GLYCAEMIC INDEX: IS IT A USEFUL TOOL IN HUMAN HEALTH AND DISEASE?

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Summary

The glycemic index (GI) is a ranking of foods based on their glycaemic impact in comparison to a standard food. In recent years it has become the accepted method of classifying carbohydrate foods and over 300 separate foods have been tested. The GI approach has been applied in various situations, such as diabetes, sport and appetite, where fluctuations in blood sugar levels are considered important. In Australia, the GI concept has stepped out of the research arena and is being used as an education tool in several diabetes education centres and sports clinics. Over the last few years, virtually every study undertaken has shown that the GI concept is not only reproducible and predictable in a mixed meal context, but useful in the dietary management of insulin-dependent diabetes, non-insulin-dependent diabetes, hyperlipidaemia, exercise performance and appetite regulation.

I. INTRODUCTION

The glycemic index (GI) is a ranking of foods based on their glycaemic impact in comparison to a standard food (Jenkins et al. 1981). In recent years it has become the accepted method of classifying carbohydrate foods, replacing the old simple vs complex classification (Asp, in press). It is being used for comparing foods in areas where fluctuations in blood sugar levels are considered important such as diabetes, sport and appetite. In Australia, the GI concept has stepped out of the research arena and is being used as an education tool in several diabetes education centres. The International Diabetes Institute in Melbourne has produced educational material describing the differences between foods in terms of their GI. New editions of most textbooks of nutrition and dietetics now devote a section to the subject (Zeman 1991), although most do not give it their unqualified support, citing conflicting early studies. However, over the last few years, virtually every study undertaken has shown that the GI concept is not only reproducible and predictable, but useful in the dietary management of insulin-dependent diabetes (IDDM), non-insulin-dependent diabetes (NIDDM), hyperlipidaemia, exercise performance and appetite regulation (Brand Miller 1994).

Jenkins and co-workers introduced the GI concept in 1981 (Jenkins et al. 1981), but it was not the first time that carbohydrates had been shown to vary widely in their glycaemic impact. Otto and Niklas (1980) had published a similar concept in French the year before. Wahlqvist et al. (1978) had showed that chain length did not influence the rate of digestion and absorption of carbohydrate. For a more complete historical review, the reader is referred to Truswell (1992). Jenkins et al. confirmed what others had previously found, but unlike the earlier work, the practical implications of their study were immediately recognised. Foods producing very low glycaemic responses, such as legumes and pasta, might be the best foods for managing diabetes. GI seemed a more logical approach to the dietary management of diabetes, but it went against the prevailing dietary dogma that starches were all digested and absorbed slowly.

Some starchy foods, such as potatoes produced responses almost as high as an equivalent load of glucose while foods containing sugars appeared to have a low to moderate glycaemic

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impact. Indeed the publication of the first GI of foods suggested that the system of carbohydrate exchanges for diabetic diets had little scientific validity.

In the 13 years since the first GI figures were published, nearly 300 separate foods have been subjected to GI testing, representing about 200 different kinds of foods from all around the world. The team here at the University of Sydney's Human Nutrition Unit has been responsible for about half of the data. It is clear that all legumes, *whole* cereal grains and millets produce exceptionally low GI values contrasting with western foods such as bread, potatoes and many processed cereal products which elicit high plasma glucose and insulin responses. Factory processing and milling markedly increase glycaemic responses to foods (Brand et al. 1985; Heaton et al 1988). On average, the GI of foods containing sugar is no higher than that of common starchy foods like bread (Brand Miller 1994). In addition, there is no significant difference between the glycaemic and insulin responses to naturally-occurring sources of sugars (such as fruit) compared with sources of refined sugars (such as soft drinks). Interestingly, the staple carbohydrate foods of Nauruans, Australian Aborigines and Pima Indians, prepared by traditional methods of processing, were primarily low GI foods (Thorburn et al. 1987; Brand et al. 1990). In the past century these population groups have adopted a western lifestyle and modern foods, and now develop non-insulin-dependent diabetes (NIDDM) in alarming numbers. It is plausible that the high GI of the western diet might play some role in the development of the disease (see section IV).

