Supporting Research Bibliography

By Dr. Jason Barker, ND

Glucose/Carbohydrate efficacy in exercise

Dietary carbohydrate as an ergogenic aid for prolonged and brief competitions in sport.

Walberg-Rankin J. Int J Sport Nutr. 1995 Jun;5 Suppl:S13-28.

Reduction of body stores of carbohydrate and blood glucose is related to the perception of fatigue and the inability to maintain high-quality performance. This has been clearly shown with aerobic, endurance events of moderate intensity of over 90 min duration. Carbohydrate intake may also have relevance for athletes involved in short, high-intensity events, especially if body weight control is an issue. Prevention of carbohydrate depletion begins with a high-carbohydrate training diet of about 60-70% carbohydrate. If possible, carbohydrate beverages should be consumed during the event at the rate of 30-70 g/hr to reduce the chance of body carbohydrate depletion. Finally, replacement of body carbohydrate stores can be achieved most rapidly if 40-60 g of carbohydrate is consumed as soon as possible after the exercise and at repeating 1-hr intervals for at least 5 hr after the event.

Carbohydrate nutrition and fatigue

Costill DL, Hargreaves M. Sports Med. 1992 Feb;13(2):86-92.

Carbohydrates are important substrates for contracting muscle during prolonged, strenuous exercise, and fatigue is often associated with muscle glycogen depletion and/or hypoglycaemia. Thus, the goals of carbohydrate nutritional strategies before, during and after exercise are to optimise the availability of muscle and liver glycogen and blood glucose, with a view to maintaining carbohydrate availability and oxidation during exercise. During heavy training, the carbohydrate requirements of athletes may be as high as 8 to 10 g/kg bodyweight or 60 to 70% of total energy intake. Ingestion of a diet high in carbohydrate should be encouraged in order to maintain carbohydrate reserves and the ability to train intensely. Ingestion of a high carbohydrate meal 3 to 4 hours prior to exercise ensures adequate carbohydrate availability and enhances exercise performance. Although hyperinsulinaemia associated with carbohydrate ingestion in the hour prior to exercise may result in some metabolic alterations during exercise, it may not necessarily impair exercise performance and may, in some cases, enhance performance. Carbohydrate ingestion during prolonged, strenuous exercise, where performance is often limited by carbohydrate availability, delays fatigue. This is due to maintenance of blood glucose levels and a high rate of carbohydrate oxidation, rather than a slowing of muscle glycogen utilisation, although liver glycogen reserves may be spared. During recovery from exercise, muscle glycogen resynthesis is critically dependent upon the ingestion of carbohydrate. Factors influencing the rate of muscle glycogen resynthesis include the timing, amount and type of carbohydrate ingested and muscle damage. Adequate carbohydrate availability before, during and after exercise will maintain carbohydrate oxidation during exercise and is associated with enhanced exercise performance.

Human muscle glycogen metabolism during exercise. Effect of carbohydrate supplementation.

Tsintzas K, Williams C. Sports Med. 1998 Jan;25(1):7-23.

Carbohydrate (CHO) ingestion during exercise, in the form of CHO-electrolyte beverages, leads to performance benefits during prolonged submaximal and variable intensity exercise. However, the mechanism underlying this ergogenic effect is less clear. Euglycaemia and oxidation of blood glucose at high rates late in exercise and a decreased rate of muscle glycogen utilisation (i.e. glycogen 'sparing') have been proposed as possible mechanisms underlying the ergogenic effect of CHO ingestion. The prevalence of one or the other mechanism depends on factors such as the type and intensity of exercise, amount, type and timing of CHO ingestion, and pre-exercise nutritional and training status of study participants. The type and intensity of exercise and the effect of these on blood glucose, plasma insulin and catecholamine levels, may play a major role in determining the rate of muscle glycogen utilisation when CHO is ingested during exercise. The ingestion of CHO (except fructose) at a rate of > 45 g/h, accompanied by a significant increase in plasma insulin levels, could lead to decreased muscle glycogen utilisation (particularly in type I fibres) during exercise. Endurance training and alterations in pre-exercise muscle glycogen levels do not seem to affect exogenous glucose oxidation during submaximal exercise. Thus, at least during low intensity or intermittent exercise, CHO ingestion could result in reduced muscle glycogen utilisation in well trained individuals with high resting muscle glycogen levels. Further research needs to concentrate on factors that regulate glucose uptake and energy metabolism in different types of muscle fibres during exercise with and without CHO ingestion.

