Carbohydrates for Performance Across Adolescence and Adulthood

Joel T. Cramer, PhD, FACSM, FNSCA, FISSN

What is the difference between *sports nutrition* and *performance nutrition*? *Sports nutrition* specifically focuses on improving sports performance in athletes, ranging from marathon runners to gymnasts. When strategically fueled, athletes can perform better. Therefore, *sports nutrition* can be considered finite, focusing on acute, short-term performance improvements structured around individual sport events, seasons, athletes, and teams. In contrast, *performance nutrition* broadly encompasses performance of the human body. Specifically, the performance of skeletal muscle, which impacts nearly all facets of life. Obvious examples of muscle performance include force production and movement that keep our bodies moving during physical activities like walking, playing, swimming, or gardening. Less obvious examples include the preeminent roles of skeletal muscle performance in resting metabolism, posture, balance, low back pain, activities of daily living, and glucose homeostasis. Therefore, *performance nutrition* can be considered infinite, encompassing chronic health improvement structured around life and longevity. We have acquired critical knowledge of skeletal muscle performance through applied science and research originating in *sports nutrition*. This knowledge can be translated and applied to our broader goals of *performance nutrition*, albeit sometimes through opposing mechanisms and reverse engineering. The translation of our knowledge from *sports nutrition* science and research holds the potential to influence long-term skeletal muscle health by improving the quality of carbohydrate consumption from a *performance nutrition* perspective.

The ultimate purpose of carbohydrates in *sports nutrition* is to serve as fuel for energy during sports performance, which demands high levels of immediate and sustained energy.[1] Energy transfer in skeletal muscles occurs through the breakdown and replenishment of adenosine triphosphate (ATP), often described as the body's energy currency. For muscles to contract and produce force and/or movement, ATP is hydrolyzed to adenosine diphosphate (ADP) + inorganic phosphate (Pi) + energy transfer. Ultimately, the ADP is eventually rephosphorylated to ATP to facilitate the cyclic process of energy transfer. Our muscles have the capability to catabolize carbohydrate, fat, and/or protein to replenish ATP stores. However, the quickest and most efficient metabolic pathway that our skeletal muscles rely on for rapid resynthesis of ATP is glycolysis, which is defined as the breakdown (oxidation) of the carbohydrates, glucose or glycogen.[2] In addition to energy storage (ATP), the other basic end byproducts of glycolysis, carbon dioxide and water, are eventually eliminated or recycled by the body via cellular respiration. For the glycolytic metabolic pathway to operate most efficiently, carbohydrate must be consumed and glycogen must be stored, which emphasizes the importance of carbohydrate intake. Therefore, using glycolysis as the primary metabolic pathway by which our muscles quickly and efficiently use carbohydrates as fuel for energy, is heavily reliant on carbohydrate intake.

The rate and magnitude of carbohydrate utilization for energy during sports-related activities is dependent on the intensity and duration of the activity.[1] For the marathoner and high endurance athletes, research in *sports nutrition* indicates that optimal loading strategies can increase carbohydrate stores in the body (ie, endogenous carbohydrates) by nearly 100%.[3] Thus, not only are we capable of substantially manipulating carbohydrate storage in our bodies for sports events, there is a strong implication for evidence-based recommendations in *sports nutrition* to optimize the carbohydrate loading strategy.[1] Ultimately, scenarios like this identify three specific goals for carbohydrate recommendations from sports nutritionists, which include providing exogenous carbohydrates to (1) serve as a fuel source; (2) alter substrate utilization to preserve endogenous carbohydrates as a fuel source; and (3) resynthesize lost or depleted endogenous carbohydrates for fuel sustainability.[1]

ANHI ABBOTT NUTRITION HEALTH INSTITUTE

anhi.org | 2018 117th Abbott Nutrition Research Conference:
Carbohydrates Through the Life Cycle and Across Tissues

181414b(1)/November 2018 LITHO IN USA

Abbott

During overnight fast, there is an 80% reduction in liver glycogen stores, which is likely present when beginning exercise in a fasted state.[4] However, following a mixed meal, 20% of carbohydrate intake is stored as liver glycogen.[1] Similarly, a 42% increase in muscle glycogen has been reported after carbohydrate ingestion.[5] The recommendations for carbohydrate intake timing prior to exercise or sports performance events suggest that high glycemic carbohydrates consumed ≤60 minutes prior to exercise will likely induce hypoglycemia, which may be lessened by including protein.[1] In contrast, complex carbohydrate consumption 2-3 hours prior to exercise allows blood glucose and insulin concentrations to return to baseline, and improves performance without the risk of hypoglycemia during the activity.[1] Incidentally, the phenomenon of exercise-induced hypoglycemia occurs via the same mechanisms responsible for treatment of type 2 diabetes with exercise. Exercise stimulates the uptake of blood glucose into skeletal muscles, which is independent of insulin,[6] thereby demonstrating the translation of reciprocal knowledge obtained through *sports nutrition* research to the health benefits of exercise for the management of carbohydrate-related metabolic health and disease.