II. EARLY CONTROVERSY SURROUNDING THE GLYCAMIC INDEX

In early 1980's the debate on the GI approach to diabetes management became polarised, with the open expression and publication of directly opposing views on its usefulness (Coulston et al 1984). Its reproducibility, application to mixed meals and long-term effects were all open to question. There was a widespread belief that GI was useful only in the comparison of single foods but not in a mixed meal situation (Laine et al 1987; Hollenbeck et al 1988). This view is incorrect but still widely held. In 1986, the National Institutes of Health (NIH) consensus conference on diet and exercise in NIDDM recommended *against* the use of GI in the dietary management of diabetes (NIH 1986). The main criticisms were: no differences were apparent when individual carbohydrate foods were taken as part of a mixed meal and, secondly, there were no studies showing long term benefits.

In the intervening years since the NIH statement, these criticisms have been shown to be without foundation. There are now at least 15 studies on mixed meals and 12 long term studies using the GI approach in the dietary management of diabetes. Although several early studies failed to show any differences in glycemic response when foods of different GI were incorporated into mixed meals (Laine et al 1987; Coulston et al 1987; Hollenbeck et al 1988), there are now three times as many studies which show that GI is very predictable in mixed meal situations (Chew et al. 1985; Chantelau et al. 1986; Colagiuri et al. 1986; Collier et al. 1986; Wolever and Jenkins 1986; Bornet et al. 1987; Hermansen et al. 1987; Weyman-Daum et al. 1987; Parillo et al. 1988; Rasmussen et al. 1988). Methodological differences explain much of the conflict.

III. LONG TERM STUDIES

Studies addressing the long term effects of a low vs high GI diet are more valuable than studies of single and mixed meals. There have been at least 12 published long term studies which have specifically used the glycemic index (GI) approach to determine the clinical gains in diabetes or lipid management (Jenkins et al 1985; Jenkins et al. 1987a; Jenkins et al 1987b; Calle-Pascual et al. 1988; Collier et al. 1988; Fontvieille et al. 1988; Jenkins et al. 1988; Brand et al. 1991; Fontvieille et al. 1992; Wolever et al 1992a; Wolever et al 1992b; Frost and Wilding 1993). All but one produced positive findings. The only negative study was poorly designed and could not have shown a difference if there was one (Calle-Pascual et al. 1988). Most studies have used a crossover design with subjects assigned to receive either a high or low GI diet for a set period, followed by a similar period on the alternate diet. The time periods have varied from as short as 2 x 2 weeks to as long as 2 x 12 weeks, the average being 2 x 5 weeks. Among the crossover studies, a total of 156 subjects have been studied: 63 with NIDDM, 45 with IDDM, 42 with hyperlipidaemia alone, and six were healthy. All studies were undertaken on an outpatient basis.

An overview analysis of the 11 crossover studies (Brand Miller 1994) showed that, on average, low GI diets reduced glycosylated haemoglobin by 9%, fructosamine by 8%, urinary C-peptide by 20 % and day-long blood glucose by 16%. Cholesterol was reduced by an average of 6% and triglycerides by 9%. Improvements were found not only in well-controlled subjects but in poorly-controlled and overweight NIDDM subjects and applied to children with IDDM as well as adults. One can criticise these results as 'modest' improvements but, so too, were the changes to the diet. They were not exceptionally high in fibre or low in fat and the subjects did not have to lose weight. In most studies, only half the carbohydrate was exchanged from high to low GI which meant that foods such as bread and potatoes could still be eaten on the low GI diet. Furthermore the findings applied to free-living subjects, not to institutionalised or metabolic ward patients where food intake can be strictly controlled but is not necessarily realistic. In our own study (Brand et al. 1991), compliance was high on the low GI diets and patients remarked that they 'felt better' on them.

The results of a recent study from Hammersmith Hospital in Britain are also encouraging because it was large study in a typical clinical setting. Sixty newly diagnosed NIDDM subjects were randomly assigned to either standard dietary advice or standard plus low GI advice for 12 weeks (Frost and Wilding 1993). The low GI group not only had a significantly lower GI, but also achieved a lower fat intake and higher carbohydrate and fibre intake. There was a significantly greater fall in fructosamine and cholesterol in the low GI group. In conclusion, it is clear that the GI concept is a clinically useful tool in the management of diabetes mellitus.

