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Fueling During Endurance Exercise: Balancing Intake with Gastrointestinal Tolerances

Monique Ryan

It is well established that optimal amounts of carbohydrate and fluid consumed during endurance exercise enhances various measures of performance. The rate of gastric emptying is an important step towards providing the working muscles with exogenous carbohydrates and fluid. Once emptied from the stomach carbohydrate absorption takes place primarily in the duodenum and jejunum along with sodium and water. Individual carbohydrates are absorbed at a rate of 1 g per minute, or a maximum of 60 g per hour, with glucose and fructose absorbed via separate transporter mechanisms. Simultaneous use of separate carbohydrate transporters can increase the intestine's absorptive capacity to 75 - 90 g per hour. However, higher intake of carbohydrates and fluid can cause gastrointestinal (GI) symptoms in some athletes. "Nutritional gut training" may improve gastric emptying, intestinal absorption, and reduce the occurrence and/or severity of GI symptoms during exercise.

INTRODUCTION

Athletes should start endurance workouts or events well hydrated and optimally fueled with proper attention to their daily training diet, particularly in the hours prior to exercise.

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Carbohydrates provide approximately 50-60% of energy during 1 to 4 hours of continuous exercise at 70% of maximal oxygen capacity.[1] For a pace that requires 80-90% of oxygen consumption carbohydrates are the primary fuel source and provide up to 90% of the energy expended.[2]

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Depletion of carbohydrate stores (glycogen) and fluid leads to fatigue and the inability to sustain speed, strength and power, skills, and mental focus. Fatigue can be as dramatic as hitting the wall at mile 20 of a 26.2-mile marathon or as subtle as diminished quality of daily workouts. From a nutritional perspective, fatigue can be related to a number of factors including:

- Depleted glycogen stores
- Dehydration
- Hyperthermia
- Hyponatremia
- Gastrointestinal disturbances

Regular consumption of a combination of fluid, carbohydrates, and electrolytes can prevent onset of fatigue and maintain performance. This article will review gastrointestinal (GI) physiology as it relates to carbohydrate, fluid, and sodium assimilation during exercise, dietary carbohydrate guidelines for athletes, and evidence for nutritional gut training or "training the gut" to reduce risk of GI symptoms while enhancing endurance performance.

Table 1. Factors that Affect the Rate of Gastric Emptying

Decrease Rate	Increase Rate
• Dehydration • High calorie content of a meal • High fat meal • High osmolality (high solute load) of food or beverage • Intense exercise greater than 70% VO2 max • Stress and anxiety	• Large meal or large fluid volume due to gastric distension

Gastrointestinal Motility and Absorption

Gastric Emptying – A number of factors can influence the rate of gastric emptying (see Table 1) including hypohydration, mental stress (being keyed-up), intense exercise (steady state above 70% VO2 max or high intensity intervals), and the high solute load of sports confectionaries (carbohydrate gels and energy bars, blocks, or chews) or concentrated drinks (carbohydrate-electrolyte beverages).[3] Sports drinks at 6% concentration (6 g of mixed sugars and glucose polymers per 100 mL) are iso-osmolar, or isotonic and empty quickly. Shi, et al.[4] found no differences in gastric emptying with isotonic test solutions ranging from 250 - 434 mOsm/kg H_2O. However, hyperosmolar beverages such as fruit juice and soft drinks at a 10-15% concentration (10-15 g carbohydrate per 100 mL, osmolality of 500 – 800 mOsm/kg H_2O) can delay gastric emptying, therefore, it is advised to avoid beverages with an osmolality greater than 500 mOsm/kg H_2O during exercise. Interestingly, the temperature of liquids has little effect on gastric emptying as intragastric temperatures rapidly equilibrate.