Carbohydrate ingestion during prolonged exercise: effects on metabolism and performance.

Coggan AR, Coyle EF. Exerc Sport Sci Rev. 1991;19:1-40.

It is well recognized that energy from CHO oxidation is required to perform prolonged strenuous (greater than 60% VO2 max) exercise. During the past 25 years, the concept has developed that muscle glycogen is the predominant source of CHO energy for strenuous exercise; as a result, the potential energy contribution of blood glucose has been somewhat overlooked. Although during the first hour of exercise at 70-75% VO2max, most of the CHO energy is derived from muscle glycogen, it is clear that the contribution of muscle glycogen decreases over time as muscle glycogen stores become depleted, and that blood glucose uptake and oxidation increase progressively to maintain CHO oxidation (Fig. 1.7). We theorize that over the course of several hours of strenuous exercise (i.e., 3-4 h), blood glucose and muscle glycogen contribute equal amounts of CHO energy, making blood glucose at least as important as muscle glycogen as a CHO source. During the latter stages of exercise, blood glucose can potentially provide all of the CHO energy needed to support exercise at 70-75% VO2max if blood glucose availability is maintained. During prolonged exercise in the fasted state, however, blood glucose concentration often decreases owing to depletion of liver glycogen stores. This relative hypoglycemia, although only occasionally severe enough to result in fatigue from neuroglucopenia, causes fatigue by limiting blood glucose (and therefore total CHO) oxidation. The primary purpose of CHO ingestion during continuous strenuous exercise is to maintain blood glucose concentration and thus CHO oxidation and exercise tolerance during the latter stages of prolonged exercise. CHO feeding throughout continuous exercise does not alter muscle glycogen use. It appears that blood glucose must be supplemented at a rate of approximately 1 g/min late in exercise. Feeding sufficient amounts of CHO 30 minutes before fatigue is as effective as ingesting CHO throughout exercise in maintaining blood glucose availability and CHO oxidation late in exercise. Most persons should not wait, however, until they are fatigued before ingesting CHO, because it appears that glucose entry into the blood does not occur rapidly enough at this time. It also may be advantageous to ingest CHO throughout intermittent or low-intensity exercise rather than toward the end of exercise because of the potential for glycogen synthesis in resting muscle fibers. Finally, CHO ingestion during prolonged strenuous exercise delays by approximately 45 minutes but does not prevent fatigue, suggesting that factors other than CHO availability eventually cause fatigue.

Carbohydrate feedings before, during, or in combination improve cycling endurance performance.

Wright DA, Sherman WM, Dernbach AR.

Exercise Physiology Laboratory, School of Health, Physical Education, and Recreation, Ohio State University, Columbus 43210-1284.

This study examined the effects of no carbohydrate (PP), preexercise carbohydrate feeding (CP), carbohydrate feedings during exercise (PC), and the combination of carbohydrate feedings before and during exercise (CC) on the metabolic responses during exercise and on exercise performance. Nine well-trained cyclists exercised at 70% of maximal O2 uptake until exhaustion. Blood glucose peaked 30 min after the preexercise carbohydrate feeding and at the start of exercise was 25% below the prefeeding concentration (4.76 mM). At exhaustion, glucose had declined to 3.8 (PP), 4.0 (CP), 4.6 (PC), and 5.0 mM (CC). Insulin was 300% above basal (7 microU/ml) at the start of exercise for CC and CP and returned to baseline by 120 min of exercise. When carbohydrates were consumed, the rate of carbohydrate oxidation was significantly higher throughout exercise than during PP. Total work produced during exercise was 19-46% (P less than 0.05) higher when carbohydrates were consumed. Time to exhaustion was 44% (CC), 32% (PC), and 18% (CP) greater than PP (201 min; P less than 0.05). Performance was improved by ingestion of carbohydrates before and/or during exercise; performance was further improved by their

combination. This is probably the result of enhanced carbohydrate oxidation, especially during the later stages of exercise.

