**Carbohydrate drinks – can fructose enhance endurance for runners?**

***Despite the numerous claims to the contrary by the sports nutrition industry, real advances in sports nutrition are comparatively rare. But recent research into carbohydrate absorption and utilisation could herald a new breed of carbohydrate drink, which promises genuinely enhanced endurance performance.***

Before we go on to discuss carbohydrate formulations, it’s worth recapping just why carbohydrate nutrition is so vital for middle distance runners. Although the human body can use fat and carbohydrate as the principle fuels to provide energy, it’s carbohydrate that is the preferred or ‘premium grade’ fuel for sporting activity.

There are two main reasons for this. Firstly, carbohydrate is more oxygen-efficient than fat; each molecule of oxygen yields six molecules of ATP (adenosine triphosphate – the energy liberating molecule used in muscle contraction) compared with only 5.7 ATPs per oxygen molecule when fat is oxidised. That’s important because the amount of oxygen available to working muscles isn’t unlimited – it’s determined by your maximum oxygen uptake (VO2max).

Secondly and more importantly, unlike fat (and protein), carbohydrate can be broken down very rapidly without oxygen to provide large amounts of extra ATP via a process known as glycolysis during intense (anaerobic) exercise. And since all but ultra-endurance athletes tend to work at or near their anaerobic threshold, this additional energy route provided by carbohydrate is vital for maximal performance. This explains why, when your muscle carbohydrate supplies (glycogen) run low, you sometimes feel as though you’ve hit a ‘wall’ and have to drop your pace significantly from that sustained when glycogen stores were higher.

**Carbohydrate storage**

Endurance training coupled with the right carbohydrate loading strategy can maximise glycogen concentrations, which can extend the duration exercise by up to 20% before fatigue sets in1. Studies have shown that the onset of fatigue coincides closely with the depletion of glycogen in exercising muscles.

However, valuable as these glycogen stores are, and even though some extra carbohydrate (in the form of circulating blood glucose) can be made available to working muscles courtesy of glycogen stored in the liver, they are often insufficient to supply the energy needs during longer events.

For example, a trained marathon runner can oxidise carbohydrate at around 200-250g per hour at racing pace; even if he or she begins the race with fully loaded stores, muscle glycogen stores would become depleted long before the end of the race. Premature depletion can be an even bigger problem in longer events such as triathlon or endurance cycling and can even be a problem for athletes whose events last 90 minutes or less and who have not been able to fully load glycogen stores beforehand.

Given that stores of precious muscle glycogen are limited, can ingesting carbohydrate drinks during exercise help offset the effects of glycogen depletion by providing working muscles with another source of glucose? Back in the early 1980s, the prevailing consensus was that it made little positive contribution. This was because of the concern that carbohydrate drinks could impair fluid uptake, which might increase the risk of dehydration. It was also mistakenly believed that ingested carbohydrate in such drinks contributed little to energy production in the working muscles.

Later that decade, however, it became clear that carbohydrate ingested during exercise can indeed be oxidised at a rate of roughly 1g per minute (supplying approximately 250kcals per hour) and several studies subsequently showed that this could be supplied and absorbed well by drinking 600-1 200mls of a solution of 4-8% (40-80g per litre of water) carbohydrate solution per hour (8-11). More importantly, it was also demonstrated both that this ingested carbohydrate becomes the predominant source of carbohydrate energy late in a bout of prolonged exercise, and that it can delay the onset of fatigue during prolonged cycling and running as well as improving the power output that can be maintained.

**Drink formulation**

The research findings above have helped to shape the formulation of most of today’s popular carbohydrate drinks. Most of these supply energies in the form of glucose or glucose polymers (see box for explanation) at a concentration of around 6%, to be consumed at the rate of around 1 000mls per hour, so that around 60g per hour of carbohydrate is ingested. Higher concentrations or volumes than this are not recommended because not only does gastric distress become a problem, but also the extra carbohydrate ingested is simply not absorbed or utilised.

But as we’ve already mentioned, 60g per hour amounts to around 250kcals per hour, which provides only a modest replenishment of energy compared to that being expended during training or competition. Elite endurance athletes bur over 1 200kcals per hour, of which perhaps 1 000kcals or more will be derived from carbohydrate, leaving a shortfall of at least 750kcals per hour. It’s hardly surprising, therefore, that one of the goals of sport nutrition had been to see whether it’s possible to increase the rate of carbohydrate replenishment. And now a series of studies carried out by scientists at the University of Birmingham I the UK indicates that this may be possible.

