n = 948$), calculated value ($n = 208$), or assigned a zero value ($n = 255$). GL per 100 g was then calculated using the assigned GI and available carbohydrate per 100 g of food. The addition of GI and GL values to the FCT will allow researchers to estimate the effect of dietary carbohydrate quality on various health outcomes.

1. Introduction

The concept of the glycemic index (GI) was introduced as a means to quantify the blood glucose response to an ingested quantity of carbohydrate in a food as compared to the response using a standard reference food (Jenkins et al., 1981). A specified amount of reference food, typically glucose or white bread, is fed to study participants and their blood glucose levels measured and plotted over the following two hours, creating a glucose response curve. The same amount of carbohydrate from a comparison food is then consumed and the blood glucose levels again measured and plotted over time. The GI is defined as the percentage of the area under the curve comparing the test food to the reference food. Thus, a food with a higher GI will cause a higher rise in blood glucose levels than a food with a lower GI, if the carbohydrate content is equal. Different factors may affect GI including characteristics of the food itself (e.g., processing, fiber content, resistant starch content), use of total carbohydrate rather than available carbohydrate (defined as total carbohydrate minus dietary fiber) to determine food sample size, and differences in blood sampling procedures and timing of blood draws (Brouns et al., 2005).

The GI provides an indication of carbohydrate quality through the testing of two samples with equal carbohydrate content, but an additional calculation is necessary to take into account both carbohydrate quality and quantity. Glycemic load (GL) is defined as the product of the GI and the amount of available carbohydrate in a specific portion of food (Salmeron et al., 1997). Thus, GL takes into account both the blood glucose response and the amount of carbohydrate in a food consumed.

There has been a growing interest in GI and GL in relation to a number of chronic diseases including diabetes, cardiovascular disease, cancer, and obesity (Augustin et al., 2003; Ebbeling et al., 2003; Ford and Liu, 2001; Liu et al., 2000; Ludwig et al., 1999; Michaud et al., 2002; Salmeron et al., 1997; Slattery et al., 2002). The publication of an international table of GI and GL values in 2002 provided a compilation of available data, which can be used to add GI values to a food composition database (Foster-Powell et al., 2002). The purpose of this project was to evaluate existing GI values and develop a methodology for inclusion of GI and GL in the Cancer Research Center of Hawaii (CRCH) Food Composition Table (FCT).

2. Methods

2.1. Cancer Research Center of Hawaii FCT

The FCT was created and continues to be maintained by the nutrition staff at the CRCH. It contains nutrition information for 1592 individual foods and 1200 mixed foods and recipes (Murphy, 2002). The FCT is a proprietary database and at this time it is not

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accessible by researchers outside CRCH. Amounts of up to 120 nutrients and food components are carried in the FCT for each individual food and then calculated for mixed foods. This database is uniquely designed to capture the diet typically consumed by ethnically diverse populations in Hawaii, California, and other areas of the Pacific. In particular, the FCT contains many foods commonly consumed in the Pacific Islands and Asia. Nutrient values are regularly updated using data from the current United States Department of Agriculture Standard Reference Nutrient Database (USDA, 2007), other FCTs (e.g. McCance and Widdowson's The Composition of Foods Holland et al., 1991), FCT for Use in East Asia Leung et al., 1972), literature sources, and nutrient analyses performed at CRCH.

2.2. Evaluation of available data

For this project, we compiled references containing GI values published through 2003. The primary reference identified was the *International table of GI and GL values*: *2002* (Foster-Powell et al., 2002). This table is an update of an earlier publication from 1995 and compiles GI values for over 750 foods from both published and unpublished verified sources. In addition to the international table, two other references were identified as sources of GI values. *The New Glucose Revolution Complete Guide to GI Values* (Brand-Miller et al., 2003) was used primarily to impute GI values for items that could be reasonably assumed to be zero. There are multiple items in this reference noted as "[0]" meaning "the food has so little carbohydrate that the GI value cannot be tested. The GL therefore, is 0". An additional GI database created by Brand-Miller (2004) can be accessed via the Internet. This database was used to obtain values that were recently analyzed and not available in the other references.

2.3. Adding GI values to the FCT

A review of the GI values published in the international table indicated the use of glucose as a reference value was the most common method of reporting GI values. Therefore, we chose to use glucose as the reference food (GI glucose = 100), rather than white bread when adding GI values to the FCT.

