Glycemic Index and Glycemic Load: relevance for athletes in training

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Not all carbohydrates are the same

It has long been accepted that carbohydrates are essential for optimum athletic performance and that depletion of the body's carbohydrate stores are associated with premature fatigue.[1] Athletes are therefore advised to consume a diet high in carbohydrates, supplement carbohydrates before exercise, drink carbohydrates during exercise, and replace them as soon as possible after exercise.[2] More recently, there has been an interest in exploring the effects of different types of carbohydrates on athletic performance.[3] Carbohydrates have been classified (nutritionally) into simple and complex forms depending on their structure. In the last 8-10 years or so, the concept of Glycemic Index (GI) has been promoted as a more appropriate way of nutritionally classifying carbohydrates.[4] This article explains the concept of GI as well as Glycemic Load (GL), before discussing how they can be utilised by athletes and coaches to reduce body fat, promote the growth of lean muscle mass, prevent fatigue and enhance recovery.

Carbohydrate-containing foods include breads, potatoes, pasta, vegetables, rice and sugars. Traditionally, carbohydrate-based foods were classified as either complex or simple, with this classification being based upon the number of monosaccharide units linked together and also the fibre content of the food.[4] Foods that had a high fibre content with many monosaccharides were classed as 'complex carbohydrates' (e.g. potatoes and pasta) whereas foods with a low fibre content and containing a single or few monosaccharides were classed as 'simple' carbohydrates (e.g. glucose, fructose, sucrose, and maltodextrins). The rate at which carbohydrates are digested and released as glucose into the bloodstream varies considerably and for many years there was also a common assumption that simple carbohydrates induce a rapid rise in blood sugar compared with consumption of complex carbohydrates. This assumption led to the development of dietary guidelines to maximise athletic performance based upon splitting carbohydrates into simple and complex.[5] However, despite this being an easy system of classification, the assumption that simple carbohydrates cause a rapid rise in blood sugar compared with complex carbohydrates does not always hold true.[6] An example of this is that fructose is classed as a simple carbohydrate but does not result in a rapid rise in blood sugar, whereas mashed potato, which would be classed as complex carbohydrate, causes a rapid rise in blood sugar. Therefore a more informative system has been developed classifying carbohydrates according to the rate at which they increase blood sugar, known as the Glycemic Index (GI).

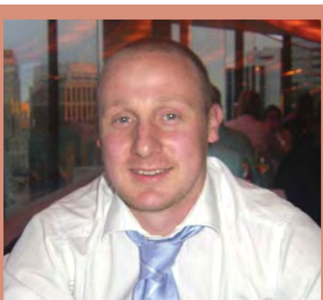

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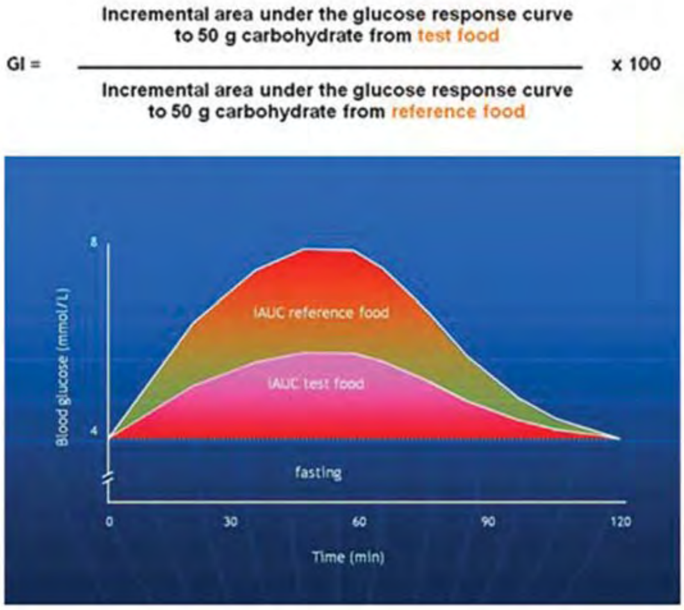
Figure 1. Method of calculating the glycemic index of food.