**Carbohydrate type and performance**

Many of the early studies on carbohydrate feeding during exercise used solutions of glucose, which produced demonstrable improvement in performance as discussed. In the mid-1990s, some researches experimented by varying the type of carbohydrate used I drinks, for example by using glucose polymers or sucrose (table sugar). However, it seemed that there was little evidence that these other types of carbohydrate offered any advantage

But, at about the same time, a Canadian research team were experimenting with giving mixtures of two different sugars (glucose and fructose) to cyclists. In one of experiment cyclists pedalled for two hours at 60% of VO2max while ingesting 500mls of one of five different drink mixtures:

* 50g glucose;
* 100g glucose;
* 50g fructose;
* 100g fructose;
* 100g of 50g glucose + 50g fructose.

These sugars were radio-labelled with carbon-13 so the researchers so the researchers could see how well they were absorbed and oxidised for energy by measuring the amount of carbon dioxide containing carbon-13 exhaled by the cyclist (as supposed to unlabelled carbon dioxide, which would indicate oxidation of stored carbohydrate). The key finding was that 100g of the 50/50 glucose fructose mix produced a 21% larger rate than 100g of pure glucose alone and a 62% larger rate than 100g of pure fructose alone.

Although these findings provided experimental support for using mixtures of carbohydrates in the energy supplements for endurance athletes, it wasn’t until 2003 that researchers from the University of Birmingham in the UK began looking more closely at the issue. They wanted to see whether combinations of different sugars could be absorbed and utilised more rapidly than the 0.1g per minute peak values that had been recorded with pure glucose drinks.

One of their early experiments compared the oxidation rates of ingested carbohydrate in nine cyclists during three-hour cycling sessions at 60% of VO2max (15). During the rides, the cyclists drank 1 950mls of radio-labelled carbohydrate solution, which supplied one of the following:

* 1.8g per min of pure glucose;
* 1.2g of glucose + 0.6g per minute of sucrose;
* 1.2g of glucose + 0.6g per minute of maltose;
* Water (control condition).

The results showed that while the pure glucose and glucose/maltose drinks produced an oxidation rate of 1.06g of carbohydrate per minute, the glucose/sucrose combination drink produced a significantly higher rate of 1.25g per minute. This was an important finding because while both maltose and sucrose are disaccharides*,* maltose is composed of just two chemically bonded glucose molecules, whereas sucrose combines a glucose with a fructose molecule. This being absorbed more rapidly and therefore producing higher rates of carbohydrate oxidation.

**Carbohydrate Building Blocks**

The fundamental building blocks of carbohydrates are molecules known as sugar. Although there are a few sugars, the most important is glucose, which can be built into very long chains to form starch (found in bread, pasta, potatoes, rice *etc*). Fructose is also important, accounting for a significant proportion of the carbohydrate found in fruits. The disaccharide *(i.e. two sugar unit)* sucrose is composed of glucose and fructose linked together and is more commonly known as table sugar.

Sport drinks often contain glucose and fructose, but also other carbohydrates such as dextrins, maltodextrins and glucose polymers. These consist of chains of glucose units linked together, with varying amounts of chain length and branching. Because of their more complex structure, more digestion is required, which tends to slow the rate of absorption, resulting in a smoother, more sustained uptake into the bloodstream.

**Intestinal absorption of glucose and fructose**

Like many nutrients, sugars aren’t absorbed passively – i.e. they don’t just ‘leak’ across the intestinal wall into the bloodstream. They have to be actively transported across the b special proteins called ‘transporter proteins’.

We now know that the intestinal transport of glucose occurs via a glucose transporter called SGLT1, which is located in the brush-border membrane of the intestine. It is likely that the SGLT1-transporters become saturated at a glucose ingestion rate of around 1g per minute (i.e. all the transport sites are occupied), which means at ingestion rates above 1g per minute, the surplus glucose molecules must ‘queue up’ to await transportation.

In contrast to glucose, fructose is absorbed from the intestine by a completely different transporter called GLUT-5. So, when carbohydrate is given at 1.8g per minute as 1.2g per min of glucose and 0.6g per min of fructose rather than 1.8g per min of pure glucose, the extra fructose molecules don’t have to ‘queue up’ as they have their own route across the intestine independent of glucose transporters. The net effect is that more carbohydrate in total find its way into the bloodstream, which means that more is available for oxidation to produce energy.

