



Danone Vitapole

NUTRITION AND HEALTH COLLECTION

Glycaemic Index and Health: the Quality of the Evidence



With the technical collaboration of the Food
and Agriculture Organization of the United Nations



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the Quality of the Evidence





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INTRODUCTION

In industrialised societies, the prevalence of obesity and degenerative diseases, such as diabetes, obesity, and cardio-vascular diseases (CVD) is rapidly increasing, especially in young individuals. Experts believe that lifestyle, and in particular its nutritional aspects, play a decisive role in increasing the burden of these chronic conditions. Dietary habits could therefore be modified to exert a positive impact in the prevention and treatment of chronic disease. Several hypotheses have been proposed in recent years. In particular, it has been suggested that the state of hyperglycaemia that is observed following food intake under certain dietary regimes could constitute a risk factor for the development of various metabolic conditions. This is the case in patients with poor glycaemic control such as in diabetes, and it could also be true for healthy individuals. Under such circumstances, it would be helpful to be able to reduce the amplitude and duration of post-prandial hyperglycaemia. The observation that some carbohydrate rich foods induce less post-ingestive hyperglycaemia than others opened the way to the notion that selecting the right kind of CHO foods could actually represent a strategy in the prevention and treatment of chronic metabolic disorders.

The glycaemic index (GI) refers to the blood-glucose raising potential of carbohydrate (CHO) foods. The GI allows a classification of foods based on the post-prandial blood glucose response as compared to a reference food. In healthy persons, the normal rise in blood glucose that follows a mixed meal induces the secretion of insulin by the pancreas in order to bring back blood glucose to basal levels. The amplitude of the rise in blood glucose determines the amount of insulin secreted. In several metabolic disorders, however, the secretion of insulin is inadequate or impossible, leading to a situation of poor glycaemic control. It has been suggested in the last twenty years that the careful selection of CHO foods with low GI could potentially contribute to a significant improvement of the conditions associated with poor glycaemic control. There is much research which has been devoted to the measurement of the GI of foods in a number of countries. Evidence

supporting the notion that selecting foods with low GI could improve numerous physical functions in healthy as well as diseased individuals is accumulating. Many experts now consider the manipulation of the dietary GI a useful tool for the treatment and prevention of chronic diseases typical of industrialised countries.

In the following pages, some of the supportive evidence gathered over the last twenty years is critically reviewed. The value of the GI concept in diseased populations is emphasised, and the potential benefits in healthy individuals are presented. The areas of insufficient or controversial knowledge have been underlined. Finally, a consensual statement is proposed.

“The Glycaemic Index is defined as the incremental area under the blood glucose response curve of a 50g carbohydrate portion of a test food expressed as a percent of the response to the same amount of carbohydrate from a standard food taken by the same subject.”

Definition given by the **FAO/WHO**
Expert consultation, 1997

CHAPTER I

HISTORY AND DEFINITION

The GI concept was initially proposed in 1981. The GI is a value that describes the rise in blood glucose following the intake of CHO foods, compared to the 2h-hyperglycaemia induced by the intake of an equivalent load of a standard CHO food. The GI of a given food is defined as the incremental area under the blood glucose response curve (IAUC) following the intake of a 50g CHO portion of the food, expressed as a percent of the IAUC following the intake of 50g CHO from the standard (glucose or bread) by the same individual. Figure 1 shows how the IAUC of a specific food is measured and Figure 2 gives examples of the glucose and insulin responses observed following the intake of different CHO foods. The GI of a food is expressed as a percentage of the standard response (i.e. to bread or to glucose). Table I lists the GI of several CHO foods.

Compared to the effect of the intake of a low GI food, a high GI food with the same equivalent in carbohydrate content induces an higher peak of circulating glucose and a larger area under the curve over the early post-prandial period. As a consequence of the induced insulin response, intake of a high GI food results in lower blood glucose concentrations over the late (2-3h) post-prandial period than that of a low GI food.

The notion that CHO foods could induce different post-ingestion glycaemic responses was developed after the observation, in the mid 70s, that viscous fibers present in CHO foods blunted the post-ingestive glucose and insulin responses, for identical amounts of CHO. It was recognised at the same time that starchy foods had different effects on the blood glucose of healthy as well as diabetic subjects. The importance of differing rates of digestion and of glucose absorption was recognised and research was devoted to systematically document differences between CHO foods.

In a report published in 1998, the FAO and WHO endorsed the use of the GI as a method of categorising CHO, as this provides information on the likely metabolic effects of the CHO.

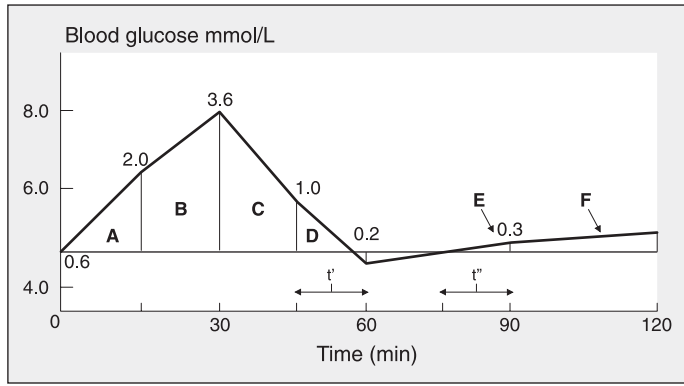


Figure 1. Glucose IAUC. (From FAO/WHO expert consultation carbohydrates in human nutrition.)

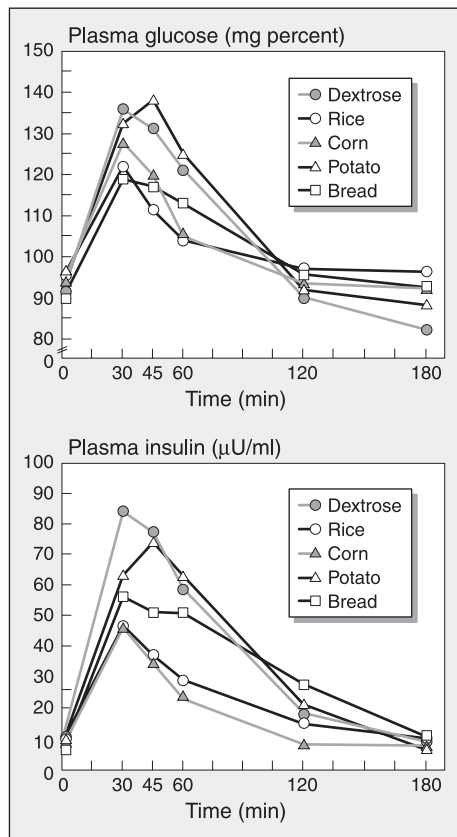


Figure 2. Different GI and II. (From Crapo et al. Diabetes 1977; 26: 1178-83.)

Table I. Glycaemic index of different foods

(From FAO/WHO expert consultation carbohydrates in human nutrition)

	GI*	n**		GI*	n**
BAKED GOODS			FRUIT		
Cakes	87 ± 5	9	Apple	52 ± 3	4
Cookies	90 ± 3	14	Apple juice	58 ± 1	2
Crackers, wheat	99 ± 4	8	Apricots, dried	44 ± 2	2
Muffins	88 ± 9	8	Apricots, canned	91	1
Rice cakes	123 ± 6	2	Banana	83 ± 6	5
BREADS			Banana, underripe	51 ± 8	2
Barley kernel	49 ± 5	3	Banana, overripe	82 ± 8	2
Barley flour	95 ± 2	2	Kiwifruit	75 ± 8	2
Rye kernel	71 ± 3	6	Mango	80 ± 7	2
Rye flour	92 ± 3	10	Orange	62 ± 6	4
Rye crispbread	93 ± 2	5	Orange juice	74 ± 4	3
White bread	101 ± 0	5	Paw paw	83 ± 3	2
Whole-meal flour	99 ± 3	12	Peach, canned	67 ± 12	3
Other products ^a	100 ± 4	5	Pear	54 ± 4	4
BREAKFAST CEREALS			Other, GI < 80 ^f	54 ± 7	7
All bran	60 ± 7	4	Other, GI ≥ 80 ^g	92 ± 4	5
Cornflakes	119 ± 5	4	GRAINS		
Muesli	80 ± 14	4	Pearled barley	36 ± 3	4
Oat bran	78 ± 8	2	Cracked barley	72	1
Porridge oats	87 ± 2	8	Buckwheat	78 ± 6	3
Puffed rice	123 ± 11	3	Bulgur	68 ± 3	4
Puffed wheat	105 ± 3	2	Couscous	93 ± 9	2
Shredded wheat	99 ± 9	3	Cornmeal	98 ± 1	3
Other, GI ≥ 80 ^b	103 ± 3	15	Sweet corn	78 ± 2	7
Other, GI < 80 ^c	72 ± 2	4	Millet	101	1
SNACKS			Rice, white	81 ± 3	13
Jelly beans	114	1	Rice, low amylose	126 ± 4	3
Lifesavers	100	1	Rice, high amylose	83 ± 5	3
Chocolate (various)	84 ± 14	2	Rice, brown	79 ± 6	3
Popcorn	79	1	Rice, instant	128 ± 4	2
Corn chips	105 ± 2	2	Rice, parboiled	68 ± 4	13
Potato chips	77 ± 4	2	Specialty rices	78 ± 2	5
Peanuts	21 ± 12	3	Rye kernels	48 ± 4	3
SOUPS			Tapioca	115 ± 9	1
Bean soups (various)	84 ± 7	4	Wheat keenelsa	59 ± 4	4
Tomato	54	1	DAIRY PRODUCTS		
			Ice cream	84 ± 9	6
			Milk, whole	39 ± 9	4

Milk, skim	46	1	Lentils, green canned	74	1
Yogurt ^d	48 ± 1	2	Lima beans	46	1
Yogurt ^e	27 ± 7	2	Peas, dried green	56 ± 12	2
PASTA			Peas, green	68 ± 7	3
Linguine	71 ± 4	6	Pinto beans	61 ± 3	3
Macaroni	64	1	Soya beans	23 ± 3	3
Macaroni, boxed	92	1	Split peas, yellow	45	1
Spaghetti, white	59 ± 4	10	POTATOES		
Spaghetti, durum	78 ± 7	3	Instant	118 ± 2	5
Spaghetti, brown	53 ± 7	2	Baked	121 ± 6	4
Other	59 ± 3	8	New	81 ± 8	3
LEGUMES			White, boiled	80 ± 2	3
Baked beans	69 ± 12	2	White, mashed	100 ± 2	3
Black-eyed peas	59 ± 12	2	French fries	107	1
Butter beans	44 ± 3	3	Sweet potato	77 ± 11	2
Chickpeas	47 ± 2	3	Yam	73	1
Canned chickpeas	59 ± 1	2	SUGARS		
Haricot beans	54 ± 8	5	Honey	104 ± 21	2
Kidney beans	42 ± 6	7	Fructose	32 ± 2	4
Kidney beans, canned	74	1	Glucose	138 ± 4	8
Lentils	38 ± 3	6	Sucrose	87 ± 2	5
Lentils, green	42 ± 6	3	Lactose	65 ± 4	2

* GI = glycaemic index (while bread = 100), mean ± SEM of mean values from various studies.

** Number of studies.

^a Bagel, stuffing mix, hamburger bun, rolls, melba toast.

^b Bran buds, Bran chex, Cheerios, Corn barn, Corn chex, Cream of wheat, Crispix, Golden Grahams, Grape-nuts, Grapenuts flakes, Life, Pro stars, Sustain, Team, Total (GI range, 83-127).