Introducing the GI system of classifying carbohydrates

The GI system of classifying carbohydrates was originally developed to help patients with diabetes to control their blood sugar,[7] but it is now commonly used by athletes to maximise performance, and by the general public as a means of controlling body fat.[8] The system involves ranking foods based on their immediate effect on blood glucose. Carbohydrate foods that break down quickly during digestion have the highest GIs. After consumption of high GI foods there is a rapid and high increase in blood sugar. The GI system normally expresses foods as a percent compared with glucose or white bread. The precise way it is calculated is by calculating 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 50g of a standard food taken by the same subject[9] *(see Figure 1)*.

Foods are usually classified as being high, moderate or low GI on a scale of 0-100.

- High GI – above 70 (potato, white bread, white rice)
- Moderate GI – 55 to 70 (table sugar, orange juice, oats)
- Low GI – below 55 (beans, berry fruits, milk)

There are many factors that affect the GI of food and this can make their selection difficult. Such factors include:

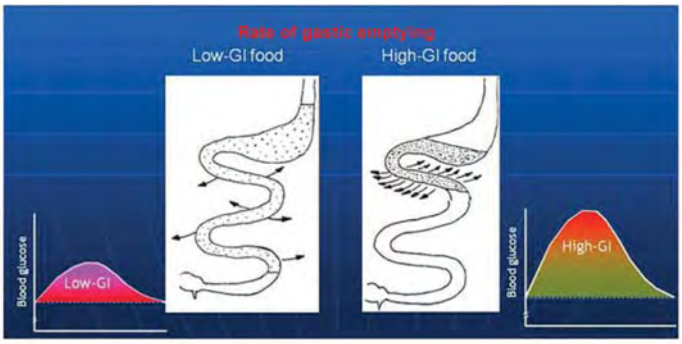


Figure 2. Glycemic Index and its affect on gastric emptying.

- Size, texture, and ripeness of a food (e.g. ripe banana has a high GI compared with an unripe banana)
- Presence of fat and/or protein (reduces GI)
- Presence of soluble fibre (increases GI)
- Presence of fructose (reduces GI)
- 'Other' factors in food e.g. phytates (reduces GI)

A common misconception is that the chain length (i.e. the number of monosaccharides) of the carbohydrate affects the GI: this is not the case. The GI value depends principally on the rate of digestion of the carbohydrate into its simple sugars (i.e. monosaccharides), and their subsequent absorption in the gastrointestinal tract *(Figure 2)*.

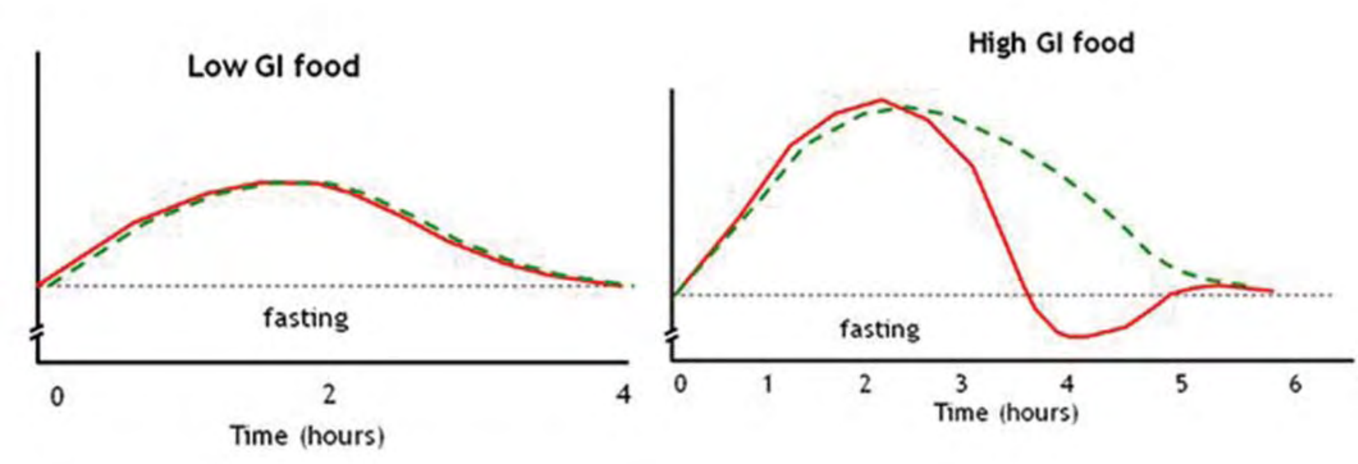
The physiological consequences of eating a high or a low GI meal on blood glucose and plasma insulin are different. *Figure 3* highlights these effects, and as can be seen, there are a few phases in response. The first 2 hours after a high GI food is one of hyperglycemia and hyperinsulinemia followed in the next 2 hours by 'reactive hypoglycemia', decreased carbohydrate and fat oxidation, as well as an increase in hunger. If an individual was to exercise approximately 3 hours after ingestion of such a food, there would be less fat and more carbohydrate oxidised than if a low GI food had been consumed.[10] Indeed, the glucose and insulin responses to a low GI meal demonstrate an attenuated response and no apparent 'reactive hypoglycemia' *(see Figure 3)*, nor is there a period of hunger associated with this type of meal.

