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Validation of estimated glycaemic index and glycaemic load, stratified by race, in the Adventist Health Study-2 (AHS-2)

Carmen N Wright[1,2], Karen Jaceldo-Siegl[1,2], Andrew Mashchak[1,2], Pramil N Singh[3] and Gary E Fraser[1,2,]*

[1]Center for Nutrition, Healthy Lifestyle and Disease Prevention, School of Public Health, Loma Linda University, Loma Linda, CA 92350, USA: [2]Adventist Health Studies, School of Public Health, Loma Linda University, Loma Linda, CA, USA: [3]Center for Health Research, School of Public Health, Loma Linda University, Loma Linda, CA, USA

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Abstract

Objective: Few studies have validated FFQ estimates of dietary glycaemic index (GI) and load (GL). We investigated how well our estimates of overall GI and GL from FFQs correlate with estimates from repeated 24 h recall data to validate overall GI and GL in the Adventist Health Study-2 (AHS-2).

Design: The AHS-2 is a prospective population-based cohort of 95 873 Seventh-day Adventist adult church members enrolled from 2002 to 2007 to investigate diet, cancer and mortality.

Setting: A 204-item FFQ was used to assess race- and gender-specific validity of GI and GL and 24 h recall data, from the calibration sub-study, were used as the reference.

Participants: The 734 calibration study participants were randomly selected by church and included approximately equal numbers of blacks and whites but were otherwise similar to the whole cohort with respect to gender, age, education and vegetarian status.

Results: The deattenuated correlation coefficients for overall GI ranged from 0·19 (95 % CI −0·06, 0·53) in black men to 0·46 (95 % CI 0·40, 0·60) in black women, with both non-black men and women falling between those values (0·45 (95 % CI 0·35, 0·65) and 0·38 (95 % CI 0·27, 0·57), respectively). GL correlations were somewhat higher for all study participants. When looking at the entire cohort, the deattenuated validity correlation value for overall GI was (r 0·38, 95 % CI 0·36, 0·47) and GL was (r 0·39, 95 % CI 0·34, 0·49).

Conclusions: Our findings support the cautious use of our FFQ in epidemiological studies when assessing associations of overall GI and GL with disease risk. However, observed differences by race should be considered when interpreting results.

Keywords
Glycaemic index
Glycaemic load
Validation
Adventist Health Study-2

Over the last few decades, there has been a growing body of research investigating the association between glycaemic index (GI) and/or glycaemic load (GL) and risk of chronic disease[1–5]. From table sugar to starch, all non-fibre carbohydrates share the same basic properties; they are either digested or converted into glucose. However, carbohydrates can vary in their chemical structure, particle size, fibre content and physical form. Once carbohydrates are ingested, different carbohydrates can elicit substantially different glucose and insulin responses[6].

It is important to note that the relationship between GL and GI is not a straightforward one. A food with a high glycaemic value can have a low GL response if eaten in a small quantity. Conversely, a low GI food consumed in a large portion will have a high GL response. Diets with a similar overall low GI may nevertheless vary in their effects depending on the constituent foods and their portion sizes. Therefore, GI values should be used in conjunction with other nutritional characteristics of foods.

In epidemiological studies, the FFQ is the most commonly used method to assess dietary intake on a large scale. This is mainly due to the feasibility and low cost associated with the FFQ compared with other more demanding methods such as 24 h recall or food diaries[7]. However, there have been a limited number of studies that have validated FFQ estimates of dietary GI and GL[7–13]. We

*Corresponding author: Email gfraser@llu.edu

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therefore investigated how well our FFQ-based estimates of overall GI and GL correlate with those from repeated 24 h recall data, in an attempt to validate overall GI and GL in the Adventist Health Study-2 (AHS-2), a diverse population with a wide range of glycaemic values.