^c Bran buds with psyllium, Red River, Special K (Australia), Sultana bran (Australia) (GI range 67-77).

^d Sweetened with sugar.

^e Artificially sweetened.

^f Cherries, fruit cocktail, grapefruit, grapefruit juice, grapes, plum, pineapple juice.

^g Pineapple, raisins, rockmelon, sultanas, watermelon.

CHAPTER II

METHODOLOGICAL
CONSIDERATIONS

The valid testing of the GI requires a standard method. The definition given above is straightforward. However, its simplicity is deceptive, and the actual testing of GI requires a high degree of methodological sophistication. Several issues potentially influence the accuracy and the precision of the results. The FAO/WHO Expert Consultation has proposed a standardised protocol.

To determine the GI of a food, tests have to be repeated in six or more subjects and the resulting GI values averaged. Subjects are studied on separate days in the morning following a 10-12 hour overnight fast. A standard drink of water, tea or coffee, should be given with each test meal. Many aspects of the protocol deserve attention:

- **The method of calculation of the IAUC.** A number of different methods have been used to calculate the area under the curve. For most glycaemic index data, the area under the curve has been calculated as the incremental area under the blood glucose response curve (IAUC), not taking into account the area beneath the fasting concentration. This can be calculated geometrically by using the trapezoid rule. When a blood glucose value falls below baseline, only the area above the fasting level is included in the final value.

- **Blood glucose is determined from capillary whole blood.** Plasma glucose may be used to determine the GI and gives similar values. Capillary blood is preferred, however, because it is easier to obtain, the rise in blood glucose is higher than in venous plasma and the results obtained with capillary blood glucose are less variable than those obtained with venous plasma. Consequently, differences between foods are larger and easier to detect statistically when capillary blood is used.

- **The definition of 50g CHO.** The portion of food tested should contain 50g of glycaemic, available CHO. In practice, glycaemic CHO is often determined as the total CHO minus dietary fibers. Since this estimate may include resistant starch (RS1 and RS2), it will be falsely considered as glycaemic CHO, when present.

- **The standard food used.** Either white bread or glucose can be used as the standard food, according to the FAO/WHO protocol. The GI values obtained with white bread are about 1.4 times as high as the values obtained with glucose. However, the relative difference between the GI of foods is the same, regardless of whether glucose or bread is used as the standard. Each GI value provided should also mention which control food was used.

- **Within and between subject variability.** Blood glucose responses show considerable day-to-day variation within subjects. In order to obtain a representative mean response to the standard food, it is recommended by the FAO/WHO that the standard food test be repeated at least three times in each subject. GI values of the same foods tested in different groups of subjects are highly correlated, regardless of the subjects' glucose tolerance status.

- **Time of day effects.** The time of day when the tests are conducted is an important factor influencing the end results. However, the GI of a food is the same when measured at breakfast or later during the day. The FAO/WHO protocol recommends that testing should take place in the morning, after an overnight fast.

- **The GI of meals.** The GI can be applied in a detailed fashion to mixed meals or whole diets, according to the FAO/WHO Expert Consultation. The weighed GI value of the meal or diet can be calculated. Table II provides an example of how the GI of individual foods included in a meal can be used to calculate the overall GI of the meal.

Table II. Calculation of the glycaemic index of meals

Food	Grams Glycaemic Carbohydrate	Proportion of total Glycaemic Carbohydrate	Food Glycaemic Index	Meal Glycaemic Index*
Bread	25	0.342	100	34.2
Cereal	25	0.342	72	24.6
Milk	6	0.082	39	3.2
Sucrose	5	0.068	87	5.9
Orange juice	12	0.164	74	12.1
Total	73			80.0

* Values for each food equals the proportion of total glycaemic carbohydrate multiplied by the food GI. The sum of these values is the meal GI.

Beyond these basic methodological considerations, other criteria exist for GI studies.

Whenever possible, such studies should include both glucose and insulin measurements. The insulinic index (II) generally shows a high degree of correlation with the GI, whether foods with equal portion of CHO or energy are tested. Only dairy products have

specific insulinotropic characteristics and their metabolic effects have to be studied. Figure 3 shows the correlation between II and GI for 35 starch-containing foods. Reducing the GI of whole diet is associated with reduced insulin secretion. However, some experts question the validity of the II. For example, the II is not needed for routine use, since the GI provides information about insulin responses. The II is relatively higher if glucose is the standard food, rather than bread (perhaps because the protein in bread stimulates insulin secretion). Moreover, there is evidence that the II of foods varies in different categories of subjects, especially in patients with diabetes. In type 2 diabetes, insulin secretion in response to a rise in blood glucose is impaired, while the insulin response to amino acids such as arginine is not. Finally, the analytic and biological variabilities of plasma insulin are greater than those of plasma glucose.

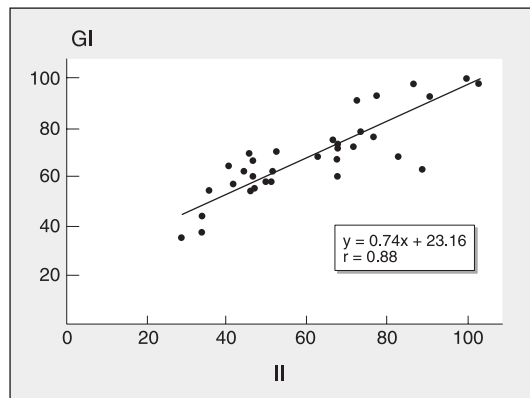


Figure 3. Correlations between II and GI. (From Björck et al.)

The II and GI responses should be investigated in individuals for whom **dietary recommendations** are proposed. Research has shown, however, that GI values for a given food are highly correlated, regardless of the glucose tolerance status of the subjects.

Studies should be performed in the context of a standardised mixed meal. This is extremely important in order to interpret the results correctly. The presence of fat or protein in mixed meals could influence the GI in as yet insufficiently assessed proportions. When reviewing the literature, the Methods and Results sections need to be read carefully because the authors' interpretation of the data may be based on inappropriate methods, faulty statistical analyses, or non-physiological test meal conditions.

Finally, GI studies should demonstrate **chronic benefits** of selectively ingesting low GI foods. As of today, 13 clinical trials on the effects of low GI in 218 diabetic patients have been published. Among these, nine demonstrated statistically significant improvement in glycaemic control, as measured by glycated proteins or glycated haemoglobin. The average improvement in all 13 studies was 7%. In addition, among the 13 studies concerning low GI diets, eight demonstrated statistically significant improvements in blood lipids, either reduced cholesterol or triglycerides or increased HDL.

POST-PRANDIAL HYPERGLYCAEMIA, HEALTH AND DISEASES

Much work has been done showing that selecting CHO foods according to their GI has a significant impact on numerous aspects of human physiology and metabolism, which, in turn, may influence physical and mental performance and contribute to the prevention and management of several chronic diseases.

DEGENERATIVE DISEASES

Insulin sensitivity

The metabolic syndrome is a cluster of metabolic and cardiovascular risk factors associated with altered post-prandial metabolism. The beneficial effects of low GI foods on post-prandial metabolism might be useful not only for the treatment but also for the prevention of this condition.

The clusters of risk factors that make up the insulin resistance syndrome are established risk factors for CHD (Frost & Leeds). Hyperglycaemia and hyperinsulinemia are important independent risk factors for CHD. Means of manipulating insulin sensitivity are important; they include drug treatments, exercise, weight loss, and others. Since the recommended level of CHO intake in the diet is over 55% of total energy, it is important to investigate the effects such a high CHO intake will exert on insulin sensitivity. There is some evidence that low glycaemic diets affect whole body insulin sensitivity and the insulin sensitivity of adipose tissue in patients with CHD and patients at risk of CHD. Low GIs have been shown to improve both adipocyte insulin-mediated glucose uptake in vitro and insulin sensitivity in vivo as assessed by the post-prandial fall in non-esterified fatty acids

(NEFA) levels. Reducing post-prandial NEFA levels is important as their concentration has a rate-limiting effect on hepatic VLDL synthesis. High levels of VLDL production result in reduced HDL-cholesterol and increased formation of atherogenic small dense LDL. This is important since adipose tissue is responsible for the insulin resistance to glucose disposal in the muscle. Low GI diets also reduce post-prandial hyperinsulinaemia, suggesting a more insulin sensitive environment. One clamp study did not confirm these observations, however, and reported no significant effect, perhaps due to the non-physiological conditions created during euglycaemic hyperinsulinemic clamps. By contrast, epidemiological evidence supports the effects of low GI diets on HDL-cholesterol, decreasing risk of both type 2 diabetes and CHD. These effects may occur through changes in insulin sensitivity. More research is needed to establish actual cause and effect relationships between low GI CHO and insulin sensitivity.

Risk factors and the glycaemic load

Nutrition experts recommend a diet containing at least 55% of energy as CHO (FAO-WHO 1998) from the age of two. It is likely that in a developed society, such a diet would include many foods with high GI (potatoes, white bread, refined cereal products, etc.) and represent a high glycaemic load (GL). This notion, in addition to that of the GI, stresses the fact that the amount of CHO in a food is important in determining fasting TG and the post-prandial plasma glucose response. The GL is a measure that incorporates both the amount and quality of dietary CHO. The GL of a specific food (the product of the food CHO content by its GI) serves as a basis to evaluate the total GL of the diet. According to the concept of GL, many fruits and vegetables are classified as low or very low GL foods. For example, the GI value for carrots has been reported to be as high as 131; the GL for one serving of carrots, however, is small because the amount of CHO is minimal (about 7 grams of CHO).

The GL has been examined in a large population of healthy women (Nurses' Health Study). In a random sample of 280 postmenopausal participants, a strong positive association appeared between GL and fasting TG levels (the relationship was especially marked in obese women with BMI higher than 25). Both overall GI and total dietary CHO independently contributed to this effect. In the same sample, GL was inversely associated with HDL cholesterol. In large cohort studies, GL has been positively associated with risk of type 2 diabetes. The relative risk comparing the extreme quintiles of intake was 1.47 over 6 years of follow-up. Women with the combination of high GL and low cereal fibre intake had an even greater relative risk of Type 2 diabetes (RR = 2.43). GL was also independently associated with CHD events (see below).

In a large cross-sectional study (2,200 healthy adults), the GI of the diet appeared to be a greater determinant of HDL cholesterol than any other aspect of the diet (fat or fibre). In women, the lowest quintile for GI had 0.25 mmol/l more HDL-cholesterol than the highest quintile. Potentially such a difference could lead to a 29% reduction in CHD morbidity

in female patients. The corresponding numbers for men would predict a 7% decrease in CHD morbidity, reflecting the 0.09 mmol/l difference in HDL-cholesterol.

The chronic use of low GI diets could exert effects on glucose and lipid metabolism, as well as on body fat distribution. In a double blind, crossover study of 11 healthy moderately overweight men, 5 weeks on a low GI diet improved several metabolic and dietary parameters as compared to 5 weeks on a high GI diet. While total energy and macronutrient intake was the same under both conditions, the fibre content of the low GI diet was higher. Changes in body weight were similar in both diets, but the total fat body mass, as measured using the DEXA (Dual-energy X-ray absorptiometry) method, decreased by 500 g more with the low than with the high GI diet. The loss in body fat was most marked in the abdominal region and was accompanied by several favourable gene expression parameters (Ob, LPL, HSL). In addition, fasting total plasma cholesterol tended to be lower after five weeks on the low GI diet, and the triglyceride area under the curve after lunch was lower during the low GI diet than during the high GI diet. These observations suggest that low GI diets could be beneficial in healthy overweight persons and could help in the prevention of metabolic disorders.