Exercise-based studies have clearly demonstrated that there is greater fat oxidation (fat burning) following a low GI meal when compared with a high GI meal. The likely cause for this concerns the insulin concentrations. It should be remembered that insulin is a potent anti-lipolytic hormone i.e. it prevents the breakdown of fat stored in adipose tissue, and as such, results in lowered levels of fatty acids in blood from fat cells. The net effect is an increase in carbohydrate oxidation following a high GI meal. The implications of this for training are considerable if a 'fat burning' session is required.

Another effect of a high GI meal is that concerning hunger and satiety. *Figure 2* illustrates the rapid digestion and absorption following a high GI meal in comparison with a low GI meal. This results in an immediate, but not long-lasting, satiety as the brain detects the sharp increase in blood glucose. However, the sharp increase is followed by a rapid decrease and hence the probability of increased hunger. A low GI meal takes longer to digest and absorb, and so results in a prolonged feeling of fullness. Studies in relation to this have been performed and concluded on the merits of a low GI meal for lowered frequency of feeding and greater levels of satiety.[11]

The health benefits of low GI meals have also been reported. McMillan-Price *et. al.*[12] randomly assigned 129 overweight or obese young adults (aged 18-40 years) to one of four reduced calorie, reduced fat diets over a 12 week period. Two of the diets were high-carbohydrate diets (high GI and low GI), and the other two high in protein (with high GI or low GI). Comparison between the two high-carbohydrate diets showed that the low GI treatment doubled fat loss, and this effect was strongest in women. Participation in the high-protein, high GI diet was equally effective for fat loss as the high carbohydrate, low GI diet, although

Figure 3. The effects of low and high GI foods on blood glucose (Red line) and blood insulin (green line) concentrations.



the two had diverse effects on LDL (bad) cholesterol - the high protein, high GI group showed increased levels of LDL or 'bad' cholesterol, while there were significant reductions in those on the high carbohydrate, low GI diet.

Carbohydrate ingestion and insulin

Carbohydrates are stored in humans as a polymer of glucose known as glycogen. This glycogen is mainly stored in the liver and skeletal muscle, although other tissues such as the brain, adipose tissue, heart and kidneys can store a small amount. Skeletal muscles are the main stores of glycogen containing approximately 400-500g of glycogen, whilst the liver contains approximately 100g.

The storage of glucose as glycogen occurs under the control of the hormone insulin. Due to insulin and other hormones such as glucagon, the body maintains blood glucose within a very narrow range (normal resting glucose is about 4-5mmol/L). When there is an increase in the concentration of blood glucose after a meal, insulin is released from the beta cells of the Islets of Langerhans in the pancreas. The release of insulin promotes the uptake of glucose into skeletal muscles, liver and other tissues, where it is stored as either muscle or liver glycogen or converted to triglycerides and stored as fat. Data suggest that the rate of rise in blood glucose plays a major role in determining if the glucose is stored as muscle/liver glycogen, or converted to triglycerides and stored as fat.