Effects of carbohydrate ingestion before and during exercise on glucose kinetics and performance.

Febbraio MA, Chiu A, Angus DJ, Arkinstall MJ, Hawley JA. J Appl Physiol. 2000 Dec;89(6):2220-6.

We investigated the effect of carbohydrate (CHO) ingestion before and during exercise and in combination on glucose kinetics, metabolism and performance in seven trained men, who cycled for 120 min (SS) at approximately 63% of peak power output, followed by a 7 kJ/kg body wt time trial (TT). On four separate occasions, subjects received either a placebo beverage before and during SS (PP); placebo 30 min before and 2 g/kg body wt of CHO in a 6.4% CHO solution throughout SS (PC); 2 g/kg body wt of CHO in a 25.7% CHO beverage 30 min before and placebo throughout SS (CP); or 2 g/kg body wt of CHO in a 25.7% CHO beverage 30 min before and 2 g/kg of CHO in a 6.4% CHO solution throughout SS (CC). Ingestion of CC and CP markedly (>8 mM) increased plasma glucose concentration ([glucose]) compared with PP and PC (5 mM). However, plasma [glucose] fell rapidly at the onset of SS so that after 80 min it was similar (6 mM) between all treatments. After this time, plasma [glucose] declined in both PP and CP ($P < 0.05$) but was well maintained in both CC and PC. Ingestion of CC and CP increased rates of glucose appearance (R(a)) and disappearance (R(d)) compared with PP and PC at the onset of, and early during, SS ($P < 0.05$). However, late in SS, both glucose R(a) and R(d) were higher in CC and PC compared with other trials ($P < 0.05$). Although calculated rates of glucose oxidation were different when comparing the four trials ($P < 0.05$), total CHO oxidation and total fat oxidation were similar. Despite this, TT was improved in CC and PC compared with PP ($P < 0.05$). We conclude that 1) preexercise ingestion of CHO improves performance only when CHO ingestion is maintained throughout exercise, and 2) ingestion of CHO during 120 min of cycling improves subsequent TT performance.

Carbohydrate ingestion improves endurance performance during a 1 h simulated cycling time trial.

el-Sayed MS, Balmer J, Rattu AJ. *J Sports Sci.* 1997 Apr;15(2):223-30.

This study examined the effect of carbohydrate ingestion on metabolic and performance-related responses during and after a simulated 1 h cycling time trial. Eight trained male cyclists (VO2 peak = 66.5 ml kg-1 min-1) rode their own bicycles mounted on a windload simulator to imitate real riding conditions. At a self-selected maximal pace, the cyclists performed two 1 h rides (separated by 7 days) and were fed either an 8% carbohydrate or placebo solution. The beverages were administered 25 min before (4.5 ml kg-1) and at the end (4.5 ml kg-1) of the ride. With carbohydrate feeding, plasma glucose tended ($P = 0.21$) to rise before the time trial. Compared with rest, the plasma glucose concentration decreased significantly ($P < 0.05$) at the end of both rides, with no statistically significant difference being observed between treatments. Thereafter, plasma glucose increased significantly ($P < 0.05$) at 15 and 30 min into recovery and was significantly higher at 30 min during the carbohydrate trial compared with the placebo trial. No significant changes in plasma free fatty acids were observed during the ride. However, a significant increase (P < 0.05) in free fatty acids was found at 15 and 30 min into recovery, with no difference between trials. Mean power output was significantly (P < 0.05) greater during the carbohydrate compared with the placebo trial (mean +/- S.E.: 277 +/- 3 and 269 +/- 3 W, respectively). The greater distance covered in the carbohydrate compared with the placebo trial (41.5 +/- 1.06 and 41.0 +/- 1.06 km, respectively; P < 0.05) was equivalent to a 44 s improvement. We conclude that pre-exercise carbohydrate ingestion significantly increases endurance performance in trained cyclists during a 1 h simulated time trial. Although the mechanism for this enhancement in performance with carbohydrate ingestion cannot be surmised from the present results, it could be related to a higher rate of carbohydrate oxidation, or to favourable effects of carbohydrate ingestion on the central component of fatigue.