Experimental methods

The AHS-2 is a prospective population-based cohort of 95 873 Seventh-day Adventist adult church members enrolled from 2002 to 2007 to investigate diet, cancer and mortality. Data on disease outcomes (including cancer) are assessed biennially with follow-up questionnaires, with additional validation of cancer data from state cancer registries. Detailed information on the cohort was previously described[14]. In brief, there are 4500 Seventh-day Adventist congregations in the USA and Canada with an estimated one million members. Of these members, it estimated that 350 000 were study eligible because they were at least 30 years of age, fluent in English and attended church regularly. After extensive recruitment, 160 000 participants requested the lifestyle questionnaire; of these there were 95 873 (26·9 % black, 65·3 % white and 7·8 % other) study participants who completed the questionnaire. After the following exclusions: 2309 resided in a state without a cancer registry, 7692 prevalent cancer cases, 633 had invalid or out-of-range non-dietary data, 3652 had invalid or missing dietary responses, 2770 had an energetic intake <2092 or >18828 kj (<500 or >4500 kcals) per d and 485 had a BMI < 14 or >60 kg/m^2, there were a total of 78 332 eligible for the analysis.

AHS-2 conducted a calibration study to assess the validity of the nutrient intake information provided on the FFQ compared with 24 h recall data. Detailed information on the calibration study was previously described elsewhere, but in brief, the AHS-2 FFQ, completed a second time in the calibration study, is a 22-page comprehensive dietary instrument with 204 foods, 54 food preparation questions and 46 open-ended questions. Frequency categories varied by type of food with the lowest category typically being never, rarely or 1–3 per month. The highest category ranged, depending on food type, between 2, 4 or 6 times per day, with portion size taken into consideration.

The Nutrition Data System for Research (NDSR) database was the primary source for nutrient estimation, including GI and GL values, for both the FFQ and 24 h recall data[15]. Additional published databases of US foods were used if the GI values were not found in the NDSR[16,17]. In the case where the databases lacked a GI value for a specific food, a GI value was chosen from similar foods in the databases.

The calibration study spanned 9–12 months for each subject, and three different unannounced 24 h recalls were obtained via telephone during the first 2 months of the study, one Sunday, one Saturday and 1 d during the week. Then approximately 6 months later another three were administered. Participants completed the second FFQ (after the baseline FFQ) during the 6-month interval between 24 h recall assessments. When assessing validity by comparing FFQ to recall data, we found that across 51 variables, the deattenuated energy-adjusted validity correlations averaged 0·52 in blacks and 0·60 in whites. Overall, there is moderate to high validity for most vitamins, minerals, fatty acids, fibre and micronutrients in the AHS-2 cohort[18].

To determine how well the FFQ measures dietary GI and GL, we used 24 h recall data from the calibration study as a reference. The calibration study participants were randomly selected by church and then by participant-within-church, from the parent study. Both parent study and calibration study participants were similar with respect to gender, age, education and vegetarian status. The calibration study was designed to include approximately equal numbers of blacks and whites[18].

Statistical analysis

To produce a synthetic week for each set of recalls, the 24 h dietary recall days were weighted (5 × week d intake + Saturday intake + Sunday intake)/7 to obtain two mean daily overall GI and GL estimates (g/d) for each subject.

The food GL was calculated as:

$$\text{Food GL} = \sum(\text{ingredient available carbohydrate (ACHO)} \times \text{ingredient GI}/100)$$

The overall GI was calculated as:

$$\text{Overall GI} = \text{food GL}/\text{total ACHO in diet}$$

The overall dietary GL for each study participant was estimated by multiplying the GL value for each reported food item by the participant's frequency of consumption accounting for serving size. This value was then summed across all food items. The overall GI value for each study participant was then calculated by dividing the participants' summed GL values by the total grams of ACHO in their diets. Overall GI then becomes the average, weighted by grams of ACHO, of GI values for the foods consumed by a study participant. GI and GL values were calculated using glucose as the reference.

We took the following data analysis steps: (a) overall GI, GL, total energies, ACHO and fibre were calculated from the FFQ and each synthetic week of 24 h recalls; (b) descriptive statistics were generated for demographic and nutrient intake variables; (c) overall GI and GL dietary comparisons between FFQ and 24 h recall were calculated using Pearson's correlation coefficients, stratified by race (black/non-black) and gender (women/men) and (d) finally, cross-classification analyses were performed.