Using the selected references, GI values for direct matches were assigned to individual food codes on the FCT whenever possible. If the description of the food in the reference matched that on the FCT, it was considered a direct match. For example, the description "Strawberries, fresh, raw" in the literature was matched to "Strawberries, fresh" on the FCT. Table 1 provides additional examples of direct matches. When more than one GI value was available in the literature for the same food description, a value for a food sample with US origins was preferentially assigned. If none of the samples was of US origin, the mean of the available values was assigned. For example, there were two GI values provided in the international table for the description "apricot, dried" both of non-US origin (Australia and Canada). The average of these two values, provided in the reference, was assigned to the corresponding food code in the FCT.

The selected references contained GI values determined using both healthy and diabetic subjects. Due to the limited number of values available, GI values determined using diabetic subjects were included in the assignment of GI values to the FCT food codes.

2.4. Imputations used in adding GI values to the FCT

GI values were imputed from similar foods when a direct match was not available. Imputed values were based on the food type, description, and selected nutrient content (i.e., carbohydrate, sugar, fat, and fiber). GI values were not typically imputed from outside a particular food type (e.g., a GI value for a fruit was imputed from a similar fruit), thus the carbohydrate quality of the food used as an imputation source and the assigned food was likely to be similar. Although specific ingredient and nutritional information was often not available for food items in the references, some basic assumptions were made (e.g., whether the food was likely to have a high or low carbohydrate content). For example, the GI value for "Candy, gum drops" was imputed from "Jelly beans, assorted colors" in the literature based on the similar food type and carbohydrate content. Table 2 provides additional examples of FCT foods with imputed GI values. Whenever possible the carbohydrate source was taken into consideration although ingredient information, including the type of sweetener (e.g., sucrose or corn syrup), was not always available.

Foods without a close match in the literature for which the main contributor to carbohydrate was sugar were assigned the GI for table sugar (sucrose). For example, the primary ingredient contributing to the carbohydrate content of "Sauce, barbeque or barbecue" was assumed to be sugar. The GI of sucrose was imputed for this food code. Although other ingredients in these foods might alter the GI to be less like sucrose, the small

Table 1
Examples of Cancer Research Center of Hawaii Food Composition Table foods considered to be a direct match to foods in the literature

Description of food in FCT	Description of food in literature
Beans, pinto, cooked	Pinto beans, dried, boiled
Soybeans, dried, cooked	Soya bean, dried, boiled
Grapefruit, unspecified	Grapefruit, raw
Oranges, raw, all varieties	Oranges, raw
Mango, raw, ripe	Mango, raw
Strawberries, fresh	Strawberries, fresh, raw
Bananas, ripe	Banana, ripe, all yellow
Raisins	Raisins
Cranberry juice cocktail	Cranberry juice cocktail
Cereal, All Bran (Kellogg's)	All Bran
Cereal, Crispix (Kellogg's)	Crispix
Milk, whole, fluid	Milk, full-fat
Milk, skim or non-fat	Milk, skim
Candy, Twix, caramel	Twix cookie bar, caramel
Soda, cola-type	Coca cola, soft drink

Table 2
Examples of Cancer Research Center of Hawaii Food Composition Table foods with GI values imputed from similar foods

Description of food in FCT	Description of similar food
Beans, azuki, cooked, plain	Kidney beans
Potatoes, hash browned, home prepared	French fries, frozen, reheated in microwave
Yam bean, cooked, drained	Carrots, peeled, boiled
Poi	Taro, peeled, boiled
Water chestnuts, Chinese, raw	Beetroot
Brussels sprouts, cooked, drained	Cabbage, raw
Tomatoes, ripe, raw	Tomato juice
Pomelo, raw	Grapefruit, raw
Nectarines, raw	Peach, raw
Ume or umeboshi (preserved plum)	Plum, raw
Cake, coffee, from mix	Pound cake
Puff pastry, frozen, baked	Croissant
Won ton or wun tun wrappers	Wheat tortilla
Chips, taro	Potato Crisps, plain, salted
Peanut butter, salted	Peanuts

quantities typically consumed are unlikely to contribute significantly to total dietary GI.