GI and II participate in the regulation of post-prandial lipid metabolism. A recent study showed that in ten healthy male volunteers, following the intake of isocaloric meals of different GI (35, 75, or 100) and II, a strong positive correlation appeared between apoB-48 plasma concentration and insulin plasma concentration over the six hour post-prandial period. In a follow-up study, a 3h hyperinsulinic, euglycaemic clamp was performed in five healthy male volunteers. A biphasic response was observed: first a markedly reduced level of plasma apoB-48 during the insulin infusion, and secondly a late accumulation of plasma apoB-48 and triglycerides. These observations suggest that portal and peripheral hyperinsulinism, a situation that follows the ingestion of high GI and II foods, delays and increases the post-prandial accumulation of intestine-derived chylomicrons in the plasma, and is involved in the regulation of apoB-48 triglyceride-rich lipoprotein metabolism, in the absence of any insulin resistance syndrome.

CORONARY HEART DISEASE

Changes in environmental conditions, such as the increasing availability of energy-dense, usually high-fat foods and the diminishing levels of habitual activity, appear to be responsible for the increasing prevalence of risk factors for coronary heart diseases (CHD). Low-fat high CHO diets are recommended to prevent weight gain in normal weight individuals and promote weight loss in obese individuals. The diets, however, may be as energy-dense as high-fat foods because of their high CHO content. Moreover, it has been argued that low-fat foods may decrease HDL-cholesterol and increase triglycerides in the blood and therefore have a negative effect on cardiovascular risk.

In the Health Professional Follow-up Study of 244 middle-age women, the GI was independently associated with CHD events after adjustment for age, smoking, total energy

intake, and other CHD risk factors (total fat, saturated fat...). CHD was better predicted by the GI than by the typical measures of total, simple, or complex CHO in the diet. The adverse effects of a high GI diet were most obvious in women with a BMI higher than 23.

In the Nurses Health Study (n = 75,521), GL was directly associated with risk of myocardial infarctions over a ten-year follow-up period, after adjustment for other CHD risk factors. There was a marked gradient of CHD risk from the lowest to the highest quintiles of GL (Figure 4). In diabetic women participating in the Nurses' Health Study (n = 4,055), 74 fatal and 129 non-fatal myocardial infarctions occurred over the ten years of the follow-up period. GL was directly associated with risk of myocardial infarction after adjustment for other CHO risk factors. Again, the GL was a better predictor of CHD than any other measure of CHO consumption.

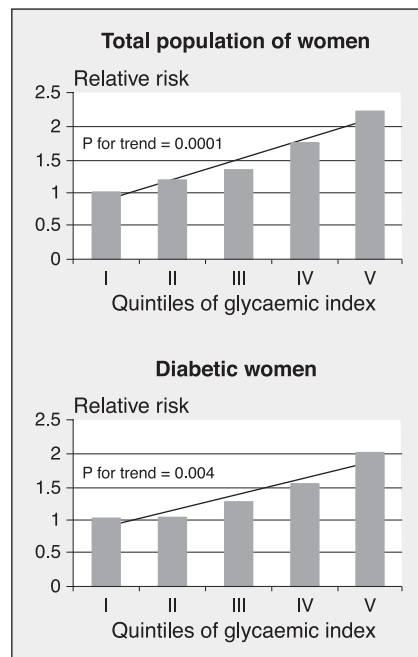


Figure 4. Relative risk of CHD according to GI.

A study examined whether high dietary GI was associated with hyperinsulinaemia, hyperglycaemia, dyslipidaemia and CHD risk in elderly men. Men aged 64-84 years (n = 646), without any history of CHD or diabetes, were followed prospectively from 1985 to 1995 for the incidence of major CHD (non-fatal myocardial infarction or death due to CHD). The overall GI and GL were assessed in this population using the cross-check dietary history method. A glycaemic load score was computed for each participant. The average GI in this population, with white bread as the reference, was 82. The GI was inversely correlated with fibre, fruit, and milk intake, while it was directly related to the intake of white bread and sugar

products. The GL was more strongly correlated with overall CHO intake than the GI. Individual GI was not appreciably associated with blood levels of total cholesterol, HDL-cholesterol, triglycerides, or insulin and glucose. During 4,572 person-years of follow-up, 94 cases of CHD were documented. The risk ratio for CHD was 1.11 for the highest, compared to the lowest, tertile of GI. The GL was not associated with CHD risk.

DIABETES

Diabetes mellitus is defined by elevated circulating glucose concentrations that are associated with an increased risk of developing vascular complications. The contribution of post-prandial blood glucose to the abnormal hyperglycaemia (blood glucose excursions over physiological values) can be evaluated between 20% and 40%. The glycaemia of 60 type 2 diabetic patients and 12 healthy control subjects was followed throughout the waking hours (from 8 am to midnight). The post-prandial blood glucose excursions in diabetics clearly exceeded the responses in healthy volunteers. Over the whole study period, the excessive glucose area represented 38% more than normal values and the total duration of excessive hyperglycaemia was 13 hours and 28 minutes.

Following an oral glucose tolerance test (OGTT), the blood glucose concentration rises. A concentration greater than 11.1 mmol/l two hours after the load is indicative of a diabetic risk. Following a mixed meal, the level of hyperglycaemia that would reveal the risk of microvascular complications is not known but should be identified by future research. A study on 113 patients with early type 2 diabetes mellitus showed that plasma glucose levels were lower after breakfast than in the OGTT condition (8.3 mmol/l). The post-breakfast hyperglycaemia was significantly higher at 7 am than at 11 am, confirming an effect of time of day. This study suggests that post-prandial glucose concentrations associated with risk could be lower than previously thought, perhaps as low as 8.3 mmol/l, and that the first meal of the day is associated with very large post-ingestive glucose excursion, thus contributing disproportionately to increase in microvascular risk and glycosylated hemoglobin elevation.

Glycosylated hemoglobin (HbA1c) is a crucial parameter that is a function of both fasting blood glucose and post-prandial blood glucose levels. Diabetic patients have HbA1c levels above normal values. This marker of poor glycaemic control is a correlate of the complications of diabetes. When a patient has a level of HbA1c equal to 8%, instead of the normal value of 6%, then it is important to improve glycaemic control and reduce the HbA1c level. If HbA1c can be decreased by only 0.5% absolute units, then the improvement represents 25% of the 2% absolute units that is needed; if the HbA1c level is decreased by 1%, then the improvement represents 50% of what is needed. These changes constitute important goals for the treatment of diabetic patients and should be pursued. Dietary advice can contribute to improving the metabolic status of diabetic patients; in particular low GI foods alter post-prandial blood glucose in such a way that several metabolic improvements are observed.

A meta-analysis of 11 studies (carried out between 1987 and 1992) published in 1994 lists the following improvements: a 16% decrease in mean blood glucose levels, a 20% decrease in urinary C-peptide, a 9% fall in HbA1c, a 6% decline in total cholesterol, and a 9% fall in triglycerides. As a consequence, every means to improve post-prandial blood glucose levels should be included in the treatment of diabetic patients. Although several pharmacological agents, both specific (e.g. alpha-glucosidase inhibitors, glinides, humalog, nasal or pulmonary insulin, GLP-1, Amylin, etc.) and non-specific (e.g. SU, Metformin, Thiazolidine-diones, long acting insulins, etc.) can be used, the dietary aspects of the treatment should be strongly emphasized. The selective use of low GI foods is a well-documented dietary approach to the problem. Earlier strategies included limiting CHO intake, spreading CHO intake over the waking hours, selecting high dietary fibre foods, etc. The low GI diet offers a particularly flexible and efficient solution to dietary management of the post-prandial blood glucose response. The selection of low GI foods affords efficient control over post-prandial insulin and glucose excursions. As opposed to high GI foods, low GI items induce only moderate or low glucose elevations following intake, which in turns elicit minor regulatory insulin output. The large increases in glycaemia observed after consumption of high GI foods are often followed by a subsequent decrease in glycaemia values below baseline. In contrast, after intake of low GI foods, the moderate elevations in blood glucose are followed by a slow return to baseline values, without any sign of hypoglycaemia. The sustained glycaemia level following the intake of low GI foods could be the origin of positive effects on satiety, mood, cognitive performance and vigilance reported in both diabetic patients and healthy control subjects. Improving post-prandial blood glucose excursions also improves fasting blood glucose levels.

In diabetic patients with good glycaemic control, however, sucrose taken during a mixed meal exerts no additional post-ingestive action on the response induced by the starch present in the meal. In addition, sucrose and honey included in breakfasts ingested by type 2 diabetic patients produce no additional acute hyperglycaemic response beyond the effect produced by bread.

The variations of the GI of the diet were studied in 2,810 European outpatients with type 1 diabetes mellitus. Possible relationships with HbA1c and serum lipid concentrations were investigated. The GI was calculated from a 3-day dietary record obtained from participants in the EURODIAB Complications Study, an epidemiological European Union Project including 31 centres throughout Europe. The GI of the patients' diet was positively correlated with the level of HbA1c. In Southern European patients with the lowest quartile of GI values, the HbA1c was 11% lower than in patients of the highest quartile. In other parts of Europe, the difference between extreme quartiles was 6%. Among serum lipids, only HDL-cholesterol was independently related to the GI. Intake of bread, potatoes and temperate-climate fruits has the strongest impact on the overall dietary GI in European populations. In countries of Southern Europe, the intake of pasta also had an important impact. This large European study confirmed that in outpatients with type 1 diabetes, a low dietary GI is related to low HbA1c, independently of fibre intake.

Several differences in biological parameters have been observed between two comparable groups of type 1 ($n = 60$) versus type 2 ($n = 70$) diabetic patients in a Czech study. Both groups did not differ in age, gender distribution, or BMI, while duration of diabetes was significantly longer in type 1 patients. Family history of diabetes and myocardial infarction did not differ between groups. Systolic and diastolic blood pressure was higher in type 2, as well as total cholesterol and triglycerides, plasma uric acid and plasma ferritin. Hypoglycaemia and hypoglycaemic coma, retinopathy, symptoms of diabetic foot were significantly more frequent in type 1 diabetics. The prevalence of diabetic nephropathy and neuropathy was the same in both groups. In spite of the longer duration of diabetes in the type 1 group, the data indicate lower cardiovascular risk in type 1 than in type 2 patients of comparable age and sex. The Czech investigators suggest that patient education and diet therapy should be different in type 1 and type 2 diabetes mellitus, because of the numerous differences in associated risk.

According to the hyperglycaemia-pancreatic exhaustion hypothesis, the pathologic pathway of type 2 diabetes mellitus includes prolonged hyperglycaemia and hyperinsulinaemia. Thus, the physiological impact of foods on post-ingestive glucose and insulin levels should be integrated in prevention and treatment strategies.

Both acute and chronic effects of low GI foods have been confirmed by animal experiments. The GI of various foods (waxy corn, mung bean, wheat) have been compared to a glucose standard in laboratory rats. The GI of mung bean is considerably lower than that of glucose and waxy corn. The insulin index of these foods parallels the GI. After chronic exposure, it has been confirmed recently that dietary amylose-amylopectin starch content affects glucose and lipid metabolism and adipocytes size and metabolism of healthy and diabetic rats. The effects in animals are consistent with the data obtained from human subjects.

