

# Carbohydrate Metabolism & Performance

## Carbohydrate Metabolism Basics

Of the three main macronutrients (fat, protein, carbohydrates) the human body relies on for energy, carbohydrates are the body's preferred fuel source for biological functions and muscle contraction.<sup>1</sup>

Carbohydrates provide energy for the nervous system and active, working muscles, enable metabolism of fat, and inhibit the use of protein as energy.

After consumption, carbohydrates are digested into their most basic components (glucose, fructose, galactose) in the stomach and small intestine. After digestion, these nutrients are absorbed into the bloodstream and transported to the liver.

Glucose moves through the bloodstream to be used as an immediate fuel source for muscle tissue and the brain. Fructose, sucrose and galactose, on the other hand, must first be metabolized into glucose by the liver.

When excess energy is ingested in the form of carbohydrates, it is stored in the skeletal muscles and liver as glycogen. When glycogen stores are replete, excess glucose is oxidized and stored as fat.<sup>2,3</sup> Glycogen is called upon for energy when blood levels of glucose are unable to meet energy demands, such as during prolonged (more than 1-2 hours) exercise. The body's glycogen capacity averages 2,000 calories; this is why carbohydrates are considered a limited fuel source in exercise.

In the presence of inadequate carbohydrates during exercise, there may be a shift toward protein catabolization to sustain blood glucose. During catabolization, amino acids derived from muscle tissue are oxidized for fuel, while others provide substrate for gluconeogenesis.<sup>4</sup>

In this situation, proteins are directed away from their primary task—muscle and connective tissue building blocks—and preferentially used to sustain energy needs. This results in an inefficient, unsustainable use of the body's protein reservoir for energy needs. Athletes deprived of adequate carbohydrate energy during extended bouts of exercise may be at increased risk of poor recovery. In order to prevent catabolism during exercise, athletes need to sustain adequate levels of carbohydrates to prevent the loss of muscle tissue.

The central nervous system depends on glucose as its primary fuel source, with the brain requiring roughly 120 grams of glucose daily.<sup>5</sup> Inadequate blood glucose levels are manifested as weakness, fatigue, dizziness and low blood sugar (hypoglycemia).

When the body's energy demands during activity are not met with adequate carbohydrate levels, performance is impaired, manifested by both physical and mental fatigue.

In a resting state, insulin is required for glucose to enter the cells of the body. During exercise, however, insulin is not needed for either skeletal muscle uptake of glucose<sup>6</sup> or glucose uptake in the brain.<sup>7</sup>

Outside of exercising states, insulin serves as the gatekeeper whereby carbohydrates enter the cells for metabolism. At the time of ingestion (and even in anticipation of carbohydrate consumption<sup>8</sup>), insulin is released and signals the cells to absorb glucose. Once ingested, glucose has three main fates: used for energy, stored as a readily accessible form of energy (glycogen) or stored as a less accessible form of energy (fat).

### **Glucose, Exercise and Energy Demand**

Circulating stores of glucose in the blood stream average 4 grams in a 154-pound person, or roughly a teaspoon of sugar.<sup>9</sup> Numerous tissues are highly sensitive to glucose and rely on this seemingly infinitesimally small amount of carbohydrates, hence blood sugar is under the influence of a sophisticated control system that remarkably balances this supply.

Once exercise commences, the blood sugar regulatory system taps glycogen stores to maintain a near-constant level of blood glucose.

Glycogen stores are not infinite. The majority is stored in the skeletal muscles (500 grams) and liver (100 grams),<sup>10</sup> providing roughly 2,400 kcals of energy. This is only enough energy to fuel more intense exercise for one or two hours.<sup>11</sup> Glycogen becomes depleted as exercise intensity and duration increases, hence the need for athletes to introduce additional carbohydrates to maintain blood glucose.

### **Pre-exercise Carbohydrate Consumption**

Carbohydrate supplementation has demonstrated benefits in the pre, during and post-exercise windows. Carbohydrate intake in the pre-exercise period enhances exercise capacity and time trial performance.<sup>12,13,14,15</sup>

During high-intensity exercise, muscle glycogen is used at a greater rate by Type II (fast twitch) muscles than Type I (slow twitch) muscles. Extensive use of glycogen by Type II fibers may precipitate fatigue.<sup>16</sup>

For many athletes who engage in shorter duration high-intensity exercise, obtaining pre-race energy through meals is problematic due to predictable gastrointestinal distress. Fueling with easily or rapidly digested carbohydrates from liquids or other non-bulky solids, like wafers, 'gummies' or bars, is a viable option for the athlete who requires a pre-race meal but wants to avoid gastrointestinal problems.

Carbohydrate oxidation is required for more strenuous (60% or greater Vo<sub>2</sub> max) exercise,<sup>17</sup> and the majority of carbohydrate energy used during the first hour of high-intensity (70%+ greater Vo<sub>2</sub> max) exercise is derived from muscle glycogen. As stores decline over time, energy is preferentially derived from blood glucose to maintain ongoing levels of carbohydrate oxidation, making blood glucose an important contributor to energy metabolism.<sup>17,18</sup>

### **Carbohydrate Consumption During Exercise**

Carbohydrate ingestion during continuous high-intensity exercise serves to maintain blood glucose concentration and provide ample amounts of carbohydrates for oxidation and exercise tolerance.