The residual method was used to produce energy-adjusted GL, ACHO and fibre variables. This method produces estimates of nutrient intake that are not correlated with total energetic intake but related directly to overall variation in food composition and choice[19]. There are

Table 1 Selected characteristics of subjects in the Adventist Health Study-2 calibration study (2003–2008), stratified by race: dietary data from 24 h recalls

	Black women (*n* 232)		Non-black women (*n* 260)		Black men (*n* 94)		Non-black men (*n* 148)		Overall (*n* 734)	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
Age (years)										
Mean	54·77		58·56		55·42		60·46		57·34	
SD	12·8		13·4		12·1		13·6		13·3	
Education										
High school or less	52.0	22·4	55.0	21·2	21.0	22·3	28.0	18·9	156.0	21·3
Trade school/Associates	97.0	41·8	114.0	43·9	38.0	40·4	35.0	23·7	284.0	38·7
Bachelors or higher	83.0	35·8	91.0	35·0	35.0	37·2	85.0	57·4	294.0	40·1
BMI (kg/m^2)										
<18·5	4.0	1·7	6.0	2·3	3.0	3·2	3.0	2·0	16.0	2·2
18·5–24·9	65.0	28·0	120.0	46·2	30.0	31·9	66.0	44·6	281.0	38·3
25·0–29·9	76.0	32·8	82.0	31·5	41.0	43·6	54.0	36·5	253.0	34·5
30+	87.0	37·5	52.0	20·0	20.0	21·3	25.0	16·9	184.0	25·2
Glycaemic load* (g/d)										
Mean	111·06		107·82		117.43		114·16		111·35	
SD	22·8		20·3		21.3		21·3		21·6	
Min–max	58·5–179·0		40·5–164·4		65·4–178·8		49·0–180·7		40·5–180·7	
Overall glycaemic index (g/d)										
Mean	53·72		54·21		55·39		55·07		54·38	
SD	3·9		3·7		3·3		3·4		3·7	
Min–max	42·8–65·0		39·6–62·8		46·1–61·8		41·0–64·0		39·6–65·0	
Available Carbohydrates* (g/d)										
Mean	207·17		199·06		212·00		206·66		204·81	
SD	42·2		36·1		36·1		33·3		37·8	
Min–max	53·3–415·9		60·7–397·1		94·8–476·5		70·6–482·7		52·3–482·7	
Fibre* (g/d)										
Mean	30·72		32·54		29·30		30·98		31·24	
SD	9·5		9·0		8·2		7·5		8·8	
Min–max	4·6–48·6		6·0–65·8		8·4–56·7		7·9–61·8		4·6–65·8	
Total energies (kj/d)										
Mean	7016.1		6988.1		7005.3		7024.9		7006.5	
SD	1488.2		1196.2		1197.9		1101.2		1276.5	
Min–max	2259.8–12870.8		1850.2–12349.5		3553.9–15462.8		2388.2–15056.1		1850.2–15462.8	
Vegetarian status										
Vegan	19.0	8·2	24.0	9·2	9.0	9·6	13.0	8·8	65.0	8·9
Lacto-ovo	32.0	13·8	93.0	35·8	14.0	14·9	59.0	39·9	198.0	27·0
Pesco	30.0	12·9	26.0	10·0	21.0	22·3	14.0	9·5	91.0	12·4
Semi	9.0	3·9	16.0	6·2	2.0	2·1	8.0	5·4	35.0	4·8
Non-vegetarian	142.0	61·2	101.0	38·9	48.0	51·1	54.0	36·5	345.0	47·0

*Energy-adjusted values presented.

two reasons energy-adjusted values are used. The first is the need to take into account that total energy requirements differ by body size, physical activity and individual metabolisms. Second, energy adjustment partially addresses the issue of measurement error that occurs when using self-reported data such as FFQ data[20]. Mean and SD for dietary intakes were calculated from the average of the two synthetic weeks generated from the 24 h recalls and also from the FFQ. Crude and deattenuated Pearson's correlation coefficients were calculated. The deattenuated validity coefficient estimates the correlation between the intakes, eliminating the within-subject variation in the 24 h recalls. We estimated the deattenuated correlation coefficient as the correlation coefficient between the reference instrument (24 h recall) and the FFQ, divided by the square root of the intraclass correlation coefficients of the two replicates of the 24 h recalls[21].