In summary, low GI foods or diets favourably affect several biological markers in diabetic patients. These markers include plasma glucose, plasma insulin, HbA1c, blood lipids, adipocyte metabolism as well as satiety and control of food intake.

OBESITY

Obesity is a severe public health problem in all industrialised countries, as well as in developing ones. The prevalence is extremely high in adults (in certain countries, 50% of adults are overweight). In children, the prevalence of obesity and particularly massive obesity is increasing rapidly. Dietary factors seem to play a crucial role in this trend, along with other aspects of lifestyle (inactivity). The recommended CHO-rich, and fibre-rich diet can induce weight loss in overweight persons, when it is sustained over weeks or months. Among the mechanisms that can contribute to the body weight reducing effect, the spontaneous reduction in energy intake due to a low energy density (large volume) of the diet probably plays a crucial role.

A recent meta-analysis of low-fat diets concluded that a decrease of 10% in fat energy was associated with a reduction of body weight of 16 g/day, leading to a body weight loss of 1.4 kg over three months, or 2.8 kg over six months, provided the diet is followed without any energy compensation. When energy from dietary fat decreases, then energy from CHO is likely to increase in proportion. The impact of different types of CHO on risk factors for obesity and other metabolic diseases remains to be investigated. Epidemiological data have shown repeatedly that sucrose intake is negatively correlated with the BMI in children and in adults. A high sucrose intake usually co-exists with a low intake of fat (the sugar-fat see-saw) and a low prevalence of obesity. The impact of starch, as compared to sugars, on body weight control has been recently investigated.

A pilot study investigated the effects of ad libitum intake over 14 days in nine post-obese and eleven never obese normal-weight women. Three different diets were prescribed: high fat, high starch, and high sucrose. The high starch diet induced a decrease in energy intake and body weight when compared to both other diets. The AUC for glucose and non-esterified fatty acids decreased on the high sucrose diet. No difference appeared in the insulin AUC. The triglyceride AUC was higher in patients on the high fat and high sucrose diets than on the high starch one. After 14 days on the high sucrose diet, 24h energy expenditure and leptin concentrations were higher than in the other conditions. This short study concluded that high starch and high sucrose diets exerted no adverse effects on post-prandial glycaemia, insulinaemia and lipidaemia, compared with the high fat diet. A rich diet might increase energy expenditure and improve glycaemia, but exert adverse effects on lipidaemia, compared to a starch-rich diet.

The CARMEN study expanded these observations to a larger population and over a longer period of time. The CARMEN study was a large scale, multi-centre investigation of the effects of various diets on body weight and metabolic parameters. It was carried out in five European countries with the aim of testing the effects of reducing the fat and increasing the CHO content of the diet on body weight and blood lipids in overweight individuals; in addition, the impact of changing the CHO simple to complex ratio of the diet was investigated. A total of 316 overweight men and women (BMI 26-35) were followed during 6 months. Four groups were compared: low-fat high simple CHO, low-fat high complex CHO, control, and seasonal control. The objective of the intervention was to maintain the habitual dietary intake in the control groups, to reduce habitual fat energy intake by 10% in the two low-fat groups and at the same time to bring the simple/complex CHO ratio to 1.5 in the high simple CHO group and to 0.5 in the high complex CHO group.

A shop system was developed in order to provide appropriate foods (100-150 appropriate foods for each group) to the otherwise free-living populations. The subjects visited the shops once a week and obtained 70% of their total energy intake from the shop foods. The low-fat groups were offered a variety of low-fat alternatives to regular products (like cheese, spreads, desserts and mixed dishes). The high simple/complex CHO ratio group was offered soft drinks, sugar-sweetened cereals, desserts, sweets, jam, sauces, sugar and candies. The high complex/simple CHO ratio group could obtain light soft

drinks, sugar-free products, cereals, pasta, rice and vegetables. This shop system was very effective in changing the composition of the diet in the various groups over 6 months. Fat intake was reduced by 10.2% in the low-fat high simple CHO group and by 7.9% in the low-fat high complex CHO group. Energy from simple CHO intake increased by 7.2% in the high simple CHO group, and decreased by 3.5% in the high complex CHO group. By contrast, energy from complex CHO increased by 1.2% in the high simple CHO group and by 8.3% in the high complex CHO group.

At the end of the 6 month intervention (drop out rate 19%), there was no change in body weight in the control groups; modest weight losses (0.9-1.8 kg) were obtained in the two low fat groups; amount of body weight loss and loss of body fat were not different between the two low fat high CHO groups (complex versus simple CHO). Neither diet induced any detrimental effects on blood lipids (total cholesterol, HDL and LDL cholesterol, triglycerides). There were no changes in blood lipids in any of the groups. The results of the CARMEN study show that a modest body weight loss can be achieved on an ad libitum low-fat diet, without negative effects on blood lipids. The increased CHO intake did not lead to weight gain, in agreement with epidemiological data documenting the inverse relationship between CHO intake and body adiposity. The simple or complex nature of CHO does not seem to differentially affect body weight regulation and health, as was previously thought.

A novel approach to the obesity problem may involve reductions in dietary GI or GL. Acute feeding studies have shown that the rate of CHO absorption after a meal is inversely proportional to satiety and directly related to voluntary energy intake in the post-prandial period. A recent study explored the hormonal and metabolic changes that occur after consumption of isoenergetic meals differing in GI and GL. Obese teenage boys participated in three test meals of low, medium or high GI. They ate 53% more energy in the five hours after the high GI meal compared to the medium GI meal, and 81% more energy after the high GI meal compared to the low GI meal. The changes in energy intake were associated with different metabolic profiles: blood glucose and fatty acid concentrations were low, while counter-regulatory hormones were elevated 3 to 5 hours following the high GI meal when compared to the low GI meal. This study suggests that the metabolic consequences of a high GI meal limit the availability of metabolic fuels in the post-absorptive period and stimulate overeating.

One way to account for the effects of low GI foods on appetite and subsequent intake is the hypothesis that it significantly retards the hunger signal that will trigger the onset of the next meals. The duration of post-meal satiety is related to post-prandial glycaemic profiles. After the fuel ingested in the preceding meal has been used (for oxidation and storage), a "hunger signal" appears and precedes the start of the next meal. This hunger signal is a transient (about 5 minutes in duration), modest drop in blood glucose, which is thought to reflect a sudden decrease in immediately available glucose. According to this hypothesis, the duration of the satiety state that follows food intake depends on glucose utilization (oxidation and storage) and on the amount of glucose spared by fat

oxidation. The spontaneous duration of the post-meal interval, as assessed in time-blinded subjects, provides a marker of the satiety power of foods. This method has been insufficiently used up to now to study the satiety induced by foods of equal energy and nutrient content but differing in GI. The satiating effects of foods are usually evaluated by means of ratings of subjective sensations. In a study to be published soon, it was established that a low GI breakfast biscuit induced moderate hunger sensations over the morning.

The effects of energy restricted low and high GI diets were investigated in an inpatient crossover study of one-week duration. Overweight to moderately obese young men with stable body weight over the previous six months participated in this study. Following a two-day period of baseline observation of their spontaneous diets, the subjects were fed either high or low GI diets containing 50% of their estimated total energy requirements for six days. Resting energy expenditure was significantly lower in young obese men following the high versus the low GI diet (7.38 versus 7.78 MJ/d). In addition, nitrogen balance tended to be more negative in subjects on the high compared to the low GI diet (−9.7 versus +25.7 mgN/kg-d). These observations suggest that the physiological adaptations to energy restriction can be modified by GI and that low GI diets could be better tolerated over the long-term.

Body weight decreased more over 12 weeks in 15 obese female subjects when the prescribed diet was low GI compared to high GI, while fasting insulin level decreased more on the low GI diet. The dietary prescription was controlled for total energy and macronutrient content. Obese children lost more weight on an ad libitum low GI diet than patients assigned to an energy-restricted low-fat diet. These studies suggest a role for GI and GL in the regulation of food intake and body weight.

In rats, it has been shown that following breakfasts of contrasting GI levels, animals ate more in the 180 minutes following a high GI than a low GI meal, thereby confirming the effect of GI levels on post-meal satiety and eating behaviour.

GI AND MENTAL PERFORMANCE

It has been repeatedly demonstrated that having breakfast is associated with improved memory and mood in the morning, as compared to missing breakfast. This has been confirmed in both children and adults. For example, 11-13 years-old children remembered more words half an hour after a breakfast of sugar-sweetened cornflakes. This effect had disappeared 90-120 minutes after breakfast. The suggested hypothesis to account for these data is that mental functions could be facilitated by the rapid rise in blood glucose that follows breakfast. In agreement with this notion, it has been shown that young adults exhibited poor memory after missing breakfast; by contrast, ingesting a glucose drink improved memory in subjects who had missed breakfast. Memory performance two hours after breakfast correlates with blood glucose level. Does the GI exert an effect on mental performance in the minutes and hours that follow a breakfast or any other meal?

Low and high GI breakfasts that provided 50 g of available CHO were compared in 408 young women. Memory and vigilance were better following breakfasts containing a greater amount of fibre. Post-meal mood (30-120 minutes) was not affected by the GI conditions, however subjects with higher levels of blood glucose had better mood later in the morning. Other mental tasks are affected by blood glucose level: focused attention, sustained attention, face recognition, maze learning, and arithmetic ability. It is possible that the degree of cognitive demand or mental effort required by a task may predict its susceptibility to enhancement by glucose and other metabolic substrates. In relation to the haemoglycemic response to a glucose load, a clear association between the rate of post-apex fall and cognitive performance has been demonstrated. Experiments have examined the relationship between glucose levels and cognitive demand. In these experiments, demand was typically manipulated using serial subtraction tasks, where subjects are required to repeatedly subtract a fixed number from a given start number. Using both subjective and objective measures, it has been established that the amount of mental effort required for serial subtraction of three (Serial Threes) is less than that involved in serial subtraction of seven (Serial Sevens).

A first study examined the interactions between glucose administration (versus placebo), cognitive performance and mental demand required to perform three tasks. Participants rated Serial Sevens as the most mentally demanding, followed by Word Retrieval, then Serial Threes. Glucose intake significantly improved performance in Serial Sevens, and a trend appeared for improved performance in Word Retrieval. Pre-task glucose levels were significantly correlated with total number of subtractions during the Serial sevens task in both the glucose and placebo conditions. Performance in the Word Retrieval Task was positively related to pre-task blood glucose, but only in the placebo condition. The magnitude of fall in glucose levels during the tasks also correlated positively with the total number of subtractions in both the Serial Threes and Serial Sevens tasks in the glucose condition only. Word Retrieval performance was unrelated to the fall in blood glucose in either condition. In another study, changes in blood glucose were compared during various mental tasks (Serial Sevens, key-pressing tasks, short interval Word Memory, Verbal Fluency task). Again glucose intake, as compared to placebo, significantly improved performance on Serial Sevens, and a trend for improved performance appeared in Word Retrieval. No effect appeared for the Word Memory task. The Serial Sevens test resulted in a significant reduction in blood glucose in both the placebo and glucose intake conditions.

In other words, demanding mental tasks are improved following a glucose load as compared to a placebo. The amount of cognitive demand associated with task performance may be an index of its sensitivity to enhancement by glucose. In a reciprocal manner, blood glucose level decreases more rapidly when the subject is performing a demanding mental task, as compared to an easier one. A period of intense cognitive processing leads to a measurable decrease in levels of peripherally measured blood glucose. Although the effects of glucose loads have been studied in this context, much remains to be done in order to establish the cognitive effects associated with foods of low or high GI.