Effect of GI on muscle protein synthesis and protein degradation

Insulin also has a second major function in the human body that is particularly important for strength and conditioning. As well as facilitating the storage of glucose as glycogen, insulin is also one of the body's major anabolic hormones. Once insulin binds to its receptor, it activates a series of phosphorylation (activation) reactions, eventually resulting in the activation of a protein kinase called AKT. Once AKT has been activated, it promotes protein synthesis through the mTOR pathways whilst also preventing protein breakdown,[13] *(see Figure 4)*. Therefore, insulin has the ability to promote skeletal muscle hypertrophy by increasing protein synthesis and decreasing protein breakdown. Recent data suggests that the major effect of insulin post-exercise is inhibiting the effect on protein breakdown, whereas the provision of amino acids is the most important nutrient to promote protein synthesis.[14]

The control of insulin though dietary carbohydrate intake is therefore extremely important following resistance training. Studies from Professor Mike Rennie's laboratory in Nottingham, have shown that providing amino acids immediately post resistance exercise is essential to facilitate muscle protein synthesis, and in a recent excellent review on this topic 20g of protein was suggested to be most effective.[15] Since insulin has also been shown to be highly important in promoting an anabolic environment through preventing protein degradation,[13] it would therefore appear wise to increase insulin concentrations post-exercise through the provision of high GI carbohydrates along with protein supplementation.

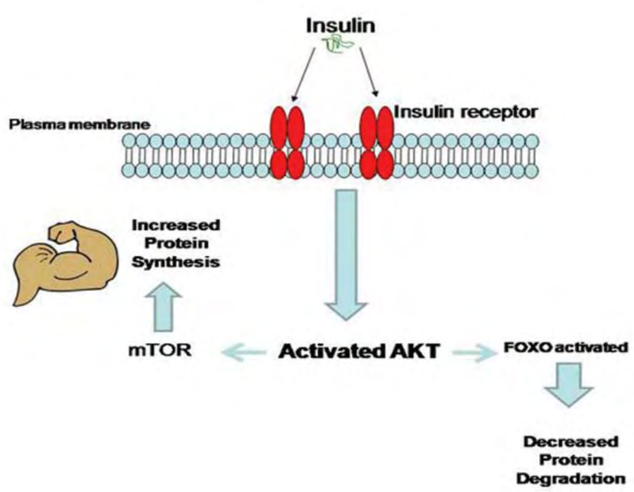


Figure 4. Insulin binds to its receptor (IR) and results in a series of activation reactions. This ultimately activates AKT resulting in increased protein synthesis and decreased protein degradation (adapted from Close et al., 2009, paper in press).

Effect of carbohydrate timing and GI on muscle glycogen restoration after exercise.

It is now generally accepted that the highest rates of muscle glycogen storage occur immediately after exercise (within the first hour), due to the activation of glycogen synthase activated by glycogen depletion,[16] together with exercise-induced insulin sensitivity[17] and enhanced permeability of the muscle cell membrane to glucose.[6] Studies by Ivy *et. al*.,[18] have shown that glycogen storage rates can reach 7.7mmol per kg wet weight per hour during the first 2 hours, compared with 4.3mmol per kg wet weight thereafter. Moreover, failure to consume carbohydrate immediately post exercise leads to low rates of glycogen restoration until feeding occurs. These findings are especially important when there is a short space of time between exercises, for example during a tournament.