Carbohydrate supplementation and perceived exertion during prolonged running.

Utter AC, Kang J, Nieman DC, Dumke CL, McAnulty SR, Vinci DM, McAnulty LS. Med Sci Sports Exerc. 2004 Jun;36(6):1036-41.

PURPOSE: The purpose of this study was to investigate the relationship between carbohydrate energy substrate and hormonal regulation on the perception of exertion during prolonged running. METHODS: Sixteen experienced marathoners ran on treadmills for 3 h at approximately 70% VO2max on two occasions while receiving 1 L x h carbohydrate (C) or placebo (P) beverages. Blood and vastus lateralis muscle biopsy samples were collected before and after exercise. RESULTS: The pattern of change in ratings of perceived exertion (RPE) over time was significantly different between C and P ingestion (P < 0.01) with attenuated RPE responses found in the latter part of the 3 h run. The pattern of change in the respiratory exchange ratio and carbohydrate oxidation rates were significantly greater (P < 0.01) in the C than P condition. Change in muscle glycogen content did not differ between C and P (P = 0.246). C relative to P ingestion was associated with higher plasma levels of glucose, insulin, and lactate and lower levels plasma cortisol. CONCLUSIONS: These data indicate that a lower RPE was associated with a higher carbohydrate oxidation, plasma glucose, and insulin levels, and lower plasma cortisol during prolonged running after C supplementation as compared with P feeding despite no differences in muscle glycogen content. These findings support a physiological link between RPE and carbohydrate substrate availability as well as selected hormonal regulation during prolonged running.

Effect of carbohydrate ingestion and hormonal responses on ratings of perceived exertion during prolonged cycling and running.

Utter AC, Kang J, Nieman DC, Williams F, Robertson RJ, Henson DA, Davis JM, Butterworth DE. Eur J Appl Physiol Occup Physiol. 1999 Jul;80(2):92-9.

This randomized, double-blind, placebo-controlled study was designed to determine the influence of exercise mode, and 6% carbohydrate (C) versus placebo (P) beverage ingestion, on ratings of perceived exertion (RPE) and hormonal regulation to 2.5 h of high-intensity running and cycling (approximately 75% maximum oxygen uptake) by ten triathletes who acted as their own controls. Statistical significance was set at P < or = 0.05. The pattern of change in RPE over time was significantly different between C and P ingestion (P < 0.001) and between running and cycling modes (P = 0.001). The lowest RPE values were seen in the C-cycling sessions and the highest in the P-running sessions. The pattern of change in the respiratory exchange ratio and fat and carbohydrate oxidation rates were significantly different between the C and P conditions but not between the running and cycling modes. C relative to P ingestion (but not exercise mode) was associated with higher plasma levels of glucose and insulin and lower plasma cortisol and growth hormone levels. The pattern of change in plasma levels of catecholamines and lactate did not differ between the C and P conditions. These data indicate that a lower RPE was associated with a higher level of carbohydrate oxidation, higher plasma glucose and insulin levels, and lower plasma cortisol and growth hormone levels during cycle exercise following C supplementation as compared to P feeding. These findings support a physiological link between RPE and carbohydrate substrate availability as well as selected hormonal regulation during cycle exercise.

Oral [(13)C]glucose and endogenous energy substrate oxidation during prolonged treadmill running.

Couture S, Massicotte D, Lavoie C, Hillaire-Marcel C, Peronnet F. J Appl Physiol. 2002 Mar;92(3):1255-60.