The positive effects of a high CHO breakfast were confirmed with mental tests performed in a group of 99 Spanish schoolchildren (aged 10-13 years). The children whose habitual breakfast CHO density was higher than average (more than 22 g CHO per 1,000 kcal) performed better than children with lower CHO breakfasts in tests of reasoning included in the TEA-1 test of scholastic aptitude. Their total score in this test was also improved. The results suggest that breakfasts supplying inadequate amounts of CHO might negatively influence aptitude and performance in schoolchildren. The GI of high versus low CHO breakfasts in this population were not known however.

It is interesting that the differential effects of blood glucose levels on physical and learning performance have been confirmed by animal studies. Glucose is the major source of energy for the brain and is essential for the optimal functioning of the central nervous system. A series of experiments carried out in rats demonstrated how physical and learning performances are affected by post-ingestive glycaemic responses. While most studies of the action of glucose on memory and learning have used oral glucose solutions, the present series of tests has investigated the different impact of various CHO. In particular, the role of low GI foods is of special interest in this context, because the slow release of glucose from the intestine may facilitate performance. Several groups of rats were fed commercial foods with different CHO compositions and GI. These foods were served as the first meal of the rats' activity phase (the equivalent of breakfast in humans) and remained available for 30 minutes. Then the animals fasted for 150 minutes before participating in physical or learning ability tests. After low GI biscuits, rats performed significantly better in the Locomotor Coordination test (escape from water), and in three learning tests (Aversive light avoidance test, Morris Water Maze test, learning a task following an exhausting 10-minute swim). These tests represented different tasks, different motivations, and different criteria of success. It appears that the animals were more efficient after low GI food intake in treating information and changing their behaviour in order to control their environment. The mechanism linking the GI of breakfast foods to post-meal physical and learning performance remains to be elucidated.

The above-described studies were performed in healthy individuals. In type 2 diabetes mellitus, cognitive impairments are often reported, including selective attention deficits, verbal and visuo-spatial memory deficits. Impaired glucose tolerance has been identified as a predictor of cognitive impairment with age. Interestingly, recent studies have shown that cognitive deficiencies in patients with poor glucose tolerance are not necessarily permanent correlates of the condition, but can be reversed by short-term (1-2 months) treatment with oral hypoglycaemic agents. These observations suggest that at least some cognitive impairment is associated with ongoing glucose regulatory status rather than permanent anatomical functional alterations produced by diabetes.

In healthy subjects, variations in normal glucose regulation capacity could also affect mental functions. This has been investigated in a sample of elderly individuals divided in two groups on the basis of glucose recovery index. Individual blood glucose levels at 60 minutes post-ingestion were subtracted from individual baseline blood glucose levels

following the consumption of 50 g glucose. The subjects with the highest recovery index were assigned to the “worse” glucose regulation group and the remaining subjects were assigned to the “better” glucose regulation group. Subjects in the “worse” glucose regulation group were impaired in several cognitive tasks relative to the subjects in the “better” regulation group. In young healthy volunteers, glucose regulation was assessed on the same basis as in the older sample, and again appeared as a good predictor of memory performance. Poorer glucose regulation was associated with memory deficits in young people. In addition to these data, recent observations showed that the impairment in memory reported in younger and older persons with poorer glucose control is independent of indicators (high cholesterol, triglycerides) of risk factors for cerebrovascular disease, a condition associated with brain lesions and cognitive dysfunction.

Individual differences in the ability to control blood glucose have a strong influence on the cognitive effects of ingesting 0-70g glucose loads. In one experiment, 21 year-old women consumed glucose drinks (0, 10, 30, 50, or 70g of glucose) after an overnight fast. Changes in blood glucose were monitored. The taking of the drinks, per se, did not influence cognitive performance. In some women with a low baseline blood glucose level, a rapid rise from a low blood glucose level prior to the tests improved reaction times in cognitive tasks. By contrast, again in women with low baseline levels of blood glucose, rapidly decreasing blood glucose levels during task performance were likely to shorten decision times. Rather than the amount of glucose consumed, individual differences in the ability to control blood glucose levels appeared to influence cognition. More work is needed in order to understand the mechanisms at play in the complex interrelations of glycaemia and cognitive performance.

GI AND PHYSICAL PERFORMANCE

The GI concept is also used in exercise physiology. Muscle glycogen depletion has been hypothesized to be one of the main contributors to the onset of fatigue during endurance exercise and it should therefore be avoided or retarded as much as possible. In a recent study, subjects were fed either low GI (lentils, GI = 29) or high GI (potatoes, GI = 98; glucose, GI = 100) single foods 60 minutes before exercise; in the low GI condition, endurance capacity was increased, possibly due to a slow release of glucose into the blood. When mixed meals with relatively low or high GI were ingested 3h before exercise, no difference in running endurance capacity was observed. An important shift in substrate utilization occurred, however: in the low GI condition, CHO oxidation was 12% lower while fat oxidation was 118% higher than after the high GI meal. Muscle glycogen increased by 15% three hours following high GI meals, but there was not significant increase in muscle glycogen three hours after the low GI meal.

Recovery of muscle and liver glycogen stores after prolonged exercise is an important goal of nutrition. CHO intake immediately after prolonged exercise facilitates the resynthesis of muscle glycogen. A study has been performed about substrate utilisation

after prolonged exercise. High (78) and low GI (36) CHO meals consumed in the 4h recovery phase following a 90 min run induced the same substrate utilisation when exercise was resumed after the recovery period. No difference in energy expenditures, CHO or fat oxidation was noted between these conditions. Insulin and glucose responses were significantly greater, however, in the high GI trial than in the low GI trial. These observations suggest that low GI foods may be advantageous before exercise because they induce a slow rate of glucose release into the systemic circulation, whereas high GI foods, that induce a higher insulin release, might accelerate muscle glycogen resynthesis rate after prolonged intensive exercise.

An alternative hypothesis attributes fatigue during prolonged exercise to a central (brain) governor, the function of which is to prevent bodily damage. The central governor regulates the mass of skeletal muscle that is activated and then determines the appropriate exercise intensity that is safe under the prevailing conditions: less muscle mass is activated during hypoglycaemia, and more when muscle glycogen stores are intact. According to this hypothesis, the GI of CHO ingested prior to exercise does not influence subsequent exercise performance provided CHO is ingested during exercise so that hypoglycaemia is prevented. Although the ingestion of CHO of different GIs either before or during exercise may cause slightly different metabolic responses, no evidence exists that such differences influence subsequent exercise performance.

FACTORS THAT MODULATE THE GLYCAEMIC INDEX

INDIVIDUAL FACTORS

The glycaemic response to a meal is determined by individual factors (insulin sensitivity, β -cell function, gastrointestinal motility, physical activity, metabolism of previous meals, day-to-day variation in metabolic parameters, etc.). Regulation capacity of glucose metabolism varies even in healthy subjects and is crucially impaired in diabetes. Although the GI responses in healthy versus diseased subject groups are different, it has been established that the GI values for the same foods are highly correlated regardless of the subjects' glucose regulation capacity.

FOOD FACTORS

The original dietary fibre hypothesis predicted that CHO foods would result in different physiological responses, notably lower glycaemic responses for the same amount of high fibre, less processed foods. In addition, several food specific factors affect the GI: amount of CHO, volume, form, biological source and digestibility of starch, nature of sugars, presence of fat and protein, fibre, acidity, anti-nutrients, etc. (Table III). Often, complex CHO act like simple sugars.

The presence of particular food components can be critical, among which viscous dietary fibre, organic acids (formed, added, intrinsic), and anti-nutritional factors. The type of CHO substrate is influenced by genotype and maturity (e.g. fruits, berries, legumes) and sugar addition. For example, different apple varieties have a broad range in GI values

Table III. Food factors influencing glycaemic responses

Amount of carbohydrate	Cooking/food processing
Nature of the monosaccharide components	Degree of starch gelatinization
Glucose	Particle size
Fructose	Food form
Galactose	Cellular structure
Nature of the starch	Other food components
Amylose	Fat and protein
Amylopectin	Dietary fibre
Starch-nutrient interaction	Antinutrients
Resistant starch	Organic acids

(50-70). The maintenance of botanical integrity plays a role, as in cereals and vegetables. For example, boiled intact barley has a GI of 30 while barley flour bread has a GI of 100. Starch interactions are important: starch crystallinity and physico-molecular interactions (as in pasta products). Food-mediated effects on gastrointestinal motility (e.g. particle size, fat, viscous fibre) and post-prandial CHO metabolism (e.g. variations in the metabolism of different sugar moieties and the effect of protein on insulin secretion) can also influence the GI.

The RAG and SAG fractions

Studies that have demonstrated the benefits of low GI diets have predominantly investigated slowly digested starch. The rate and extent of starch digestion is determined by the botanical origin of the product and type of food processing to which it has been submitted (Figure 5).

The glycaemic CHO fraction, which is available for absorption in the small intestine, is measured as the sum of sugars and starch, excluding resistant starch (RS). The glucose fraction can be divided into rapidly and slowly available glucose (respectively RAG and SAG), in vitro analysis which reflects the likely rate of release and absorption of glucose in the small intestine. Analytical procedures have been developed to characterise dietary CHO with respect to chemical composition and likely gastrointestinal fate. The RAG and SAG measures can be considered as describing the physicochemical characteristics of foods, which in turn reflect their likely physiological fate.

The hypothesis is that the RAG fraction is rapidly (within 20 minutes) released and absorbed and is a major determinant of the glycaemic response (Figure 6). By contrast, the SAG fraction is released and absorbed slowly and is not expected to contribute to the glycaemic response. RS does not elicit any glycaemic effect, since it is not absorbed. The physico-chemical approach to characterising CHO focuses solely on the contribution of the CHO component of foods in describing their GI values, and does not describe any of the numerous non-CHO nutrients that can also have an effect. They are mainly appropriate for

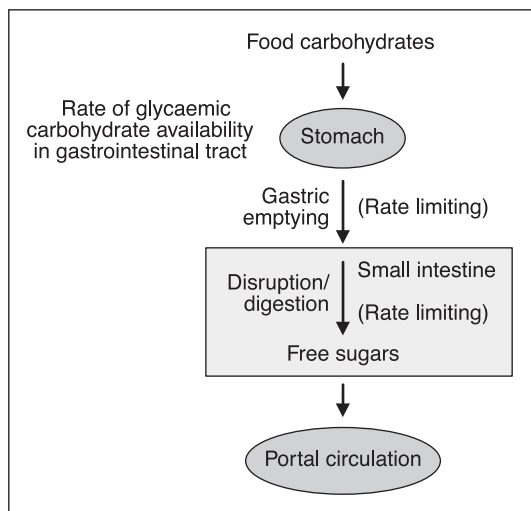


Figure 5. Rate of CHO availability. (From K. Englyst.)