It is also of interest as to whether the GI of the food affects muscle glycogen restoration after exercise. Early investigations into this question unfortunately used the classification of simple versus complex carbohydrates,[19] and thus these data cannot provide the answers.[6] The first reported study investigating the effects of low and high GI foods was by Burke *et. al*.[20] These authors reported a 30% increase in glycogen storage within 24h post recovery following the consumption of high GI carbohydrates compared with an identical amount of low GI carbohydrates. Interestingly, the authors went on to suggest that the mechanisms responsible for this greater glycogen storage were not purely a consequence of the enhanced glucose and insulin response, and recent studies have suggested that a large amount of the carbohydrates in low GI carbohydrate meals may be malabsorbed and that indigestible carbohydrates provides a poor substrate for muscle glycogen resynthesis.[21] Based on this data it would appear that giving low GI carbohydrates post-exercise may lead to overestimation of the amount of carbohydrate provided to restore muscle glycogen, and therefore emphasis should be placed on medium to high GI carbohydrates to restore muscle glycogen following exercise.

Glycemic Load

The concept of GI has at least one weakness, and this relates to the fact that GI is determined by ingesting 50g of carbohydrate from the food source and comparing it with 50g of glucose. In effect, it may well be that to get 50g of carbohydrate from (say) an apple requires an individual to eat 3-4 whole apples. Some foods have a very high GI but actually do not contain much carbohydrates e.g. watermelon has a high GI, but there is very little carbohydrate in a watermelon (most of it being water). So, GI does not account for the amount of carbohydrate in a particular food. This has given rise to the concept of Glycemic Load (GL), which takes into account the GI value of the food, as well as the carbohydrate content of that food. The GL is calculated by multiplying the amount of carbohydrate contained in a "normal" portion for the food in question by its GI, then diving this by 100. Glycemic Load is usually expressed as low, medium or high:

- Low GL = 1-10
- Medium GL = 11-19
- High GL = 20+

An example of the GI/GL paradox occurs when considering our previous example of the watermelon. Watermelon has a GI of 72 which would give it a high GI rating. However, one 20g serving of watermelon only contains 6g of carbohydrate which gives it a GL of 4, i.e. a low GL (72*6/100=4.32).

Some important considerations about GI and GL

While the GI has significant advantages over the previous classifications of simple and complex carbohydrates there are some consideration to be aware of:

- **There is a wide variation in GI measurements**. While the GI table shows a single value of GI for each food, in reality, the measurements are not so precise. Reported values are generally averages of several tests and so can vary significantly in individuals. For example, baked Russet potatoes have been tested with a GI as low as 56 and as high as 111! The GI for fruits such as the banana increase as the fruit ripens, and so can add to a degree of uncertainty when examining GI data.
- **GI values are affected by the preparation method**. The GI varies in response to differences in food preparation. Generally, any significant food processing, such as grinding or cooking, will elevate GI values for certain foods, because it makes those food quicker and easier to digest. This type of change is even seen with subtle alterations of the preparation, such as boiling pasta for 15 minutes instead of 10.
- **GI values are affected by combination with other foods**. While tests for GI are usually done on individual foods, most individuals eat meals with combinations of foods. The addition of other foods that contain fibre, protein, or fat will generally reduce the GI of the meal. The GI of this "mixed meal" can be estimated by taking a weighted average of the GI's of the individual foods in the meal. However, this averaging method may become less accurate as the total percentage of carbohydrate decreases. Therefore, foods like pizza often create a higher glycemic response than the simple weighted average of the ingredient GI's would predict.
- **There are individual differences in glycemic response**. The rate at which different people digest carbohydrates also varies, so there are some individual differences in glycemic response from person to person. In addition, it has been shown that one person's glycemic response may vary from one time of day to another. And finally, different people have different insulin responses (i.e. produce different levels of insulin), even with an identical glycemic response.
- **The reliance on GI and GL can lead to overconsumption**. It is important to remember that the GI is only a rating of a food's carbohydrate content. Use of GI and GL values as the sole factor for determining diet can result in overconsumption of fat and total energy.

Table 1. GI and GL of various foods. Green indicates low GL, orange indicates medium GL whilst red indicates high GL. Data sourced from (22) and (23).