Decisions regarding the assignment of values were also made for the following specific food groups: commercial breakfast cereal products, candy, dairy products, fruits and vegetables, legumes, seeds, and flour; details of these decisions follow. The FCT carries a large number of brand specific commercial breakfast cereal products for which imputed GI values were unavailable based on description and assumed carbohydrate, sugar, fat and fiber content. An average GI value was imputed for these cereals based on the type of cereal. To obtain this average, commercial cereal products with GI values in the literature were investigated to determine their primary ingredients and nutritional content. These cereals were then assigned to one of three product types: high fiber (bran), lightly sweetened, and highly sweetened. The average GI was calculated for each of the three product types and these averages were then assigned to similar cereals without a published GI value. The average GI values for bran, lightly sweetened, and highly sweetened were 61, 76, and 71, respectively. Although the cereals in each category were not uniform because of variation in ingredients, we did not use narrower categories because we often did not have detailed information on the specific commercial products.

GI values for candies were imputed based on description and assumed carbohydrate, sugar, fat and fiber content. For candy bars with no similar item in the literature, an average of available GI values for all candy bars (including milk chocolate) was calculated and assigned.

Many dairy foods carried on the FCT are different from foods in the references. An average of GI values for whole and skim milk was assigned for both 1% and 2% milk. Due to the higher fat content, GI values for cream and sour cream were assumed to be half that of full fat milk. GI values for non-dairy topping and creamers were imputed from chocolate milk to account for the added sugar. GI values for cheeses were imputed and generally assigned zero due to the low carbohydrate content.

GI values for fruits and vegetables were imputed from the closest match available based on name, botanical family, and/or assumed carbohydrate, sugar and fiber content. The GI was assumed zero if the carbohydrate and sugar content was minimal (less than 9 grams of carbohydrate per 100 grams of food) or similar to other items with a zero value in the references. Because vegetables are often high in fiber, it was reasonable to assume minimal blood glucose response when consuming very low carbohydrate vegetables. For food codes with added sugar (e.g., canned, frozen or dried sweetened), the GI was calculated based on similar foods for which there was a GI value for both the unsweetened and sweetened form. For example, the GI value for "Apricots, canned, heavy syrup, solid and liquid" was calculated based on the difference in GI values for "Peaches, raw" and "Peaches, canned". The absolute difference in sugar content between raw and canned fruits was fairly constant; therefore the absolute difference was used for these calculations.

Table 3 provides an example of this type of calculation. The GI value available in the literature for "Pineapple, raw" was 59 and there was no available value for "Pineapple, canned". A value for "Pineapple, canned" was calculated based on the difference between the GI values for "Peaches, raw" and "Peaches, canned" (58 and 42, respectively). The difference between the GI values for raw and canned (58–42 = 16) was added to the GI value for "Pineapple, raw" to obtain a GI value of 75 for "Pineapple, canned". Similarly, food codes with a GI value for dried but not for fresh or vice versa were assigned the average of the difference between other available GI values for dried and fresh codes.

For vegetables containing enough carbohydrate so that they could not be assumed zero (i.e., approximately 9 or more grams of carbohydrate per 100 grams of food), but no similar foods were available for imputation (e.g., onions, leeks, shallots, and garlic), we used the GI of raw carrots, which has carbohydrate and sugar content similar to raw onions, as the GI value for these vegetables.

Table 3
Example of the calculation used to estimate the GI of sweetened foods without an appropriate match in the literature

Calculation of GI value for pineapple, canned	
Food description	GI value
Peaches, raw	42
Peaches, canned	58
Difference of GI for canned and raw peaches	+16
Pineapple, raw	59
Difference of GI for canned and raw peaches	+16
GI value assigned for pineapple, canned	75

The FCT carries a number of soybean-based products. Soybean products with GI values in the literature were cooked soybeans and soybean milk. Soybean products on the FCT were assigned GI values imputed from these two foods or were assumed zero according to description and/or assumed carbohydrate, sugar and fat content. Nutritional data for cooked soybeans in the FCT indicated the ratio of fat to carbohydrate content was close to one. Therefore, if the fat and carbohydrate content of the soybean-based food item was similar, the GI value of cooked soybeans was imputed. Items with more than twice as much fat as carbohydrate were assigned a GI value equal to half that of cooked soybeans based on the assumption that the additional fat would decrease the GI value.