Six male subjects were studied during running exercise (120 min, 69% maximal oxygen consumption) with ingestion of a placebo or 3.5 g/kg of [(13)C]glucose (approximately 2 g/min). Indirect respiratory calorimetry corrected for urea excretion in urine and sweat, production of (13)CO(2) at the mouth, and changes in plasma glucose (13)C/(12)C were used to compute energy substrate oxidation. The oxidation rate of exogenous glucose increased from 1.02 at minute 60 to 1.22 g/min at minute 120 providing approximately 24 and 33% of the energy yield (%En). Glucose ingestion did not modify protein oxidation, which provided approximately 4-5%En, but significantly increased glucose oxidation by approximately 7%, reduced lipid oxidation by approximately 16%, and markedly reduced endogenous glucose oxidation (1.25 vs. 2.21 g/min between minutes 80 and 120, respectively). The oxidation rate of glucose released from the liver (0.38 and 0.47 g/min, or 10-13%En at minutes 60 and 120, respectively), and of plasma glucose (1.30-1.69 g/min, or 34 and 45%En and 50 and 75% of glucose oxidation) significantly increased from minutes 60 to 120, whereas the oxidation of muscle glycogen significantly decreased (1.28 to 0.58 g of glucose/min, or 34 and 16%En and 50 and 25% of glucose oxidation). These results indicate that, during moderate prolonged running exercise, ingestion of a very large amount of glucose significantly reduces endogenous glucose oxidation, thus sparing muscle and/or liver glycogen stores.

Nutritional strategies for promoting fat utilization and delaying the onset of fatigue during prolonged exercise.

Lambert EV, Hawley JA, Goedecke J, Noakes TD, Dennis SC.
J Sports Sci. 1997 Jun;15(3):315-24.

Carbohydrate ingestion before and during endurance exercise delays the onset of fatigue (reduced power output). Therefore, endurance athletes are recommended to ingest diets high in carbohydrate (70% of total energy) during competition and training. However, increasing the availability of plasma free fatty acids has been shown to slow the rate of muscle and liver glycogen depletion by promoting the utilization of fat. Ingested fat, in the form of long-chain (C16-22) triacylglycerols, is largely unavailable during acute exercise, but medium-chain (C8-10) triacylglycerols are rapidly absorbed and oxidized. We have shown that the ingestion of medium-chain triacylglycerols in combination with carbohydrate spares muscle carbohydrate stores during 2 h of submaximal (< 70% VO2 peak) cycling exercise, and improves 40 km time-trial performance. These data suggest that by combining carbohydrate and medium-chain triacylglycerols as a pre-exercise supplement and as a nutritional supplement during exercise, fat oxidation will be enhanced, and endogenous carbohydrate will be spared. We have also examined the chronic metabolic adaptations and effects on substrate utilization and endurance performance when athletes ingest a diet that is high in fat (> 70% by energy). Dietary fat adaptation for a period of at least 2-4 weeks has resulted in a nearly two-fold increase in resistance to fatigue during prolonged, low- to moderate-intensity cycling (< 70% VO2 peak). Moreover, preliminary studies suggest that mean cycling 20 km time-trial performance following prolonged submaximal exercise is enhanced by 80 s after dietary fat adaptation and 3 days of carbohydrate loading. Thus the relative contribution of fuel substrate to prolonged endurance activity may be modified by training, pre-exercise feeding, habitual diet, or by artificially altering the hormonal milieu or the availability of circulating fuels. The time course and dose-response of these effects on maximizing the oxidative contribution of fat for exercise metabolism and in exercise performance have not been systematically studied during moderate- to high-intensity exercise in humans.

Glucose/Carbohydrate Pre-Race

Carbohydrate feedings 1 h before exercise improves cycling performance.

Sherman WM, Peden MC, Wright DA. Exercise Physiology Laboratory, School of Health, Physical Education, and Recreation, Ohio State University, Columbus.

The effects of consuming two different amounts of liquid carbohydrate 1 h before exercise on the metabolic responses during exercise and on exercise performance were determined. Subjects consumed either 1.1 g (LC) or 2.2 g (HC) carbohydrate/kg body mass or a placebo (P). Subjects cycled at 70% of maximal oxygen consumption (VO2max) for 90 min and then underwent a performance trial. Blood glucose and insulin responses during exercise were different among the three trials. Total carbohydrate oxidation was greater for the carbohydrate trials compared with P. Time-trial performance was significantly improved by LC and HC. Despite elevated insulin concentrations at the start of and during exercise, and despite an initial drop in blood glucose, consumption of between 1.1 and 2.2 g liquid carbohydrate/kg body mass 60 min before moderately intense prolonged exercise can improve performance, presumably via enhanced carbohydrate oxidation.

The effect of glucose ingestion on endurance upper-body exercise and performance.