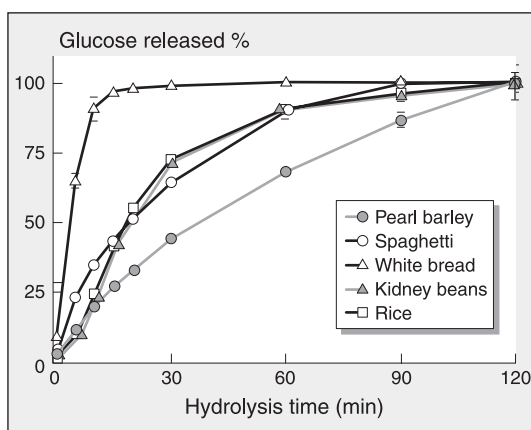


Figure 6. Glucose release in five foods. (From K. Englyst.)

the identification of the mechanisms responsible for GI values of different foods, and especially in distinguishing between foods that have low GI values due to a high content of starch that is slowly digested (high in SAG). By contrast, caution is required when applying these measures to the prediction of glycaemic responses to meals and diets, as this relationship will be confounded by a combination of other meal mediated factors and the effects of within and between subject variations in gastrointestinal function and glucose tolerance.

These notions have been confirmed by an experimental investigation: a given percentage change in RAG intake was associated with the same percentage change in glycaemic response while the SAG fraction made no contribution to the glycaemic response. It remains necessary to determine how the RAG and SAG fractions interact with other

physico-chemical properties of complex foods in determining the GI. Various cereal products, representing a range of ingredients and processing techniques, were used for the investigation. Neither the starch or sugar fractions were correlated with GI, but both RAG ($r = 0.737$) and SAG ($r = -0.794$) were. A given percentage change in RAG was associated with the same percentage change in GI.

The RAG, SAG and other CHO fractions may provide a tool for the assessment of "CHO quality", based on both the chemical and physico-chemical properties of CHO. Taking into account the CHO fractions contained in foods should provide not only an indication of their likely GI value, but also suggest a food related mechanism to account for the effect. Caution is required when applying these notions to meals and diets, as the basic relationships can be confounded by a combination of meal and subject specific factors.

During food processing, physico-chemical treatments may have a profound impact on the profile of starch digestibility (Figure 7). For cereal foods, alterations in moisture of the dough, baking time and temperature, pressure, and mechanical treatments are important. A recent study has shown that a special biscuit manufacturing technique was the only process that allows the preservation of the SAG fraction over the different steps of the process, whereas in bakery products and ready-to-eat cereals, the SAG was progressively converted into RAG during the successive steps. In these various types of products, the food processing influences the extent of starch gelatinisation. In bread, croissants, brioche, corn flakes and extruded ready-to-eat cereals, starch is totally gelatinised, while in some crackers and biscuits, starch is moderately and lightly gelatinised, respectively. This is explained by the main physico-chemical parameters of the food processing. In bakery products and corn flakes, high temperature baking of the high moisture dough leads to starch alteration. In extruded ready-to-eat cereals, high mechanical shearing at high pressure is responsible for the main changes of the starch. In biscuits, however, very little water is available in the dough, which limits starch gelatinisation in spite of high baking temperature. In crackers, moderate gelatinisation of starch occurs because of a medium level of moisture of the dough prior to baking.

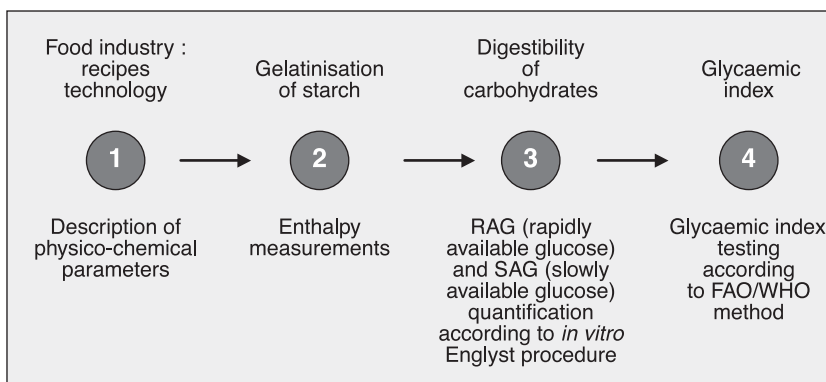


Figure 7. Food technology and GI. (From V. Lang.)

Table IV lists the GI and II of several cereal products, tested according to FAO/WHO methodology, using glucose as the reference. The GI of the foods corresponds to the level of gelatinisation of starches and is correlated with the II. The GI and II of the tested products vary between and within the four types of cereal foods studied. Ready-to-eat cereals have the highest GI, crackers and bakery products have medium GIs, and most biscuits have a low GI. Among ready-to-eat cereals, extruded products have the highest GI values, while muesli has a medium GI. Rotary moulded and sheeted biscuits have a low GI, while jam-filled biscuits have a higher GI. Some varieties of biscuits show a very low GI (28). Biscuit manufacturing is a process that leads to moderate or slight starch transformation. Therefore, it produces low GI foods containing partially ungelatinized starch that is digested slowly. A different set of six types of biscuits was studied in 11 healthy, normal weight adults (18-38 years; BMI 22.5), according to the FAO/WHO recommended protocol using sample calculations of the IAUC at two hours intervals; again, a significant correlation appeared between the GI and the II of the six products.

Table IV. GI and II of cereals and biscuits

Product	Manufacturer	Origin	GI	II
Ready-to-eat cereals				
Chocapic	Nestlé	France	84	86
Corn Flakes	Kellogg's	France	93	69
Energy Mix	Quaker	France	80	83
Special K	Kellogg's	France	84	97
Alpen original	Wheetabix	UK	55	76
Bakery product				
Baguette with butter & jam	Bakery	France	62	77
Baguette with chocolate spread	Bakery	France	72	81
Pain au lait	Pasquier	France	63	74
Crackers				
Triunfo cracker	Danone	Brazil	64	106
High calcium cracker	Jacob's	Malaysia	52	86
Biscuits				
Barquette Abricot	LU	France	71	77
Prince Chocolat	LU	France	53	77
Véritable Petit Beurre	LU	France	51	72
Prince Meganana Chocolate	LU	Spain	42	75
Prince Petit Dej Vanille	LU	France	45	72
P'tit déjeuner honey & chocolate	LU	France	45	66
Thé	LU	France	41	72
Gran'Dia Banana and honey	Danone	Brazil	28	61

Viscous fibre and gut fermentation

Generally speaking, high fibre foods might have a low GI because of their high viscosity and their physical structure. Another mechanism involved could be gut fermentation. A study investigated these influences in 10 patients with type 2 diabetes mellitus patients (54 years old; BMI 26; diabetes duration 5 years). The patients were treated with diet alone or diet plus glibenclamide. The patients consumed, in random order and at one-week intervals, four isoenergetic diets differing in water-soluble fibre content. The study established that, in contrast to diets enriched with added guar (a viscous fibre) or hydrolysed guar (a fibre that is not viscous but induces colonic fermentation), only a diet made of naturally fibre-rich foods (natural fibre is viscous, it ferments, and reduces the accessibility of starches to amylolytic enzymes) improved post-prandial plasma glucose (–63%), insulin (–31%) and lipid metabolism (66% reduced triglycerides). Neither delayed gastric emptying nor colonic fermentation appeared to play a role in the effect of dietary fibre on GI. This study suggests that only fibre-rich foods can help correct metabolic disturbances during the post-prandial period, whereas artificially enriched foods do not exert any effect. Naturally fibre-rich foods might thus contribute, via this mechanism, to the prevention of the metabolic syndrome.

Digestion in the small intestine

One study showed the possibility of using the stable isotope technology to investigate the processing of various types of starches in the small intestine. This in vivo study was carried out in human volunteers. The digestion of highly digestible corn starch and the resistant starch sources Hylon VII and Novelose, naturally enriched in ^{13}C was compared by measuring the serum response to exogenous glucose and the $^{13}\text{CO}_2$ excretion in breath. After administration of 40g starch or ^{13}C -enriched glucose, glucose and exogenous glucose concentrations in serum and $^{13}\text{CO}_2$ excretion in breath were monitored during 6 hours. ^{13}C GI for digestible corn starch, Hylon VII and Novelose was calculated to be 82, 44, and 43 respectively. Comparison of the 6h cumulative percentage dose recovery in breath revealed that 28% digestible corn starch, 23% Hylon and 26% Novelose were digested in the small intestine. The method shows that digestion of resistant starch in the small intestine amounts to approximately 50%.

Breads and grains

Breads, whether whole-grain or made of ultra-fine-ground whole-grain wheat flour, result in high GI, although the AUCs are lower than after the intake of glucose. Intake of breads made with ultra-fine-ground whole-grain wheat flour resulted in plasma glucose and insulin responses as well as areas under the curve similar to those following the intake of conventional whole-grain wheat bread. The particle size of whole grain wheat flour did not substantially affect the glycaemic response. Oatrim, a fibre extract developed to contain

higher levels of soluble beta-glucans than oats, lowers plasma glucose, insulin, and cholesterol after four weeks of consumption.

Further investigation of grains and extracts in non-diabetic men and women showed that GI values were lower following the intake of oats, barley, and oat and barley extracts than the responses to glucose solutions. Insulin responses to barley extract were the lowest, and were significantly lower than after the intake of a glucose solution. Responses to other foods were intermediate. In conclusion, barley and oat extracts retain the beneficial GI effects of the grains.

When test meals composed of sweetened cereals were compared in overweight women, barley induced lower GI and II values than oats and glucose. IAUC for glucose were reduced by 15-30% by oats and 57-61% by barley. Barley also reduced the insulin response. Plasma glucose values were normalised in two women with impaired glucose tolerance after intake of oatmeal and barley. Particle size of the oats and barley had little effect on the responses.

Amylose

Consumption of products containing 70% amylose, compared with 70% amylopectin cornstarch, resulted in significantly lower plasma insulin and glucose responses in acute morning tolerance tests and after several weeks. In particular, consumption of products made with 70% amylose compared with 70% amylopectin cornstarch resulted in significantly lower plasma insulin and glucose responses. Average plasma glucose and insulin AUC after amylose test meals were approximately half of those observed following the amylopectin test meals. The amount of amylose necessary in a meal to allow a beneficial effect to appear is an important question. Recent tests have addressed this problem by feeding volunteers glucose or different breads made with 70% amylose cornstarch, standard cornstarch (30% amylose) and blends of the two starches (40%, 50% and 60% amylose starch). The lowest peak plasma glucose response occurred following the ingestion of bread containing 50% to 70% amylose starch, while the lowest AUC were observed after the 60% and 70% amylose starch breads. In addition, the post-ingestive insulin response was significantly lower after the 60% and 70% amylose starch breads as compared to glucose or the other breads. These observations suggest that the amylose content of the starch used in the acute meal needs to be greater than 50% in order to significantly reduce the post-ingestive plasma glucose and insulin response.

Pancreatic α -amylase

In order to understand the mechanistic basis of the observed differences in GI, studies have investigated the activity of pancreatic α -amylase, an enzyme critically involved in the initial stage of starch digestion. The pancreatic α -amylase's action is likely to be affected by several factors such as the botanical source of the starch, the food texture affecting the ability of starch granules to swell, and the amylopectin content. Full 3-D

structures for human and porcine pancreatic amylases are now available. They suggest that the active site region contains 7-11 subsites for sugar residues to ensure maximal binding. In addition, the enzyme seems to possess a starch-binding domain remote from the active site, which is probably important for tethering the enzyme onto its insoluble substrate. In a two-phase system such as soluble α -amylase acting on insoluble starch, the reaction mechanism involves a kinetically significant absorption step, and the reaction rate and enzyme concentration are related by a logarithmic equation, provided that the fraction of total enzyme molecules bound to starch is small. The catalytic efficiency of amylase acting on various botanical starches, in both native and gelatinised forms, has been assessed by using kinetic experiments.