During exercise, carbohydrate feeding is generally accepted to improve exercise performance and time to exhaustion (endurance) during prolonged (2+ hours) exercise bouts.<sup>19,20,21</sup>

If blood glucose is maintained beyond depletion of glycogen stores, it can provide all the carbohydrate energy needed to support ongoing exercise at 70%+ Vo<sub>2</sub> max.<sup>17</sup> Fatigue can be prevented by consuming 30-60 grams of rapidly absorbed carbohydrates throughout each hour of exercise.<sup>22</sup>

### **Post-exercise Carbohydrate Consumption Benefits**

The post-exercise window is regarded by many as the most important period of nutrient timing.<sup>23</sup> Consumption of the proper nutrients in correct ratios during this time period can improve repair of damaged muscles and replete energy stores.<sup>24</sup> These benefits are thought to occur in an expedited process that benefits future exercise performance and body composition, hence the multiple references to the concept of the "anabolic window" — a specific post-exercise time period during which heightened nutrient repletion and exercise adaptations occur.

Glycogen is rapidly replaced when carbohydrates are consumed in the immediate post-exercise period, while delaying carbohydrate consumption by two hours will decrease the rate of glycogen re-synthesis by 50%.<sup>25</sup> Additionally, exercise improves insulin-stimulated glucose uptake post-exercise, leading to glucose uptake proportional to the amount of glycogen used.<sup>26</sup> Further, glycogen synthase, the main enzyme involved in glycogen storage, is induced by exercise.<sup>27</sup> These factors combine to produce rapid uptake of glucose post-exercise, facilitating replenishment of glycogen at a rapid rate. Delay of carbohydrates post-exercise will attenuate the rate at which glycogen is repleted and limit recovery.<sup>28</sup>

### **Carbohydrates Versus Fat for Performance**

Diets higher in fat and protein with little carbohydrates have driven some studies looking at performance differences between this and a more traditional, carbohydrate-centric diet for exercise performance. Higher fat, lower carbohydrate (ketogenic) diets led to a carbohydrate-sparing effect during exercise, but no ergogenic benefits were noted.<sup>29,30</sup>

Regardless, carbohydrate-rich foods with a moderate to high glycemic index are the irrefutable post-exercise energy source for rapid restoration of glycogen stores.

### **Carbohydrates, Exercise Performance and Diabetes Risk**

The current obesity epidemic is unarguably fueled by a combination of prevalent societal factors that include, at a minimum, a sedentary lifestyle and caloric overfeeding. Obesity is a well-established precursor to the majority of chronic,<sup>31</sup> but is most often linked with diabetes, resulting in the addition of a new term into our lexicon — diabetesity.<sup>32</sup>

Multiple theories exist to explain this epidemic (changes in our microbiome, viral exposures, genetic polymorphisms and environmental endocrine disruptors), yet none can readily explain the diabetesity epidemic so much as the basics of what is readily apparent: people eat too much and exercise too little. Our modern lifestyles are directly associated with infinite access to energetically dense foods and an attendant decline in energy expenditure.

Prevailing health information focuses on “low fat” and, more recently, “low sugar” foods (to simplify the seemingly infinite parade of fad diets) as the solution for weight loss. Despite these foci, society continues to gain weight and suffer from the consequences.

To solely associate fat or sugar with weight gain and loss misses the point. Weight loss can be achieved, in many instances, on any number of diets that only reduce calories.

Eating a diet consisting mainly of sugary, processed foods, one researcher lost weight over a 10-week period.<sup>33</sup> Despite eating a sugar-rich diet (complemented by a multivitamin, minimal protein supplement and sparing amounts of vegetables), he lost 27 pounds by the end of the experiment.

The recommended daily caloric intake for a man of his size is roughly 2,600 calories; he ate only 1,800 calories each day of the diet. Other indices of health improved as well. His LDL (“bad”) cholesterol lowered by 20%, and his HDL (“good”) cholesterol increased by 20%. His triglycerides (a type of fat in the blood) decreased by 39%.

Examples like this lead to an important conclusion: sugar consumption does not cause weight gain or Type 2 diabetes all by itself. (Type 1 diabetes develops due to genetic and poorly understood environmental factors).

Being overweight and sedentary increases the risk of Type 2 diabetes, wherein the cells of the body become resistant to insulin and lose the ability to metabolize blood sugar.<sup>34</sup>

Weight gain is the result of excess caloric intake and limited caloric expenditure. Regardless of the food type eaten, a person can gain weight and eventually become a Type 2 diabetic. Among the primary risk factors for Type 2 diabetes are overweight/obesity, inactivity, elevated cholesterol and triglycerides, family history and age 45 or older.<sup>35</sup>

Carbohydrate consumption in active, healthy people does not contribute to excessive weight gain or the development of Type 2 diabetes. When healthy athletes purposefully consume carbohydrates to maintain exercise performance, it is oxidized for the sole purpose of energy production, instead of storage. Similarly, moderate carbohydrate consumption in the immediate post-exercise window will replace oxidized glycogen stores, aid in recovery and improve exercise gains.

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