Spendiff O, Campbell IG. Int J Sports Med. 2002 Feb;23(2):142-7.

The physiological responses to glucose supplementation during arm crank exercise were investigated. Ten subjects of mean age 28 +/- 8 years; stature 180.8 +/- 6.5 cm; mass 82.7 +/- 11.5 kg, .VO(2) peak 3.10 +/- 0.50 l x min(-1) were tested on two occasions separated by a week. A 7.6% glucose drink or placebo was administered in a blind crossover design 20 min prior to exercise. Subject's arm cranked for 60 min at an exercise intensity of 65% .VO(2)peak followed by a 20 min performance test. Rate of ventilation, oxygen uptake, RER, heart rate and blood lactate demonstrated similar responses between trials throughout the course of the hour. The blood glucose concentrations at rest were similar between trials increasing after glucose ingestion to show a significant difference ($p < 0.05$) to the placebo trial at the onset of exercise, then returning to resting values after 20 min. The 20 min performance tests revealed that after glucose ingestion athletes achieved a greater mean distance of 12.55 +/- 1.29 km than in the placebo trial of 11.50 +/- 1.68 km ($p < 0.05$). In conclusion, the results showed that after one-hour of arm crank exercise, performance over a further twenty minutes was improved when glucose was ingested twenty minutes prior to exercise.

Influence of pre-exercise glucose ingestion of two concentrations on paraplegic athletes.

Spendiff O, Campbell IG. J Sports Sci. 2005 Jan;23(1):21-30.

In this study, we assessed the influence that pre-exercise glucose ingestion of two concentrations has on the physiological responses of paraplegic athletes. Eight men with paraplegia ingested a drink containing 4% (low) or 11% (high) carbohydrate in a randomized double-blind crossover design, 20 min before exercise. The participants performed wheelchair exercise at 65% of peak oxygen uptake for 1 h followed by a 20 min performance test. During both trials, the physiological responses were similar and indicated steady-state exercise. At the onset of exercise, blood glucose concentrations in both trials increased after carbohydrate ingestion ($P < 0.05$) before returning to resting values after 20 min of exercise and there were no differences between trials. Free fatty acid concentrations increased from rest to 1 h of exercise in both trials, with a greater increase during the low carbohydrate trial that led to a difference in free fatty acids between trials at the end of the 1 h tests ($P < 0.05$). There was a tendency for the performance distances and power outputs achieved during the high carbohydrate trial to be greater than those achieved during the low carbohydrate trial ($P= 0.08$). In conclusion, when paraplegic athletes ingested low and high carbohydrate drinks before exercise, the decline in blood glucose concentrations was similar. The tendency for higher blood glucose concentrations, respiratory exchange ratios and power outputs and lower free fatty acid concentrations ($P < 0.05$) during the high carbohydrate trial suggests that a higher concentration of carbohydrate in a sports drink might be a better choice for paraplegic athletes.

Pre-exercise glucose ingestion at different time periods and blood glucose concentration during exercise.

Tokmakidis SP, Volaklis KA. Int J Sports Med. 2000 Aug;21(6):453-7.