The volume of liquid consumption is a main factor that determines the speed of gastric emptying, with larger volumes emptying faster than smaller volumes. Mears, et al.[5] investigated how the pattern of sport drink ingestion affected carbohydrate oxidation rates (as a surrogate to gastric emptying) and GI discomfort during exercise. Runners completed two 100-minute moderate treadmill runs. For one run subjects consumed 200 mL every 20 minutes and for the other run they consumed 50 mL every 5 minutes. Carbohydrate oxidation rates were 2% higher during the run when 200 mL was consumed every 20 minutes, thus confirming that larger volumes of fluids empty from the stomach more rapidly compared to smaller volumes. There were no reported differences in GI comfort of symptoms between trials.

Small Bowel Absorption - After emptying from the stomach, digestive enzymes act on carbohydrates and the resulting monosaccharides are absorbed by way of active and passive transport in the small intestine (Figure 1). Two carbohydrate transporters have been identified; SGLT 1 is the sodium-dependent glucose and galactose transporter while GLUT 5 is the non-sodium dependent fructose transporter. Osmotic gradients from active transport of sodium and glucose (SGLT 1) result in rapid water absorption across the small bowel mucosa. Glucose can increase the absorption of sodium. With regular ingestion of sports fuels and water the SGLT 1 and GLUT 5 transport systems maintain appropriate blood glucose, sodium, and hydration levels for the working muscles and central nervous system.

General Nutrition Guidelines for Exercise

Fueling during exercise is an important component of the athlete's nutrition plan. Routine, planned and practiced, intake during training sessions lasting longer than 75 minutes brings several benefits including:

- Delays and minimizes dehydration and its negative impact on cardiovascular and thermoregulatory physiology
- Prevents hypoglycemia
- Offsets muscle and liver glycogen depletion
- Maintains carbohydrate fuel for the brain
- Offsets electrolytes losses and prevents hyponatremia

Daily recovery or fueling between training sessions requires the correct amount of energy, protein and fat tailored to the athlete's training cycle and specific duration and intensity of workouts. Carbohydrate requirements are based on training intensity and duration (see Table 2) and are needed to replenish the limited fuels of muscle and liver glycogen. For longer training sessions and events, carbohydrates are consumed during exercise to offset the depletion of this stored fuel source. The capacity to absorb carbohydrates during competition can be reduced when athletes restrict carbohydrates, or when following a low-carbohydrate, high fat, or ketogenic diet. It is advised that endurance athletes include some high carbohydrate diet days in their training diet.

Protein intake should meet requirements for growth and maintenance/building of muscle tissue. Fats are required for recovery of muscle triglycerides when exercise sessions are more than 4 hours and

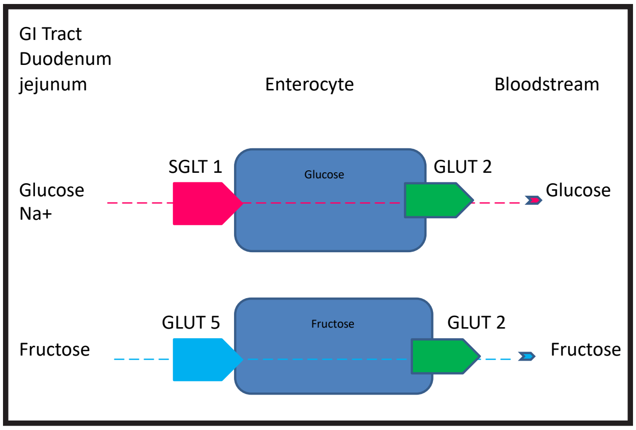

Figure 1. Absorption of Glucose and Fructose

Table 2. Recommended Carbohydrate Intake During Exercise

Exercise	Exercise Duration	CHO*Amount (g/hr)	Comments
Brief	<45 minutes	Not needed	• Not practical
Sustained High Intensity	45-75 minutes	0 to 25	• Beneficial when training in fasted state
Endurance	1-2 hrs	30	• Most forms of CHO
Extended Endurance	2-3 hrs	60-75	• Plan for refueling, hydration, and GI tolerances
Extensive Endurance	2.5 - ≥5 hrs	75-90	• CHO mixes of glucose and fructose, plan for refueling, and GI tolerances • For very long events easily digested foods may be needed and include energy bars, dried fruit, pretzels, peanut butter and jelly sandwich bites, Fig Newtons™, rice cakes, bananas. However, excess consumption of foods may slow gastric emptying and result in significant GI symptoms.