		Per "normal" serving				
		Size	**GI**	**KCals**	**Carbs**	**GL**
Breakfast	All bran	40	30	108	19	6
	Crumpets	40	69	71	15	11
	Porridge (with water)	250 (ml)	58	216	22	13
	Wholemeal bread	40	77	87	17	13
	White bread	40	70	94	20	14
	Croissants	60	67	224	26	17
	Cornflakes	30	72	113	27	19
	Weetabix	40	69	140	30	20
	Bagels	70	72	191	40	29
Lunch and dinner	Sprouts	80	1	28	3	0
	Green beans	80	1	20	2	0
	Kidney beans	80	28	80	14	4
	Quinoa	40	53	55	10	6
	Parsnips (boiled)	80	97	53	10	10
	Baked beans	135	48	113	20	10
	Sweet potatoes (boiled)	120	46	101	25	11
	Mashed potatoes	100	86	57	14	12
	Egg noodles	200	46	124	26	12
	White Spaghetti	150	37	156	33	12
	Brown Spaghetti	150	37	170	35	13
	Wholemeal bread	40	77	87	17	13
	White bread	40	70	94	20	14
	Potatoes (boiled)	100	101	72	17	17
	Basmati rice	100	58	138	33	19
	Pitta Bread	60	57	153	33	19
	Couscous	150	65	168	35	22
	Baked potatoes	100	85	136	32	27
	White rice	100	98	138	31	30
	Baguettes	85	95	207	43	41
Snacks	Apricots (fresh)	40	1	76	1	0
	Peanuts	25	14	141	3	0
	Cashew nuts	25	22	153	5	1
	Apricots (dried)	10	30	19	4	1
	Strawberries	100	40	27	6	2
	Oranges	120	42	44	10	4
	Apples	100	38	47	12	4
	Yoghurt (fat free)	200	24	105	14	4
	Apple juice	100	40	38	10	4
	Watermelon	20	72	31	6	4
	Orange juice	100	53	36	9	5
	Bananas	100	52	91	14	7
	Pretzels	10	83	38	8	7
	Custard (with skimmed milk)	120	35	125	19	7
	Chocolate mousse (low fat)	125	37	154	23	8
	Honey	25	55	75	18	10
	Malted fruit loaf	35	47	103	23	11
	Dates	15	103	41	10	11
	Milk chocolate	55	41	286	31	13
	Scones	50	92	182	27	25
	Pancakes	110	67	332	38	26
	Doughnuts	75	76	252	37	28
	Waffles	150	76	501	59	45

Conclusions and recommendations

There is no doubt that much more research is required investigating how best to utilise the GI/GL of foods to maximise performance and enhance recovery, but based on the existing literature the following recommendations can be made:

- The majority of carbohydrates for athletes should come from low GI/GL sources.
- Try to eat a breakfast consisting of low GI/GL carbohydrates such as oat based cereals and wholemeal bread.
- Focus upon medium to high GI/GL carbohydrates post exercise to optimise the replenishment of muscle glycogen. Since fat lowers the GL of a meal ensure that this post exercise meal does not contain large amounts of fat.
- If there is a need to lose body fat, ensure that most of the ingested carbohydrates are low GI/GL, especially during the evening when muscle and liver glycogen stores are likely to be full. The exception to this is if training late in the evening following which muscle and liver glycogen stores will need to be replenished.
- Try to avoid late night high GI/GL snacks and choose low GI/GL alternatives.
- The evidence for high or low GI/GL foods pre-exercise is still confusing and may be due to inter-individual variations. During short duration exercise, there does not appear to be any advantage of choosing one form over the other, although during longer term exercise consuming low GI/GL foods may prolong performance, especially if no carbohydrates are ingested during the exercise. Furthermore, if body fat reduction is an aim, then low GI/GL foods pre-exercise may promote greater fatty acid oxidation and help with weight loss. In addition, any individuals who are prone to fluctuations in blood sugar would be advised to consume low GI foods pre-exercise to prevent any rebound hypoglycaemia.
- Try to include some medium to high GI/GL foods immediately after resistance training to promote muscle protein synthesis and prevent muscle protein degradation. Ideally this should be with approximately 20g of high quality protein to maximise net protein synthesis.

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