The purpose of this study was to investigate the effects of glucose ingestion (GI) at different time periods prior to exercise on blood glucose (BG) levels during prolonged treadmill running. Eight subjects (X+/-SD), age 20+/-0.5yr, bodymass 70.7+/-4.1 kg, height 177+/-4 cm, VO2max 52.8+/-7.8 ml x kg(-1) x min(-1) who underwent different experimental conditions ingested a glucose solution (1 g/kg at 350 ml) 30 min (gl-30), 60 min (gl-60), 90 min (gl-90), and a placebo one 60 min (pl-60) prior to exercise in a counterbalanced design. Afterwards they ran at 65% of VO2max for 1 hour and then at 75 % of VO2max till exhaustion. Fingertip blood samples (10 microl) were drawn every 15 min before and during exercise for the determination of BG levels. Oxygen uptake (VO2), heart rate (HR), and blood lactate (La) were also measured every 15 min during exercise. Peak BG values were reached within 30 min after GI but were different (p < 0.01) at the onset of exercise (gl-30: 147+/-22, gl-60: 118+/-25, gl-90: 109+/-22, pl-60: 79+/-5mg/dl). The two-way ANOVA repeated measures and the Tukey post-hoc test revealed a higher BG concentration (p < 0.05) for the gl-30 and the pl-60 as compared to the gl-60 and gl-90 during running (e.g. 15min run: 82+/-11, 68+/-5, 64+/-3, 78+/-7, and 60min run: 98+/-12, 85+/-12, 83+/-11, 94+/-11 mg/dl for gl-30, gl-60, gl-90, and pl-60, respectively). However, this did not significantly affect the duration of treadmill running. The La levels were higher (p < 0.05) after GI as compared to placebo throughout exercise (values at exhaustion: 4.6+/-0.2, 5.0+/-1.5, 4.8+/- 1.7 mmol/l for gl-30, gl-60, gl-90, and 3.5+/-0.8 mmol/l for placebo). The gl-30 and the placebo fluctuated closer to normoglycaemic levels. The glucose ingestion (60 to 90 min) prior to exercise lowered the blood glucose levels without affecting the duration of running performance at 75% VO2max. Thus, in order to maintain normoglycaemic levels, pre-exercise glucose supplementation should be given 30 min before the onset of exercise.

Improvements in exercise performance: effects of carbohydrate feedings and diet.

Neufer PD, Costill DL, Flynn MG, Kirwan JP, Mitchell JB, Houmard J. J Appl Physiol. 1987 Mar;62(3):983-8

In an effort to determine the effects of carbohydrate (CHO) feedings immediately before exercise in both the fasted and fed state, 10 well-trained male cyclists [maximum O2 consumption (VO2 max), 4.35 +/- 0.11 l/min)] performed 45 min of cycling at 77% VO2 max followed by a 15-min performance ride on an isokinetic cycle ergometer. After a 12-h fast, subjects ingested 45 g of liquid carbohydrate (LCHO), solid carbohydrate confectionery bar (SCHO), or placebo (P) 5 min before exercise. An additional trial was performed in which a high-CHO meal (200 g) taken 4 h before exercise was combined with a confectionery bar feeding (M + SCHO) immediately before the activity. At 10 min of exercise, serum glucose values were elevated by 18 and 24% during SCHO and LCHO, respectively, compared with P. At 0 and 45 min no significant differences were observed in muscle glycogen concentration or total use between the four trials. Total work produced during the final 15 min of exercise was significantly greater (P less than 0.05) during M + SCHO (194,735 +/- 9,448 N X m), compared with all other trials and significantly greater (P less than 0.05) during LCHO and SCHO (175,204 +/- 11,780 and 176,013 +/- 10,465 N X m, respectively) than trial P (159,143 +/- 11,407 N X m). These results suggest that, under conditions when CHO stores are less than optimal, exercise performance is enhanced with the ingestion of 45 g of CHO 5 min before 1 h of intense cycling.(ABSTRACT TRUNCATED AT 250 WORDS)

Effects of preexercise carbohydrate ingestion on mountain bike performance.

Cramp T, Broad E, Martin D, Meyer BJ. Med Sci Sports Exerc. 2004 Sep;36(9):1602-9.

PURPOSE: This study examined the performance and metabolic effects of consuming 1.0 (LC) and 3.0 (HC) grams of carbohydrate (CHO) per kilogram body mass (BM), 3 h before a 93-min simulated mountain bike race. METHODS: After two familiarization trials, eight male subjects undertook two CHO trials in a double-blind counterbalanced fashion on a cycle ergometer. The HC meal was supplemented with maltodextrin while maintaining the same glycemic index and apparent volume of food as the LC meal. Stochastic cycling was undertaken for 93 min (4 x 22.50-min laps) with performance measured as the total work performed in 6 x 30-s periods each lap during the test. RESULTS: Performance in lap 1 was better with LC ($P < 0.03$) whereas performance in lap 4 was better with HC ($P < 0.02$). Overall performance was 3% greater in HC compared with LC (NS, $P = 0.13$). Serum glucose was significantly lower ($P < 0.04$) in HC immediately before the mountain bike test (180 min postprandial) and at 10 min into the test ($P < 0.01$). Gastrointestinal comfort decreased similarly for both trials over time ($P < 0.05$). CONCLUSION: These data suggest that ingestion of 3.0 g x kg(-1) BM of CHO 3 h before a 93-min mountain bike simulated race does not produce a statistically significant improvement in overall performance compared with 1.0 g x kg(-1) BM. However, in real terms, a 3% performance improvement may benefit athletes in a race situation. Differences in performance during the first and last laps indicate a variation in pacing strategies that may have resulted from differing blood glucose levels between trials.