*CHO = carbohydrate

as a concentrated source of energy. Some athletes have variable, yet specific, macronutrient timing and portioning for pre-exercise, post-exercise and in the hours to the next training session to optimize muscle repair and building glycogen fuel replenishment. See Table 3 for more information on the daily training diet.

Hydration requirements are variable and depend on the exercise duration and intensity, the environment's temperature and humidity, as well as individual sweat rates. Athletes are advised to gather sweat loss data to develop a systematic plan for each event and to practice this plan for at least 8 weeks during workouts prior to the event. Sweat losses can be estimated by converting weight change during training into fluid loss (see Table 4). This is best done for workouts lasting 45 to 75 minutes and fluid can be consumed during the workout if desired. Athletes can use this technique in various conditions to become familiar with sweat losses in various weather conditions. Alternatively, athletes can use commercially available devices/services to measure sweat loss (see Table 5).

Sweat rates can range from 0.5L to over 3L per hour. Athletes are advised to avoid over-hydration; it is recommended to replace only 70% to a maximum 100% of sweat losses. Hydration needs will vary depending on the type of training

Table 3. The Daily Training Diet and Practical Carbohydrate Issues

Endurance athletes typically follow training cycles that vary in specificity, volume, and intensity and general nutrition requirements can vary day to day and cycle to cycle.

Example: Triathlete Jack weighs 75 kg and 8% body fat. Using the Cunningham equation, RMR = 370 + (21.6 X lean body mass {kg}), resting metabolic rate (RMR) is estimated at 1860 calories. Jack has a desk job so RMR is multiplied by 1.2 for 2,232 daily activity calories. Training for today is a 60 minute high intensity swim and a 90 minute moderate intensity run in the evening.

Nutrition Requirements

Total Energy Requirement:
(1860 x 1.2 = 2,232 daily activity) + (Swim: 700 calories) + (Run: 1200 calories) = 4132 or 4100-4200 kcal/d

Carbohydrate Requirement:
75 kg x 10 g/kg = 750 g

Protein:
75 kg x 1.8 g/kg = 135 g

Fat:
75 kg x 1g/kg = 75 g

- Jack's distribution of macronutrients is a function of his training schedule.
- He may have a light carbohydrate snack 30 – 60 mins before his morning swim and consume some carbohydrate from a gel (with water) midway through the swim.
- A recovery breakfast with ample carbohydrate and some protein starts the muscle glycogen replenishment process (current recommendations for a recovery meal or snack are 1-1.5 g/kg carbohydrate and 10 to 25 g high quality protein).
- Lunch will provide a steady consumption of carbohydrates post training (every 3 hours) to replenish the muscle glycogen depleted from the swim and allows for adequate fuel for the 90-minute run.
- A light carbohydrate snack before the evening run and a sports drink during the 90 min run.
- Dinner is consumed after the run with moderate amounts of protein and remainder of carbohydrate requirements.
- Protein and fat will be evenly distributed among meals with slight adjustment according to preferences.
- Fiber can be consumed after training sessions, though avoided 1-2 hours prior to training, and is typically limited in pre-event meals.

session planned (to account for variations in training duration and intensity and environmental conditions).

Fueling Products for Exercise

Athletes typically use commercially available sports drinks and confectionaries to ingest required nutrients and fluids with the best tolerance. As stated above, drinks up to 6 g carbohydrate per 100 mL empty from the stomach at rates similar to water. While most sports drinks fall into this range, athletes may mix their drinks to a more concentrated solution, or higher energy density, based on personal fueling requirements, desired sodium content, and sweat rates. For example, an athlete with a lower sweat rate and higher fueling requirements might benefit from a more concentrated drink. Electrolyte mixes, mainly sodium, can be added to drinks if needed. Other than sports drinks, endurance athletes may consume