GI values were not available for any type of seed products. An average GI value for all nuts was calculated and imputed for all seeds based on similarities in nutrient content. GI values were also not available for any type of flour. The different flours carried on the FCT were assigned the GI value of the closest whole food. For example, the value for white wheat flour was imputed from white bread and the value for rice flour was imputed from cooked rice (raw rice is not carried on the FCT).

In addition to calculations used for imputing values, a weighted average was used for mixed foods carried as a single food code on the FCT. For example, Chex Mix is carried as a single food code on the FCT although it is actually a mixture of ingredients. The GI for this food code was calculated as a mixture of Corn and Wheat Chex, pretzels, and melba toast. The percent contribution of each ingredient was determined by creating a recipe for the product using the ingredients listed on the product label and matching the product's nutrition facts label. The weighted average calculations were performed as indicated in available literature for mixed meals (Wolever and Jenkins, 1986). It was assumed that the calculations for mixed meals could be applied to that of mixed foods.

2.5. FCT foods assigned a zero value for GI

GI values were often not available for foods with low carbohydrate levels. As was done in the published references, we assigned a GI value of zero to these foods. For example, beverages with little or no carbohydrate such as tea, coffee, and diet cola were assigned a zero value. A zero GI value was also assigned for items that are typically consumed in insignificant amounts (e.g., herbs, baking powder, vanilla, yeast) and items that are primarily fat (e.g., butter, margarine, lard, vegetable oils).

2.6. GL calculation

For the purpose of investigating associations with health outcomes, GL is a more appropriate measure than GI because it considers both carbohydrate quality (GI) and quantity. Values for available carbohydrate are needed to calculate GL, but carbohydrate values on the FCT are obtained from Standard Reference Nutrient Database and thus include total dietary fiber in the total carbohydrate value USDA's (2007). As a result, an estimate of available carbohydrate can be calculated as total carbohydrate minus dietary fiber. For the FCT, GL was calculated per 100 g of an individual food or recipe using the formula: $\mathrm{GL} = \mathrm{GI} \times (\text{total carbohydrate–fiber})/100$. Investigators using the FCT can then calculate the GL for each food in a diet by multiplying the GL for each food item by the amount consumed.

3. Results

3.1. Assignment of GI and GL values

All individual food codes carried on the FCT were assigned GI values ($n = 1592$). A total of 181 (11%) food codes were considered a direct match and 1156 (73%) were imputed or calculated. A total of 255 (16%) food codes were assigned a GI value of zero. Of the food codes assigned zero GI values, 99 were assigned zero due to no carbohydrate content, 115 were assigned zero due to very minimal carbohydrate content, 36 were assigned zero because the food was typically consumed in insignificant amounts, and five were assigned zero because the food item was greater than 50% fat.

After all GI values were assigned, GL values were calculated for all individual food codes using the method described previously. GI and GL values for mixed foods on the FCT were calculated based on the GI and GL of individual ingredients and the proportion contributed to the mixed food by each ingredient.

4. Discussion

We have described the method used to expand the CRCH FCT to include values for GI and GL using data from available references. An important consideration when expanding a food composition database is the source of data. In addition to GI and GL values for over 750 foods, the international table published by Foster-Powell et al. provides information on the country of origin, brand or manufacturer (for applicable commercial products), number of subjects tested (including health status), reference food, time period of blood glucose assessment, and a citation of literature or laboratory source (Foster-Powell et al., 2002). This additional information allows those who intend to use the GI values in food composition databases to make informed decisions regarding imputation of values and enhances the ability to match foods carried on a particular database to similar foods in the literature. Although this information is helpful for adding GI values to a food composition database, the determination of appropriate matches and assignment of GI values often involves estimation and subjective decisions. The methods used to assign GI values to the FCT were systematic in their application to specific food groups. Tailoring the methods and decisions to the food groups provided a means of more specific imputation and assignment of values than if broad assumptions were made across food groups. As a means of enhancing quality control, the assignment and procedures for adding the values was a collaborative process among the staff of the Nutrition Support Shared Resource (NSSR) office at CRCH. One dietitian performed the initial assignment of GI values and this assignment was reviewed by two other dietitians. Any values that were identified as a concern were evaluated and discussed. Additionally, two colleagues outside the NSSR were asked to review the procedures used for assignment of values and provide feedback. We believe this collaboration enhanced the quality of the assignment of GI values to the FCT.