Glucose & Glycemic Index

Ingestion of a high-glycemic index meal increases muscle glycogen storage at rest but augments its utilization during subsequent exercise.

Wee SL, Williams C, Tsintzas K, Boobis L. School of Sport and Exercise Sciences, Loughborough University, Loughborough, Leicestershire LE11 3TU, UK.

The aim of this study was to compare the effect of preexercise breakfast containing high- and low-glycemic index (GI) carbohydrate (CHO) (2.5g CHO/kg body mass) on muscle glycogen metabolism. On two occasions, 14 days apart, seven trained men ran at 71% maximal oxygen uptake for 30 min on a treadmill. Three hours before exercise, in a randomized order, subjects consumed either isoenergetic high- (HGI) or low-GI (LGI) CHO breakfasts that provided (per 70 kg body mass) 3.43 MJ energy, 175 g CHO, 21 g protein, and 4 g fat. The incremental areas under the 3-h plasma glucose and serum insulin response curves after the HGI meal were 3.9- ($P < 0.05$) and 1.4-fold greater ($P < 0.001$), respectively, than those after the LGI meal. During the 3-h postprandial period, muscle glycogen concentration increased by 15% ($P < 0.05$) after the HGI meal but remained unchanged after the LGI meal. Muscle glycogen utilization during exercise was greater in the HGI (129.1 +/- 16.1 mmol/kg dry mass) compared with the LGI (87.9 +/- 15.1 mmol/kg dry mass; $P < 0.01$) trial. Although the LGI meal contributed less CHO to muscle glycogen synthesis in the 3-h postprandial period compared with the HGI meal, a sparing of muscle glycogen utilization during subsequent exercise was observed in the LGI trial, most likely as a result of better maintained fat oxidation.

Glycemic index--a new tool in sport nutrition?

Burke LM, Collier GR, Hargreaves M. Int J Sport Nutr. 1998 Dec;8(4):401-15.

The glycemic index (GI) provides a way to rank foods rich in carbohydrate (CHO) according to the glucose response following their intake. Consumption of low-GI CHO foods may attenuate the insulin-mediated metabolic disturbances associated with CHO intake in the hours prior to exercise, better maintaining CHO availability. However, there is insufficient evidence that athletes who consume a low-GI CHO-rich meal prior to a prolonged event will gain clear performance benefits. The ingestion of CHO during prolonged exercise promotes CHO availability and enhances endurance and performance, and athletes usually chose CHO-rich foods and drinks of moderate to high GI to achieve this goal. Moderate- and high-GI CHO choices appear to enhance glycogen storage after exercise compared with low GI CHO-rich foods. However, the reason for this is not clear. A number of attributes of CHO-rich foods may be of value to the athlete including the nutritional value of the food or practical issues such as palatability, portability, cost gastric comfort, or ease of preparation.

Glucose & Diabetic Athletes

Blood glucose changes in diabetic children and adolescents engaged in most common sports activities.

Corigliano G, Iazzetta N, Corigliano M, Strollo F. Acta Biomed Ateneo Parmense. 2006;77 Suppl 1:26-33.

Circulating insulin levels decrease and substrate glycogenolysis-mediated conversion into glucose increases just a few minutes after normal subjects start exercising, but during sustained physical activity muscles massively utilize blood glucose, thus causing glycogenolysis to increase further until the end of the session. After that, in order to get liver and muscle glycogen stores up to pre-exercise levels again, blood glucose is mostly utilized, thus causing late-onset hypoglycaemia in the absence of any extra carbohydrate supply and rebound hyperglycaemia after a while. This and other patho-physiological mechanisms are dealt with in the present paper, and practical hints are provided to the clinician to cope with children-specific adaptation phenomena to exercise in t1DM.