Validity correlations of 0·40 or above from FFQ have been labelled as 'acceptable: to represent that dietary item in statistical analyses'[22]. Dietary variables were log-transformed to address the positively skewed data and to improve correlation coefficients[18]. Participants were categorised into quintiles of intake. Then, exact agreement, agreement within one quintile and agreement within two quintiles were calculated, comparing the FFQ and 24 h recall data. The 95 % CI for all validity coefficients were calculated using bootstrap resampling methods (50 000 samples)[23]. Statistical analyses were conducted using SAS 9·4 (SAS Institute Inc.).

Results

Of the 734 calibration study participants in the current analysis, 232 were black women, 260 were non-black

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Table 2 Comparison of overall glycaemic index, glycaemic load, energy, ACHO and fibre intake as measured by 24 h recall and an FFQ in the Adventist Health Study-2 calibration study by gender and race

	Black women (*n* 232)				Non-black women (*n* 260)				Black men (*n* 94)				Non-black men (*n* 148)			
	24-h recall		FFQ		24 h recall		FFQ		24 h recall		FFQ		24 h recall		FFQ	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Overall glycaemic index (g/d)	53·7	3·9	58·3*	3·8	54·2	3·8	56·8*	3·6	55·4	3·3	58·0*	3·5	55·1	3·4	57·5*	3·6
Glycaemic load‡ (g/d)	111·1	22·8	99·9*	17·0	107·8	20·3	114·3†	19·0	117·4	21·3	103·5*	16·5	114·2	21·3	117·4	20·0
Total energies (kjd)	7016·1	1488·2	5807·8*	945·2	6988·1	1196·2	6678·9†	1077·0	7005·3	1197·9	5845·5*	899·6	7024·9	1101·2	6804·0	1004·6
Available carbohydrates‡ (g/d)	207·2	42·2	171·6*	27·2	199·1	36·1	201·1	30·4	212·0	36·1	178·8*	28·4	206·7	33·3	204·0	31·4
Fibre‡ (g/d)	30·7	9·5	20·2*	7·1	32·5	9·0	25·4*	8·2	29·3	8·2	21·5*	7·9	31·0	7·5	25·8*	7·8

*Intake from the FFQ was significantly different from the intake reported during the 24 h recall $P < 0·0001$.
†Intake from the FFQ was significantly different from the intake reported during the 24 h recall $P < 0·05$.
‡Energy-adjusted values presented.

women, 94 were black men and 148 were non-black men (Table 1). Significant differences between black women, non-black women, black men and non-black men were observed for all baseline characteristics except for total energetic intake. When comparing FFQ data to the reference 24 h recall data, significant differences were also observed by race and gender, with the FFQ overestimating overall reference dietary GI for both women and men irrespective of race (Table 2). However, in black women, the FFQ underestimated dietary values for GL, total energies, ACHO and fibre intake. This is in contrast to non-black women where the FFQ underestimated dietary values for total energetic intake and fibre but overestimated GL and ACHO. In black men, the FFQ underestimated all remaining dietary values, GL, total energies, ACHO and fibre intake. In non-black men, the FFQ overestimated GL and underestimated total energies, ACHO and fibre.

Generally, there was a good agreement between the 24 h recall and FFQ response for the dietary variables presented (Table 3). When assessing the exact quintile agreement overall, GI had a 25·6 % agreement which improved to 61·6 % agreement when assessed within +/- one quintile and 82·3 % within +/- two quintiles. GL had an exact agreement of 24·9 % that increased to 62·3 % within +/- one quintile and 84·2 % within +/- two quintiles.