Table 4. Estimating Sweat Loss

1. **Check your weight before and after training (preferably without clothing)**

   ____________ (lb/kg) Weight prior (a)

   ____________ (lb/kg) Weight post (b)

   ____________ (lb/kg) Weight change (a-b)

2. **Convert the weight change (loss) to ounces or mL of fluid loss**

   1 lb equals 15 ounces of fluid

   0.5 kg equals 500 mL fluid

   ___________ lb/kg weight change = ___________ oz/mL

3. **Amount of fluid consumed during the training session**

   _________ oz /mL fluid

   (Do not consume semi-solid or solid foods during training)

4. **Total sweat loss is equal to the fluid loss from exercise plus the fluid consumed**

   _________ oz/mL fluid loss + ________ oz/mL fluid consumed =

   _____________ Total Fluid Loss (oz/mL) over ________ minutes of exercise

Example:

1. Calculate weight change during 1 hour training:
   - 75 kg start weight – 74.5 kg after training = 0.5 kg weight change
2. Convert weight change to fluid loss
   - 0.5 kg weight = 500 mL fluid
3. Fluid consumed during training (1 hour) = 600 mL
4. Total amount of estimated sweat losses =
   - 500 mL + 600 mL = 1100 mL per hour

Table 5. Commercial Devices to Monitor Sweat Rates

Device	Comments
Gatorade® GX Sweat Patch	• Single use patch worn during exercise • Patch is scanned by corresponding app after exercise • Provides sweat and sodium data
Nix™	• Biosensor with app • Continuous measurment of sweat loss • Provides real-time feedback on fluid needs • Integrates with phone, watch or bike computer
Levelen™	• Sweat test kit • Wear a test patch during exercise and then mail the patch to the company • Emailed report of sweat electrolyte analysis
Precision Hydration Centers	• In-person measurement of sweat and sodium losses

carbohydrate products such as gels, energy bars, blocks, or chews.

Oxidation of Combined Carbohydrates During Exercise

Several studies have looked at substrate oxidation rates when combined carbohydrates are ingested during exercise.[6-8] These studies confirmed that utilization of both carbohydrate transporters (SGLT 1 and GLUT 5) with ingestion of mixed carbohydrates increased absorption from 1 g per minute with SGLT 1 only to 1.5-1.7 g per minute with activation of both transporters. The following carbohydrate combinations were tested and found to produce greater oxidation than with the SGLT 1 glucose transporter alone:

1. Maltodextrin (chains of glucose units) and fructose
2. Glucose and fructose
3. Glucose and sucrose (glucose + fructose) and fructose

Both the SGLT 1 and GLUT 5 transporters saturate at the rate of 1 g/min or 60 g/hr. In the above carbohydrate combinations where the ratio of glucose to fructose is at 2:1 the glucose transporter saturates at 60 g/hr and the additional 15 to 30 g of fructose (can be released from sucrose) can occur simultaneously for a total carbohydrate utilization of 75-90 g/hr.[8] If tolerated, higher amounts of fructose can be added moving towards a 1:1 ratio for greater total carbohydrate absorption per hour.

The uptake rates described above (2:1 ratio of glucose to fructose) are often used to formulate sports drinks for endurance training to allow for comfortable consumption of 75-90 g carbohydrate per hour over several hours. If an athlete were to consume 100 g of glucose per hour, they would only absorb/oxidize 60 g/hr, with the rest remaining in the intestine and leading to GI symptoms; the same is true for consumption of high amounts of fructose during exercise.

Researchers have tested the effects of ingesting a glucose and fructose beverage versus a glucose only beverage versus water on endurance cycling performance.[9] They found that ingestion of glucose at 1.2 g/min and fructose at 0.6 g/min (total 1.8 g/min or 108 g carbohydrate) improved endurance cycling performance when compared to 1.8 g/min of glucose only. Subjects cycled for 2 hours at 60% VO2 max followed by 40 km time trial. The time-trial times improved by 8% with the ingestion of glucose plus fructose mix.