**Fructose connection**

the same team has also performed another carbohydrate ingestion study on eight cyclist pedalling at 63% of O2max for two hours (16). In this study the cyclists performed four exercise trials in random order while drinking a radio-labelled solution supplying of one of the following:

* 1.2g per min of glucose (medium glucose);
* 1.8g per min of glucose (high glucose);
* 1.2g of glucose + 0.6g of fructose per minute (glucose/fructose blend);
* Water (control).

There were two key findings; firstly, the carbohydrate oxidation rate when drinking high glucose drink was no higher than when medium glucose was consumed; secondly, the peak and average oxidation rates of ingested glucose/fructose solution were around 50% higher than both glucose-only drinks.

These findings point strongly to the fact that the maximum rate of glucose absorption into the body is around 1.2g per oxidation – probably because the absorption mechanism is already saturated. But because giving extra fructose does increase overall carbohydrate oxidation rates, they also indicate that fructose in the glucose/fructose drink was absorbed from the intestine via different mechanisms than glucose (*see box above*).

The studies above and others had shown that glucose/fructose mixtures do result in higher oxidation rates of ingested carbohydrate, especially in the later stages of exercise. But what the team wanted to find out was whether this extra carbohydrate uptake could help with water uptake from the intestine, and whether the increased oxidation of ingested carbohydrate had a sparing effect on muscle glycogen, or other sources of stored carbohydrate (*e.g.* In the liver).

To do this, they set up another study using a similar protocol to that above (eight trained cyclists pedalling at around 60% VO2max on three separate occasions, ingesting one of the three drinks on each occasion)). However, in this study, the duration of the trial was extended to five hours during which the subjects drank one of the following:

* 1.5g per minute of glucose;
* 1.5g per minute of glucose/fructose mix (1.0g glucose/0.5g fructose);
* Water (Control).

The water used in the drinks was also radio-labelled (to help determine uptake into the bloodstream) and the cycling trials were conducted in warm conditions (32˚C) to add heat stress. Exercise in the heat results in a greater reliance on carbohydrate metabolism, which is thought to be due to increased muscle glycogen utilisation and is associated with higher levels of fatiguing lactate concentrations.

There were several important findings from this study:

* During the last hour of exercise, the oxidation rate of ingested carbohydrate was 36% higher with glucose/fructose than with pure glucose;
* During the same time period, the oxidation rate of endogenous (i*.e.* stored) carbohydrate was significantly less with glucose/fructose than with pure glucose;
* The rate of water uptake from the gut into the blood stream was significantly higher with glucose/fructose than with pure glucose;
* The perception of stomach fullness was reduced with the glucose/fructose drink compared to pure glucose;
* Perceived rates of exertion in the later stages of the trial were lower with glucose/fructose than with pure glucose.

Although no direct muscle glycogen measurements were made, the kinetics of the rate of appearance and disappearance of glucose in the bloodstream from the drinks led the researchers to postulate that the extra carbohydrate oxidation observed could be as a result of increased liver oxidation, or the formation of non-glucose energy substrates during exercise, such as lactate, which is known to be an important fuel for exercising muscles. More research is needed to determine the exact mechanisms involved.

**Implications for athletes**

These research findings are very encouraging; higher rates of energy production from ingested carbohydrate, lower rates from stored carbohydrate and increased water uptake sounds like a dream combination for endurance athletes. But can a glucose/fructose drink enhance endurance performance in real athletes under real race conditions?

That’s the question scientists at the University of Hertfordshire are currently trying to answer in a double-blind, placebo-controlled study to test commercially available drinks, which was set up earlier this year. The main goal is to compare the effects on cycling performance of a popular glucose/glucose polymer (containing very low levels of fructose - ~ 3-4%) drink with a 2:1 glucose/fructose drink (trade name of ‘Super Carbs’ – 33% fructose) on cycling performance. The results of these trials are yet to be published, but according to the research team, the initial findings are ‘very promising’.

**Recommendations for athletes**

It is worth rushing out and trying to get hold of a glucose/fructose drink to use during training/competition? Despite the promising initial research, the cautious approach would be to hold back until scientists have confirmed beyond doubt that these drinks really do confer a performance advantage.

However, fructose is cheap, which means these drinks are no more expensive than conventional glucose/fructose polymer drinks; as all the indications are that any performance difference produced by a glucose/fructose drink will be positive, there’s certainly no harm in a ‘try it and see approach’, and possible much to gain.

Having said that, it’s important to remember that conventional glucose/glucose polymer drinks can still confer proven advantages for endurance athletes when taken during training or competition; both glucose/glucose polymer and glucose/fructose drinks can boost endurance performance over using nothing at all! But should the initial findings above be confirmed, the future for glucose/fructose carbohydrate drinks looks bright.