Table 4 presents deattenuated correlation coefficients, adjusted for age and BMI for overall GI, GL, total energies, ACHO and fibre intake. In black women, the deattenuated correlation coefficient value for overall GI was 0·46 (95 % CI 0·40, 0·60) and for non-black women 0·38 (95 % CI 0·27, 0·57). For GL, the values were 0·36 (95 % CI 0·25, 0·61) and 0·53 (95 % CI 0·46, 0·70) for black and non-black women, respectively. The lowest deattenuated validity correlation, in black women, was total energetic intake (r 0·29, 95 % CI 0·17, 0·50) and in non-black women, overall dietary GI (r 0·38, 95 % CI 0·27, 0·57). The highest deattenuated correlations were for fibre in both black (r 0·71, 95 % CI 0·66, 0·84) and non-black (r 0·77, 95 % CI 0·74, 0·84) women. In black men, the deattenuated correlation coefficient value for overall GI was 0·19 (95 % CI −0·06, 0·53) and for non-black men 0·45 (95 % CI 0·35, 0·65). For GL, the values were 0·40 (95 % CI 0·22, 0·68) and 0·59 (95 % CI 0·50, 0·77), respectively. In men, the lowest deattenuated validity correlation was total energetic intake for both black (r 0·14, 95 % CI 0·07, 0·40) and non-black men (r 0·43, 95 % CI 0·29, 0·64). Similar to results for women, fibre had the highest validity correlation for both black (r 0·69, 95 % CI 0·57, 0·85) and non-black (r 0·75, 95 % CI 0·71, 0·86) men. For the overall cohort, the deattenuated validity correlation value for overall GI was (r 0·38, 95 % CI 0·36, 0·47) and GL was (r 0·39, 95 % CI 0·34, 0·49). Overall fibre had the highest deattenuated correlation coefficient (r 0·71, 95 % CI 0·70, 0·75). Overall total energetic intake had a rather low correlation (r 0·31, 95 % CI 0·25, 0·41).

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Table 3 Cross-tabulation agreement between FFQ and 24 h recall measures of overall glycaemic index, glycaemic load, energy, ACHO and fibre intake in the Adventist Health Study-2 cohort

	Exact agreement		Agreement within +/- one quintile		Agreement within +/- two quintiles	
n 734	*n*	%	*n*	%	*n*	%
Overall glycaemic index	188	25·6	450	61·6	604	82·3
Glycaemic load*	183	24·9	457	62·3	618	84·2
Total energies	181	24·7	428	58·3	597	81·3
ACHO*	198	27·0	443	60·4	605	82·4
Fibre*	281	38·3	562	76·6	684	93·1

*Energy-adjusted values presented.

Table 4 Corrected correlation coefficients and 95 % CI between FFQ and 24 h recall measures of overall glycaemic index, glycaemic load, energy, ACHO and fibre intake in the Adventist Health Study-2 cohort

	Corrected correlation*				Corrected correlation*				Corrected correlation*	
	Black women		Non-black women		Black men		Non-black men		Overall for the cohort	
	Pearson's correlation	95 % CI	Pearson's correlation	95 % CI	Pearson's correlation	95 % CI	Pearson's correlation	95 % CI	Pearson's correlation	95 % CI
Overall glycaemic index	0·46	0·40, 0·60	0·38	0·27, 0·57	0·19	−0·06, 0·53	0·45	0·35, 0·65	0·38	0·36, 0·47
Glycaemic load†	0·36	0·25, 0·61	0·53	0·46, 0·70	0·40	0·22, 0·68	0·59	0·50, 0·77	0·39	0·34, 0·49
Total energies	0·29	0·17, 0·50	0·48	0·39, 0·64	0·14	−0·07, 0·40	0·43	0·29, 0·64	0·31	0·25, 0·41
ACHO†	0·38	0·27, 0·57	0·52	0·44, 0·70	0·34	0·17, 0·63	0·59	0·48, 0·77	0·36	0·28, 0·46
Fibre†	0·71	0·66, 0·84	0·77	0·74, 0·84	0·69	0·57, 0·85	0·75	0·71, 0·86	0·71	0·70, 0·75

*Deattenuated correlation coefficients adjusted for age and BMI; 95 % CI were calculated using bootstrap method.
†Energy-adjusted values presented.