IV. HIGH GLYCAEMIC INDEX DIETS IN THE PATHOGENESIS OF NIDDM

Our recent studies in rats support the hypothesis that high GI foods worsen insulin resistance and therefore the risk of NIDDM (Byrnes et al. in press). Rats were maintained on high GI or low GI diets by varying the content of amylose starch. Dietary starch is a mixture of amylose, a straight chain molecule, and amylopectin which is highly branched. Starches with a low amylose content (ie. low ratio of amylose to amylopectin) are digested and absorbed more quickly than high amylose starches and produce higher post prandial glucose and insulin responses. We hypothesised that a diet based on low amylose starch (high GI diet) would produce insulin resistance in the long term. Sprague-Dawley rats weighing 250 g were randomly assigned to receive either a low amylose or high amylose cornstarch diet as two meals/day (2 x 10 g) for 9 weeks. The diets were otherwise equivalent in energy (E), protein (22%E), fat (11%E), carbohydrate (69%E) and fibre. Mean body weights were not significantly different after 9 weeks of feeding. At this time the rats were cannulated and administered an IVGTT of 1 g glucose/kg body weight. Plasma glucose and insulin levels were measured at 0, 2, 4, 6, 8, 10, 15 and 30 min. Rats in the high amylose group showed a faster clearance of the glucose load. The K_g (rate of glucose disappearance 10 min after infusion) of the rats fed the high amylose diet was significantly higher (-2.44 ± 0.9, $n = 3$) compared with the rats fed the low amylose diet (-1.87 ± 0.34, $n = 4$). The insulin response to the IVGTT was two-fold higher in the rats fed the low amylose diet compared to the those fed the high amylose diet ($p < 0.05$).

The results suggested that the rats fed the low amylose diet became relatively insulin resistant over the course of the study. A second study in Wistar rats of 12 weeks duration confirmed these findings, with differences in the insulin response to the IVGTT beginning to emerge after eight weeks of feeding. In addition, after 12 weeks of feeding, basal plasma insulin concentration was two-fold higher in the rats fed the low amylose diet ($p < 0.05$). However, this species of rat did not show changes in glucose tolerance as insulin resistance progressed. These results show that the nature of the starch in the diet may have significant effects on the development of insulin resistance in rats. If the findings can be extrapolated to humans, there are important implications for the GI in the development of NIDDM.

V. GLYCAEMIC INDEX AND SATIETY

Glycaemic index has applications outside diabetes management. It may be relevant to the average healthy person because it appears to correlate with a food's capacity to induce satiety. Higher glucose and insulin responses are consistently associated with lower satiety and vice versa (Krishnamachar and Mickelsen 1987; Leathwood and Pollet 1988; Holt et al. 1992). We showed that breakfasts with a high GI such as Rice Bubbles produce much less satiety than breakfasts with a low GI, such as All Bran or porridge (Holt et al 1992) (Figure 1). The satiety measurements were corroborated by cholecystokinin (CCK) responses. Furthermore, progressive milling and reduction in the particle size of cereals (with fibre held constant) produces faster rates of digestion and absorption and proportionately lower satiety ratings (Holt and Brand Miller in press). Likewise, foods of identical appearance and composition, eg high and low amylose rices, which produce different glucose and insulin responses, induce satiety that varies inversely with the insulin responses (Holt and Brand Miller 1993). These findings provide support for Flatt's hypothesis which proposes that the respiratory quotient (RQ) after meals influences appetite and weight gain (Flatt 1988). Meals producing a high respiratory quotient result in carbohydrate being burned at the expense of fat and less deposition of glucose as glycogen. The lower glycogen stores are thought to result in hunger developing sooner and therefore greater food intake. Hence the higher carbohydrate oxidation and the lower glycogen stores could theoretically predispose to weight gain. Our own research has shown that high GI foods produce higher RQs than low GI foods, both before and during exercise, and therefore have the potential to promote greater weight gain (Thomas et al 1991).

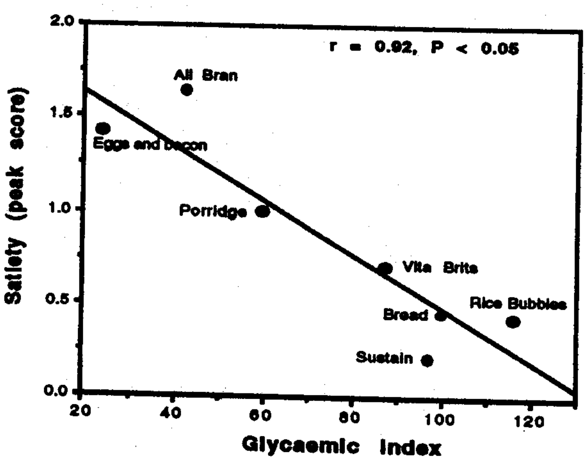

Figure 1. The glycaemic index of a foods predicts the satiety response to that food