A number of studies were then conducted to examine the effect of solid versus liquid carbohydrate sources consumed during exercise.[10,11] Glucose and fructose in a 2:1 ratio was provided as either a gel, solid bar or carbohydrate-electrolyte sports drink at rate of 1.55 g glucose + fructose/min

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(93 g/hr) with matched fluid intake between treatments. The glucose plus fructose mix from all sources resulted in similar oxidation rates, thus the form of carbohydrate ingested did not affect total carbohydrate utilization.

Nutritional Gut Training

Gastrointestinal complaints are common in athletes during endurance events, often resulting in impaired performance. During exercise, blood flow is redirected from the GI tract to the working muscles and can result in abdominal bloating, cramping, nausea, vomiting, diarrhea, and/or pain in the presence of hypohydration or inappropriate food and fluid consumption.[3] The prevalence of GI symptoms can vary greatly depending on the mode of exercise, level of athlete, and weather conditions. The prevalence of GI symptoms in endurance athletes varies from 37-93%.[12] A well-functioning GI system can greatly affect symptoms and performance outcomes.

Nutritional gut training, or "training the gut" is a new concept that refers to practiced ingestion of predetermined amounts of carbohydrates and fluid during training sessions to optimize the adaptability of the intestinal tract (substrate and fluid absorption and to alleviate adverse GI symptoms) during events.[13] Two main goals of gut training are to increase the number of intestinal carbohydrate transporters and to upregulate the transporters' utilization capacity. To increase available SGLT 1 and GLUT 5 transporters, endurance athletes must practice "gut training" in the weeks before an event with strict adherence to their fueling and hydration plans. One study suggests that carbohydrate transporters can be upregulated in a short period of time.[14] Based on animal data, increasing dietary carbohydrate from 40 to 70% of calories could result in doubling SGLT 1 transporters over a 2-week period.[13]

Pushing the Limits of Carbohydrate Absorption

More recently, it has been suggested that intake of 120 g carbohydrate/hr is possible in experienced marathon and ultra-marathon runners. One study compared the effects of carbohydrate doses of 120 g/hr, 90 g/hr, and 60 g/hr in 26 elite ultra-endurance athletes during a mountain marathon.[15] All participants carried out personalized gut training with carbohydrate intakes of up to 90 g/hr at least 2 days weekly in the 4 weeks prior to the marathon. During the marathon, the carbohydrate supplement gel contained 30 g maltodextrin and fructose in 2:1 ratio. The 120 g carbohydrate group consumed 4 gels per hour at the 15, 30, 45, and 60 minute markers. Three athletes withdrew with GI symptoms; though researchers did not disclose to which treatment group they were assigned. Results show that the 120 g/hr carbohydrate dose limited post-race exercise induced muscle damage and that ingestion of 120 g/hr carbohydrate is possible without gastrointestinal distress. While future research is needed to understand the physiological and metabolic mechanisms of this absorption rate, from a practical perspective, the potential effect of training the gut can improve carbohydrate intake, transport, and utilization during endurance exercise.

CONCLUSION

Endurance athletes should incorporate recommended diet and hydration strategies into their training regimen to optimize performance during competition/events. Current recommendations for endurance training are 60 g of carbohydrate/hr for exercise lasting up to 120 minutes. For exercise lasting longer than 2 hours, higher amounts of carbohydrates (up to 90 g/hr) are recommended and should come from a blend of glucose and fructose sources. Consumption of fluid is based on the athlete's sweat rate and personal preference of sports drinks, and sports supplements, or confectionaries. The gut is adaptable so preparing for endurance events should include practice of their event nutrition plan over several weeks; the gut can adapt to absorb and oxidize more carbohydrates which should result in less GI distress. Nutritional gut training leads to better performance, with optimal delivery of carbohydrate, and optimal GI tolerance for the individual athlete. ■

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Answers to this month's crossword puzzle:

1 G	U	2 T	M	3 I	C	4 R	O	5 B	I	6 O	M	E		7 S
A		R		S		E		I		C				P
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35 I	R		T		I			A		36 W	I	P	E	S
37 P	A	N	C	R	E	A	S		38 G	I	V	E	N	