Discussion

In general, the 204-item FFQ overestimated overall GI and underestimated GL in both black and non-black women compared with the 24 h recall. Similar results were observed in both black and non-black men when comparing overall GI reported on FFQ to the 24 h recall. GL was underestimated by the FFQ in black men but overestimated in non-black men. Based on previous findings in the AHS-2 cohort, we expected deattenuated energy-adjusted correlations to be lower in blacks compared with whites[18]. The AHS-2 FFQ, though carefully validated, is nevertheless subject to measurement errors common to subject response in all FFQ. These result from the restricted food list, imperfect ability of individuals to estimate serving size, frequency and usual food intake pattern, relying on long-term memory[9]. Our estimates of GI and GL values have a number of potential sources of error. First, the nutritional values from the NDSR and other databases may have inaccuracies, both inherently and due to incomplete representation of foods consumed by our study population[24]. This is possible, in part, because the vegetarians in our cohort tend to eat foods less commonly consumed by the general population. In cases where foods were not present in the databases, we either created recipes using ingredients present in the databases or substituted values from similar foods, either of which may have introduced error. In addition, overall dietary GI and GL estimates involve data from many foods, each with their own errors. The use of the two variables GL and ACHO in the calculation of overall GI compounds the error from both variables which may decrease the associated correlations. Despite our best efforts to do so, our questionnaire may not adequately capture special foods that blacks (African American and Caribbean) eat[25]. This potential source of error may further explain some of the differences observed between blacks and non-blacks in the study, as validity correlations in the AHS-2 cohort tended to be lower in blacks than in whites[26].

Correlation coefficients are the most commonly applied statistics used to validate FFQ data[27,28]. To our knowledge, there are only seven dietary questionnaires that have validated their GI and GL measurements[7–13]. These validations were done in European, Australian and Japanese populations; we appear to be the first to report on the

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validity of overall GI and GL in blacks and an American population. For continuous variables, a correlation coefficient of 0·5 or higher is an indication of the FFQ's ability to rank individuals' nutrient intake. For categorical variables, a correlation coefficient of at least 0·4 is recommended[29,30]. Of the six previously reported studies, the energy-adjusted correlation coefficients for GI ranged from 0·31–0·69 and for GL, 0·32–0·71[7–12]. The seventh study that validated correlation coefficients for GI and GL did so using an FFQ designed to specifically capture GI and GL dietary habits. They found that 43 % of their study participants were correctly classified in the same quartile for GI and 48 % for GL[13], thus a little better concordance than we observed.

Our corrected correlation coefficients for overall GI in black and non-black subjects, contrasted with those from a recent Japanese study that validated a 118-item FFQ using a 4-d dietary record, comprised 92 women and men 31–76 years of age, which observed energy-adjusted correlations of r 0·65 in men and r 0·72 in women[12]. Similarly, when assessing the validity of GL values measured by the FFQ, our values contrasted to those from the Japanese study where women have a corrected correlation coefficient value of r 0·66 and men r 0·71[12]. This may be due to greater cultural, and thus dietary, homogeneity.

Our value for overall GI, across the whole cohort, had a corrected correlation coefficient value of r 0·38 which is lower than that recently reported by the Preview Consortium for GI (r 0·61). However, our value for GL was r 0·39, which is similar to that from the Preview Consortium ($r = 0{\cdot}35$)[13]. We surmise that this may be due, in part, to the relatively low validity of the total energetic intake for our study.

Thus, values from AHS-2 are on the lower end of the acceptable range, perhaps partly due to the lower values observed in blacks. This is an important finding because heterogeneity among study populations can explain some of the variation in GI and GL correlation coefficients in prior research. In our case, there is also significant variation within study, between racial subgroups. A non-homogenous population, in regard to age and gender, has been shown to magnify between-person variation in diet and subsequently reduce correlations[8].

Conclusion

In conclusion, our findings support the cautious use of our FFQ in epidemiological studies when assessing associations of both overall GI and GL variables with disease risk. However, the racial differences observed should be taken into account when interpreting results based on this FFQ in blacks, with correlation values ranging from at best a GL value of r 0·36 in black women and r 0·40 in black men and a GI correlation values of 0·46 and 0·19, respectively.

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