Relative catalytic efficiencies of α -amylase are increased by heat treatment, but this effect is variable. For example, the catalytic efficiency for waxy rice increases by a factor of 13 whereas the increase is 235-fold for potato. Rice varieties, and in particular the amylopectin present in high proportions in waxy rice, are good substrates for amylase. In pre-heated wheat starch, the catalytic efficiency of amylase increases greatly above 65° but falls if the pre-treatment process is conducted above 75°. The fall certainly results from the formation of retrograded starch, which is a poor substrate for amylase. Retrograded starch can have a direct inhibitory action on the enzyme. Amylolysis is a complex process because of the many factors related to the physico-chemical properties of starch. An improved understanding of the enzymology of starch digestion may contribute to the development of novel “functional foods” capable of decreasing both GI and II after high CHO meals.

Sourdough

Sourdough leavening is known to reduce post-prandial glucose responses to wholemeal rye bread and pumpernickel bread, an effect that might be mediated by the presence of fibre. It is not known whether the effects of sourdough leavening are mediated by the presence of fibre and if the same effects could be replicated in refined wheat bread. A study performed in 8 healthy volunteers compared starch digestibility in wheat bread using two leavening methods (sourdough or *S. cerevisiae*), and two wheat flours (whole or white). The glycaemic response was measured over 120 minutes following ingestion of 50g CHO portions of the breads. A significant effect of type of leavening appeared, and the sourdough breads induced lower post-ingestive glycaemic responses than *S. cerevisiae*. The amount of fibre did not significantly affect the GI. Resistant starch levels were higher in sourdough compared to *S. cerevisiae* products. In vitro analyses revealed no difference in digestion rate, although the degree of polymerisation of sourdough products was slightly higher than that of *S. cerevisiae* counterparts. Sourdough leavening then reduces the GI of wheat bread independently from the presence of fibre.

Storage temperature

Most foods are processed and stored under different temperatures before consumption. Changes in starch structure can occur during this period and part of the starch that is normally digested can be converted into resistant starch. The GI of processed and stored foods (–20° for 30 days) has been examined in 10 healthy volunteers. Common cereal foods (polenta and spaghetti) and legumes (beans, chick-peas) were cooked. Standard tests of the GI and in vitro analyses of resistant starch and hydrolysis index were performed immediately after cooking and after 30 days of storage. The reference food was white bread. Storage increased the resistant starch content and reduced the hydrolysis index in all foods. After storage, the GI of legumes was reduced, that of spaghetti was unaffected, and that of polenta was increased. Further investigation revealed that the hydrolysis index and the rapidly digestible starch content of the foods predicted the glycaemic response. Negative correlations were also reported between GI and total dietary fibres on the one hand, and amylose content on the other hand. These latter factors are indirectly related to starch availability.

Nutrient and food interactions

Interactions between all components of the meal are important. Figure 8 presents the GI of six starch-rich foods (bread, potatoes, spaghetti, rice, lentils, and beans) measured in type 2 diabetic patients, when ingested alone or when included in a mixed meal. Although inclusion into a mixed meal tends to reduce the value of the GI, the relative GI values of the six foods remain similar.

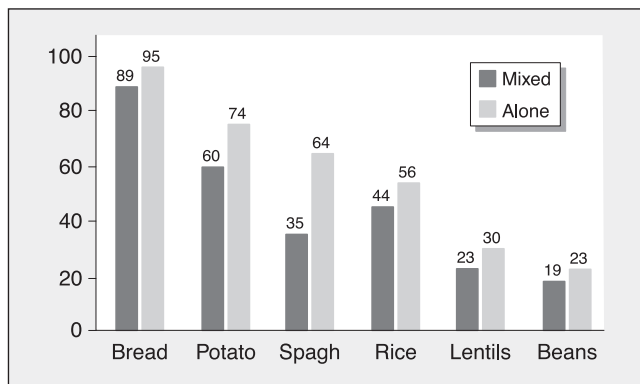


Figure 8. GI in mixed or single foods.

A moderate intake of wine lowers the glycaemic response that follows a mixed meal. Eight subjects participated in four mixed meals accompanied by one of the four following beverages: water, 11.9% ethanol solution, 11.9% ethanol red wine, and alcohol-free wine. Alcohol increased post-prandial blood acetate and triglycerides, while blunting

glucose levels. Alcohol-free wine increased blood acetate levels and lowered triglycerides. No significant difference was observed in post-meal lipid profiles. A moderate amount of red wine improved the post-prandial glycaemic profile in healthy persons, without any impairment of lipaemic control.

Milk

While milk has a low GI, it stimulates insulin secretion. Ingesting milk with a variety of CHO foods (pasta for example) is likely to modify the post-ingestive metabolic responses. The action of milk on insulin secretion needs to be acknowledged and its potential metabolic impact investigated.

Design of low GI food alternatives

Given the numerous factors that can modify the GI, it is suggested that the food industry should design low GI alternatives for common foods. It could be possible to lower the GI of starchy foods by using new genotypes with modified CHO composition and/or by optimising processing conditions (e.g. fermentation, minimal-processing). Low GI products could also be evaluated according to various qualitative differences, such as the II and the “second meal effect” that describes the reduced hyperglycaemia (accompanied by lower insulinaemia and triglycerides) when a second meal is taken following a first meal of low GI. This carry-over effect can act after several hours between meals (Figure 9). For example, it has been shown that an evening meal including either white bread (high GI) or barley (low GI) affects the blood glucose response to a standardised white bread breakfast ingested the following morning. The post breakfast hyperglycaemia is attenuated following the barley evening meal.

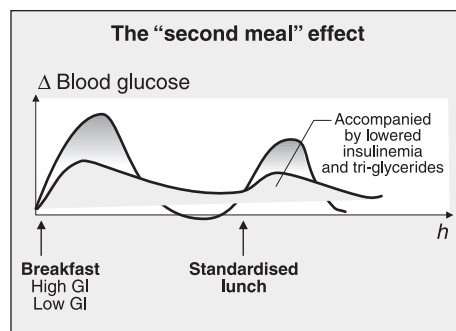


Figure 9. Second meal effect. (From I. Björck.)

Clearly, technological processes are of great importance in the final GI: fine grinding of grains or fruits, optimal gelatinisation of starch contribute to increasing the GI, whereas retrogradation, complexation of starch, and Maillard reactions could lead to a

decreased GI. It is possible to lower the final GI of foods by decreasing the bioavailability of starch by technological means. How fructose, sucrose, and lipids could be included in foods in order to decrease their GI has to be studied. The use of additives to reduce the digestion of starch can also be considered. These means could potentially produce adverse effects as well as a desired action on the GI. For example, the addition of fructose could create problems for hypertriglyceridemic patients. A potential atherogenic role of increased lipoproteins high in triglycerides (due to high fructose intake) in the post-prandial phase has been suggested. Technological means should then be strictly regulated so that the end products are consistent with a global nutritional benefit for consumers. Acceptable means include optimisation of starch treatment, optimisation of CHO environment, and limited addition of fructose, sucrose and fats.

PRACTICAL USE OF THE GI AROUND THE WORLD

The GI concept should be translated into everyday food intake behaviour. Several practical problems however make it difficult for consumers and patients to use the GI concept. Concerns are frequently expressed that the GI concept is too complex, that it introduces another burden on patients who may be led to ignore other important nutritional recommendations. Selecting foods according to their low GI value could induce a restriction in food variety. Finally, information about the GI of many familiar foods may be difficult to find, especially when novel foods are introduced.

Australia

These practical problems have been addressed by Australian experts over the last decade. They have demonstrated that these potential drawbacks can be overcome and that the GI concept can be used effectively for improving diabetes control and enhancing quality of life.

A recent study included 104 children, aged 10 ± 2 years, with type 1 diabetes mellitus. The hypothesis was that low GI diets would do better than CHO exchange diets for metabolic control and quality of life. The study was a prospective, randomised parallel protocol, comparing the effects of two diets on several metabolic (HbA1c, incidence of hypo- or hyperglycaemia, insulin dose), behavioural and quality of life parameters. The instructions given to the subjects in the low GI group emphasised low GI versions of foods that make a substantial contribution to CHO intake (breads, cereals, pasta, rice, fruits). Children were encouraged to eat regular meals and snacks based on preferred serving sizes of CHO foods to satisfy their appetite. A "serve" was the quantity of CHO food that fit into the child's hand. The recommendations were based on qualitative CHO intake using principles of the healthy food pyramid with an emphasis on low GI, aiming for a minimum of one low GI food per meal and per day (Table V). Diet food use was strongly discouraged, with preference for a moderate use of sugar sweetened products (with the only exception

Table V. Low GI dietary instructions

Carbohydrate (CHO)	Eat regular meals & snacks based on preferred serving sizes of CHO foods to satisfy appetite. A “serve” is the quantity of CHO food that fits into the child’s hand (which will be variable between individuals)
Recommendations	Based on qualitative CHO intake using principles of the healthy food pyramid with low GI emphasis, aiming for minimum of one low GI food per meal per day
Prescription	Nil prescription given – guide given to the number of serves at meals/snacks to ensure appropriate carbohydrate distribution and consistency but no specific quantity defined
Protein/fat foods	Not measured but eat in moderation Choose low fat sources where appropriate Not counted as a serve unless in pastry/battered/crumbed
Low CHO foods (most vegetables)	Identify low CHO food sources, eaten as part of a balanced diet
Diet foods (artificially sweetened)	Use strongly discouraged with preference for use of sugar sweetened products in moderation (only exception to this being diet drinks)
Refined/added sugars	Use in moderation in combination with mixed meals (1.5-2.5 tablespoons/day)
Literature provided	Basic booklet including list of low GI food sources Low GI foods listed rather than the actual GI values provided
Appetite	Eat extra CHO foods to appetite, particularly low GI foods
Recipe modification	No specific diabetes cookbook recommended Encouraged to modify existing recipes & moderate use of sugar Incorporate low GI ingredients where appropriate
Label reading	Focus on ingredient list and sources of sugars, fats, fiber & low GI ingredients & the order in which they appear on the label
Activity/exercise	Eat one extra serve of CHO food per hour of strenuous activity

of diet drinks). A booklet was provided including a list of low GI food sources. In addition, one extra serve of CHO food was allowed per hour of strenuous physical activity.

After 12 months, the children in the low GI group had significantly improved HbA1c levels compared to the children in the CHO exchange group (8.05% versus 8.61%), and lower rates of excessive hyperglycaemia (35% versus 66%). No differences appeared in insulin dose or hypoglycaemic episodes. Thus, the low GI diet lowered HbA1c without increasing the risk of hypoglycaemia. The quality of dietary intake was the same in both groups, and no restriction of food choices appeared in low GI subjects. Both parents and

children on the low GI diet reported better quality of life than the subjects on the CHO exchange diet. Children had no difficulties in selecting their own meals; fewer had difficulties in sticking to their diet after 12 months. Over half of the parents reported that the low GI diet had never been a source of tension or conflict within the family and never limited the types of familial activities performed. These results argue against the above-mentioned criticism about the low GI approach to the treatment of diabetes. A few children ($n = 53$) and their parents experienced both types of dietary approaches and expressed an overall preference for the low GI diet, compared to the CHO exchange diet. Their parents believed that the low GI diet lead to better control of blood sugar levels. The low GI diet was the preferred dietary regime that most parents and children selected to continue after completion of the study.