VI. GLYCAEMIC INDEX AND SPORTS PERFORMANCE

Our group was the first to apply the GI concept to the area of sport and exercise (Thomas et al. 1988). The sports physiologists now recommend high and low GI foods for different situations (Coyle 1991). Thomas et al. (1991) found that consumption of low GI foods one hour before prolonged strenuous exercise increased endurance time by as much as 20 min compared with a high GI food. In fact, the plasma glucose levels at the end of exercise were shown to vary inversely with the GI of the pre-exercise food [Thomas et al. in press (a)]. This applies even when the food is eaten as long as two hours before the exercise begins [Thomas et al. in press (b)]. Thus a food such as lentils with a low GI releases its carbohydrate slowly providing a source of glucose to the blood long after the meal has been consumed. In this way an athlete may avoid the need to consume carbohydrate during the event. Indeed, in some situations, such as marathon swimming, carbohydrate consumption during the event may be impossible.

While low GI foods might be the preferred carbohydrate source *prior* to prolonged strenuous exercise, high GI foods have been shown to be beneficial *after* exercise when glycogen stores need to be replenished quickly (Burke et al. 1993). Coyle and Coyle (1993) recommend that athletes consume at least 50 g of high or moderate GI foods immediately after exercise and every two hours thereafter for two or three additional feedings. These findings may also be relevant to occupational issues (eg heavy labourers) and to work animals. Similar studies using the GI approach are presently being undertaken with horses in the Department of Veterinary Clinical Sciences at the University of Sydney.

VII. WHAT CRITICISMS OF GLYCAEMIC INDEX STILL REMAIN?

The GI approach has been criticised because some foods have been rated as 'good' or 'bad' simply on the basis of their GI. It was never intended that the GI be used in isolation. The fat, fibre and salt content of a food are also relevant to diabetes. Some people have argued that GI makes high fat foods appear in a falsely favourable light because fat slows gastric emptying and blunts the glycaemic response to the carbohydrate. High fat foods tend to have a low GI, including icecream and Mars Bars™, although fat may not be the main reason. Nonetheless, foods with a low GI should only be encouraged if they have a low (saturated) fat content (Jenkins et al 1988b; Truswell, 1992). The priority in the prescription of a diet for diabetic patients should be, first, a low fat intake and (only) secondly, to prefer foods with a low GI. There is some dissension about recommending high carbohydrate diets for all individuals with diabetes because of their tendency to lower HDL cholesterol (Garg et al. 1988; Reaven 1988; Garg et al. 1992). However, this criticism of high carbohydrate diets is overcome by use of *low GI*, high carbohydrate diets or *low GI*, low saturated fat diets (see Truswell, 1992).

The insulin response to a food should also be considered. In general, insulin responses have followed the rank order of the glycaemic responses (Chew et al. 1985; Holt et al. 1992). Occasionally, the GI does not predict the magnitude of the insulin response. Some rice varieties, for example, may produce a high GI but a substantially lower 'insulin index', compared to white bread (Brand Miller et al. 1992). The clinical significance of this is not clear, but it may mean that we should be producing an insulin index of foods as well as GI. The insulin index may be more relevant to individuals with impaired glucose tolerance and hyperinsulinaemia. Another criticism of the GI is that the usual serving size is often not a 50 g carbohydrate portion. Some foods may contain so little carbohydrate that even a high GI is of little practical significance, such as the case with carrots (GI = 92), but there are few other foods in this category. Theoretically, it is possible to show that the expected glycaemic response to the usual serving size correlates well with the GI of a 50 g carbohydrate portion (unpublished findings).

Another factor which has been hindering the practical application of the GI has been the lack of a comprehensive list of GIs, including common supermarket brand names and ethnic foods. We have been addressing this issue and will shortly publish an extensive table of GI values comprising 300 separate food items representing about 200 different types of food.

Despite its limitations, the GI concept has been widely adopted around the world as a means of classifying carbohydrate foods and determining which foods may be best in different situations. No doubt there will be further applications in the future, particularly in the epidemiology of Type 2 diabetes and possibly in the study of mental function. We believe that the glycaemic index has already proven itself to be a useful tool in human health and disease.

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