Two other research groups have reported the methodologies that they used to add GI and/or GL values to a diet history questionnaire database (DHQ) database (Flood et al., 2006) and a 24-hour dietary recall database (Olendzki et al., 2006). Both groups relied on the international table of GI and GL values as their main source of values included in the databases (Foster-Powell et al., 2002). Similar to the methods used for the addition of GI/GL values to the FCT, both databases used information such as food description, geographic origin, type of food, and general nutritional content to determine initial direct matches between foods in the international table and those in the database. Similar calculations to determine average values and values for mixed foods were also applied. However, different methods were applied for foods without a direct match. The DHQ database used an algorithm approach in which criteria such as whether a food was a vegetable, mixture, or a large contributor to a DHQ food group were evaluated and a value assigned (Flood et al., 2006). The recall database assessed detailed information on nutritional content (e.g., type of sugar, fiber, fat, and protein content) as well as level of processing (Olendzki et al., 2006). The use of different methods for imputing GI/GL values may result in databases that contain values that differ for what are descriptively very similar foods and thus, the calculated dietary GI/GL may be different.

To evaluate the comparability of our data, we compared glycemic load values using our FCT with those reported by other investigators. Our database has been used to calculate the GI of diets measured using a detailed quantitative food frequency questionnaire (QFFQ) (Nothlings et al., 2007). GL values were estimated for each of 172 food items on the QFFQ, using a weighted average of the specific foods included in each (e.g., French fried and hash-browned potatoes within the fried potato item on the questionnaire). For 162,150 participants in the Multiethnic Cohort Study in Hawaii and Los Angeles who completed the QFFQ, the median value for GL was 147, and based on the carbohydrate content of the diets, the median GI was calculated as 0.55. This GI value is comparable to that reported by Olendzki et al. (2006) for the adults in their population (mean of 0.59, after conversion from a white bread standard to a glucose standard), and also to the GI values reported by Neuhouser et al. (2006) (mean of 0.50–0.51). These similarities provide reassurance that the methods reported here result in GI values that are similar to those found on other databases.

An additional consideration when incorporating GI and GL values into a food composition database is the potential variability in GI values due to differences in study design, laboratory methods and procedures used for determining GI values (Wolever et al., 2003; Wolever, 2004). These factors, in addition to possible differences in food samples (e.g., ingredients, processing, botanical differences), may result in different GI values across studies for what is descriptively the same food. To minimize the differences in food samples, we selected values from studies conducted within the US based on the rationale that foods and commercial products from within the US would more closely match the ingredients and nutritional content of those on the FCT. If there were no samples from within the US, we assigned the mean of the values of non-US origin.

Another concern regarding the addition of GI and GL values to a food composition database is the estimation of values for mixed foods or recipes when only GI values for individual foods are available. It has been argued that GI values for individual foods may have limited clinical applicability because their glycemic responses were determined in a controlled environment, rather than a mixed diet (Coulston et al., 1987). Published reviews of previous research have indicated that, in addition to carbohydrate, other nutrients present in the food (e.g., fiber, fat, protein) and processing can affect the glycemic response (Augustin et al., 2002; Brouns et al., 2005; Wolever et al., 1991). Consuming an individual food with another food containing different amounts of carbohydrate, fat and protein may produce a different glycemic response than the individual food alone. There are infinite combinations of foods consumed by any given population. It is therefore unrealistic to analytically determine the GI for all possible combinations of foods. However, previous studies have tested the GI for a sample of mixed foods and determined that a calculated GI using a weighted average of the GI values of each individual ingredient gives a reasonable approximation of the GI of the mixture (Chew et al., 1988; Wolever and Jenkins, 1986). Mixed foods or recipes carried on the FCT were calculated in this manner.

Although we identified published GI values for most of the commonly consumed foods on the FCT, it was still necessary to impute a large number of values. Furthermore, published values were seldom available for local foods and almost never available for local mixed foods. Therefore, calculated values for the average GI or GL of a diet must be considered approximate and subject to improvement as more analyses of the GI of foods become available.

5. Conclusion

Determining both dietary carbohydrate quality and quantity through the use of GI and GL is of particular interest for research on associations of diet with diabetes, cardiovascular disease, cancer and other diseases in which the glycemic response is of interest. While the addition of GI and GL values to the FCT is not without limitations, it will allow for additional research and comparisons to findings from other studies using different food composition databases. Newly published values for GI and GL will continue to be investigated for addition to the database and values will be updated as they become available.

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