In Australia, public health authorities have sanctioned a programme for helping consumers to make informed choices about CHO foods. A GI symbol programme is being developed jointly by the University of Sydney, Diabetes Australia and the Juvenile Diabetes Foundation. This programme will provide guidance to consumers in their choice of CHO foods. Foods that meet specific nutrition criteria and have been tested for their GI by an accredited laboratory will be authorised to display the symbol. The actual GI value and a short explanation will appear next to the nutrition information box. The programme will endeavour to educate consumers about the importance of the GI. It will help the food industry to reformulate and develop low GI versions of their products. Australia appears to be the most advanced country in terms of knowledge of the foods' GI and publicising the information to the consumers.

Hungary

In Hungary, a few typical dishes have been investigated for their GI in recent years. The GI responses were studied in patients with type 2 diabetes mellitus treated with diet alone or with diet plus oral antidiabetic drugs. The data, obtained in successive experiments, indicated that the typical Hungarian dishes have acceptable GI and could be included in the diabetic regime. More foods need to be investigated in this country, in other types of subjects, and the overall GI still remains to be quantified.

France

The INCA survey was carried out in France over the 1998-1999 period and included seven-day food diaries filled by a representative population of 1,985 adults and 1,018 children. The overall GI value of the diet was computed by using published and industry-provided GI values. The GI for each meal and for each individual subject was computed. The end values represented nearly 95% of total CHO intake. The data revealed that the GI value of the diet was higher in males than in females, and higher in adults than in children, while no geographical difference appeared. The daily intake occasion with the lowest GI was the afternoon snack, as compared to other meals. Bread intake was associated with

increased GI while biscuit and dairy food consumption was associated with low overall GI. The overall GI of the diet in children was also positively affected by the intake of potatoes, sugar, sandwiches and pizzas. Some foods had contrasting effects on overall GI: for example, breakfast cereals and sugar were associated with high GI in children and low GI in adults. These relationships are difficult to evaluate, however, since they are to be understood in the context of the overall diet. In adults, the GI of breakfast cereals was lower than the average GI of the diet, whereas in children, the GI of breakfast cereals was actually higher than the overall GI of the diet. Heavy consumers of high-starch foods (mostly adults) had a high GI diet, whereas children and adults with a high intake of simple sugars had a low GI diet. In the population as a whole, overall GI was correlated with the BMI. This correlation disappeared after adjustment for age.

China

In China, the concept of GI is now used as a basis for nutritional education of type 2 diabetic patients. The GI of Chinese foods have been quantified in recent years, and expressed in comparison with a glucose standard. Outpatients with type 2 diabetes mellitus (n = 93) participated in a study concerning nutritional education. One group received standard advice plus GI advice, another group received advice on food exchange serving, and a third group served as control and received no dietetic advice. The education programme lasted 12 weeks and included lectures, interviews, and follow-up. After 21 weeks, patients receiving GI recommendations had improved biological parameters: fasting blood glucose had decreased by 15.1%, post-prandial blood glucose by 16.2% and HbA1c by 12.6%; TG had decreased by 5.85% and the lipid comprehensive index had diminished from 53 to 45.6. These changes were generally better than those observed in the food exchange group. No change in blood glucose level was recorded in the control group after 21 weeks. Hypoglycaemic medication was reduced by 50% in the low GI group (36% in the food exchange group and 14.3% in the control group). Following 21 weeks of training, 92% of patients had acquired some expertise about GI and found it easier to select foods on the basis of GI than by following the traditional food exchange method.

RECOMMENDATIONS

The Food and Nutrition Division of the FAO, in collaboration with the WHO, held an Expert Consultation on Carbohydrates in Human Nutrition in April 1997. A full report was published in May 1998. The report recognizes that the GI is a key indicator of the metabolic effect of CHO and can become a powerful tool in helping patients to make appropriate CHO food choices. The WHO report recommends the use of the GI as a method of categorising CHO as it provides information on the likely metabolic effects of that CHO.

In affluent societies, excess energy intake aggravated by physical inactivity is associated with an increasing prevalence of obesity, type 2 diabetes mellitus, and CVD. Excessive fat consumption is widely believed to be a major contributing factor in these disorders. As a consequence, several public health organisations (for example, the American Heart Association, the American Diabetes Association Guidelines) recommend a low-fat diet in the prevention and treatment of obesity and diabetes. A potential adverse consequence of these recommendations is a concomitant increase in carbohydrate foods with a high GI, thus increasing the GL and the overall GI of the diet. Selecting low GI foods is important when a significant decrease in dietary lipids is achieved.

An alternative to the current high saturated fat intake could be obtained by the replacement of foods rich in saturated fats by foods containing unsaturated fats. This dietary approach recommends replacing saturated fats by unsaturated fats rather than by CHO. The beneficial effects of fish oil have been demonstrated in the prevention of insulin resistance and/or abnormal lipid profile. Food selection allowing both a decrease in GI and a decrease in saturated fats in the diet could therefore exert beneficial effects but that remains to be investigated.

FOOD LABELLING

Labelling of foods and food products for GI is on the agenda, as it could help consumers to make informed choices. Experts should consider several questions in order to make GI labelling useful. The criteria for justifying GI labelling should probably include information on which foods should be labelled, and what minimum CHO quantity foods should contain per average serving. The methodology for determining GI should be standardised, for example the reference food, laboratory accreditation, the number and characteristics of experimental subjects should be sorted out. Other questions deal with GI values (should reference ranges or specific value obtained in an accredited laboratory be provided?), GI values for composite food products, information about the dietary context in which the food is eaten, labelling of fresh foods such as fruits and vegetables, individual and interpersonal variations in GI responses, variety in diet composition, etc. Claims should take into account the short and long-term effects of GI foods, and the place of CHO in the context of the food within the total diet. Educating the public to understand and use the GI is a challenge.

The recent interest for “functional foods” suggests that low GI foods could be associated with health claims. The actual health claim should be substantiated and validated according to national and international guidelines, and these should include advice on systematic, and transparent reviews for which the totality of the evidence is brought together, on how to evaluate the strength of the evidence, whether the evidence is convincing, probable, or insufficient; check lists on safety, clarity (not misleading), level of consumption, etc. Table VI presents types of evidence ranked according to scientific weight. Optimally, human intervention studies should confirm health claims.

Table VI. Categories of evidence ranked according to scientific weight

-
- Epidemiology - sectional
 - Experimental - effects on biomarkers
 - Studies on mechanisms
 - Interventions - short term
 - Interventions - definitive end points
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CONSENSUAL STATEMENT

Low GI diets have been shown to reduce fasting and post-prandial insulin, glucose and triglycerides. In addition, these diets may increase HDL-cholesterol and decrease total cholesterol, while improving insulin-mediated glucose uptake. Prospective studies have demonstrated that low GI CHO may improve insulin sensitivity in subjects with diabetes, obesity and CHD, as well as those at risk of CHD. Intervention studies have shown that VLDL concentrations are lowered. Low GI diets are thus associated with a wide range of benefits with respect to established metabolic risk factors.

Existing evidence supports the clinical utility of the GI concept, and warrants further concerted efforts on several fronts. It is crucial to obtain Grade A evidence from long-term, large, multi-centre controlled trials in order to determine the clinical effects of low GI foods in diabetes and CVD. Following the testing of foods and widespread dissemination of the results, the next step is the development of educational tools for health professionals and the general public. Long-term randomised controlled studies are also needed to examine the effectiveness of low GI/GL diets in the prevention and treatment of obesity and related complications.

During the international Workshop held in Bandol in February 2001, the participants felt that a consensual statement should be prepared in order to delineate the areas of agreement at the time of the workshop. The resulting document is presented below, along with the signatures of the participating experts.

Consensual Statement from the International Workshop “Glycaemic Index and Health: the Quality of the Evidence” held in France, February 2001.

An international workshop was organised in February 21-23, 2001, at Bandol (France) by Danone Vitapole (Research Center of Danone Group) and LU, with the technical contribution of the Food and Agriculture Organization of the United Nations. Many topics relating to the glycaemic index were debated by the 48 experts attending the workshop. Following these discussions, the participants formulated the following consensual statement:

“The glycaemic index (GI) provides a physiological basis for ranking foods according to their postprandial glycaemic effects. There are several hundred publications examining the physiological effects of foods with different GI, the large majority of which suggest that the GI concept has implications for public health.

We believe the current evidence indicates that the GI has practical utility and that differences in GI amongst foods may have important relevance to public health. Further basic and epidemiological research and large, multicentre, prospective, randomised, controlled clinical trials in relation to the GI are required in the following areas: weight management; prevention and management of cardiovascular disease, diabetes and cancer; cognitive function.

To facilitate these aims, the following need to be accomplished: a systematic and transparent review of the literature; standardisation of methodology; understanding of quality assurance in food processing.

We recognise that the clinical applications of glycaemic index have been questioned by some experts and health policy agencies, and we welcome their participation in the design and execution of future research. International initiatives would be the preferred option to achieve these goals involving collaboration between the food industry, health professionals and consumer groups.

The labeling of foods with GI, based on specific compositional criteria, is thought to be a valid way of communicating GI information to health professionals and consumers.”

Participants: Michal ANDEL, Harvey ANDERSEN, Mette AXELSEN, Kay BEHALL, France BELLISLE, David BENTON, Inger BJÖRCK, Jennie BRAND-MILLER, Furio BRIGHENTI, Peter BUTTERWORTH, Esteban CARMUEGA, Martine CHAMP, Janusz CIOK, Didier DESOR, Hans ENGLYST, Klaus ENGLYST, Gary FROST, Amandine HARBIS, David JENKINS, Sarbjit KUNAR, Vincent LANG, Taous LASSEL, Anthony R LEEDS, Irene LENOIR-WIJNKOOP, Simin LIU, Ana María LOPEZ SOBALER, Jeanine LOUIS-SYLVESTRE, David S. LUDWIG, Claude MESSIER, Guy NANTEL, Timothy NOAKES, Anne RABEN, Gabriele RICCARDI, Salwa RIZKALLA, Andrew SCHOLEY, Elena SEBOKOVA, Gérard SLAMA, Lucjan SZPONAR, Monika TOELLER-SUCHAN, Marleen VAN BAAK, Roel VONK, Hester VORSTER, Elisabete WENZEL DE MENEZES, Thomas WOLEVER, Ching Lin WU, Yuexin YANG, Gabor ZAJKAS.

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Glycaemic Index and Health: the Quality of the Evidence

Apart from providing energy, carbohydrates are also involved in a variety of neuro-hormonal and psychological functions. These characteristics are not reflected by the historical classification of sugars and starch. The Glycaemic Index (GI) has been introduced twenty years ago in order to appreciate this physiological dimension of the quality of carbohydrates. The concept, at first developed to answer specific and critical needs in diabetes management, has now reached a general nutritional interest. The short term effects of the GI of food stuffs, such as metabolic postprandial responses, satiety, physical performances, psychological functions, as well as the medium- and long-term outcomes related to cardiovascular disease risk, diabetes and obesity, have been largely documented and have led to conclusive statements. Nevertheless, the GI is still a matter of debate and guidelines are needed in terms of food processing, nutritional recommendations, target populations and the public use of the GI concept through health and education professionals. This workshop has offered the opportunity to experts from all over the world to substantiate the knowledge on the GI and to contribute to the achievement of an accurate statement on the real importance of this fascinating and very powerful nutritional concept.

New, often unpublished data, have been presented. To avoid putting pressure on the contributors and in order to respect the engagement taken for the sake of rich scientific exchanges, no references are indicated in the text. A bibliography on the subject is available at the end of the synopsis.

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