The influence of the glycemic index of the carbohydrate ingested, specifically for exercise and athletic performance, appears to have the greatest impact on the timing of energy availability. High glycemic carbohydrate intake rapidly increases blood glucose and insulin concentrations, which can induce hypoglycemia when timed close to the initiation of exercise, but does not seem to impact overall performance compared to low glycemic carbohydrate intake.[7] However, when the goal is a rapid resynthesis of glycogen stores during recovery after exercise, a high glycemic carbohydrate intake may be valuable, but only when there are repeated exercise or athletic performance events in one day, such as a double header in baseball/softball or multiple soccer matches.[8] Subsequently, the recommendation is to consume a high glycemic carbohydrate during recovery after exercise at a rate of 1.0-1.2 $g \cdot kg^{-1} \cdot hour^{-1}$ within 4 hours of recovery, particularly, if the next exercise bout or athletic performance event is 3-6 hours later. Otherwise, the glycemic index or amount of carbohydrate intake during recovery is much less important.[8] Research shows that when low glycemic resistant starches are consumed prior to exercise, performance is not substantially impacted, yet the rate of glycogen recovery is reduced.[9] When translating this *sports nutrition* knowledge to a *performance nutrition* perspective, rapid spikes in blood glucose and insulin concentrations are potentially harmful to long-term skeletal muscle health.

Carbohydrate intake recommendations during long-term endurance athletic events is influenced by the need for high rates of gastric emptying and monosaccharide absorption.[9] During exercise, blood is shunted from the digestive system to the working muscles. Gastrointestinal distress is therefore increased when undigested food and unabsorbed nutrients remain in the digestive system and jostle during exercise bouts. Thus, rapid gastric emptying and rapid carbohydrate absorption are desirable during an athletic event lasting 2 or more hours when carbohydrate intake is usually necessary.[10] Since glucose and fructose are absorbed by two separate transporter mechanisms, carbohydrate absorption can be accelerated when a combination of glucose and fructose are ingested simultaneously. This concept is often referred to as multiple transportable carbohydrates in the *sports nutrition* literature. The effects of consuming multiple transportable carbohydrates is very rapid, large spikes in blood glucose and insulin concentrations, as well as enhanced utilization of exogenous carbohydrates as the immediate source of energy.[11] Although this is desirable during specific *sports nutrition* applications, it is possible that the widespread consequences of consuming large amounts of multiple transportable carbohydrates with high glycemic responses in the general population is damaging to long-term skeletal muscle health from a *performance nutrition* perspective.

The metabolism and substrate utilization in children and adolescents are different from adults. Children have a lower overall glycolytic capacity as evident by (1) lower blood lactate concentrations; (2) lower glycolytic enzyme turnover; (3) lower muscle glycogen; and (4) a greater reliance on slow-twitch, type I fiber mechanisms for energy transfer.[12] Although children quickly adapt to changes in carbohydrate and fat intake, children metabolize fat at a greater rate

ANHI ABBOTT NUTRITION HEALTH INSTITUTE
anhi.org | 2018 117th Abbott Nutrition Research Conference:
Carbohydrates Through the Life Cycle and Across Tissues

181414b(1)/November 2018 LITHO IN USA
Abbott

than adults, which results in more glycogen sparing. Furthermore, adolescents during puberty exhibit transient decreases in glucose tolerance and insulin sensitivity, which promote the storage of excess carbohydrates and display temporary risk factors for type 2 diabetes that return to normal shortly after puberty. Previously malnourished children who are fed for catch-up growth are particularly susceptible to storing excess carbohydrate as fat.[13] The use of low glycemic carbohydrates for children shows potential benefit in decreasing early obesity rates.

The translation of *performance nutrition* by inverting or reverse engineering our knowledge of *sports nutrition* may serve as an effective tool for long-term skeletal muscle health. To invert our *sports nutrition* principles, the reversed goal would be to encourage endogenous carbohydrates as the primary source of fuel for skeletal muscles, and limit the immediate use of exogenous carbohydrates. The new focus would be to force the body to displace and cycle carbohydrates from intake → blood glucose → muscle glycogen → energy utilization, rather than intake → blood glucose → energy utilization. This focus would de-emphasize the necessity of rapid glycogen repletion, yet still accomplish the task of glycogen resynthesis, just over a longer period. The hypothesis would be that cycling carbohydrates through the additional step of storage prior to utilization would reduce the excess amount of circulating carbohydrates, thereby reducing the likelihood of glucose storage as adipose tissue. The concept is depicted in Fig 1 below of the skeletal muscle, adipose tissue (clouds), and liver.

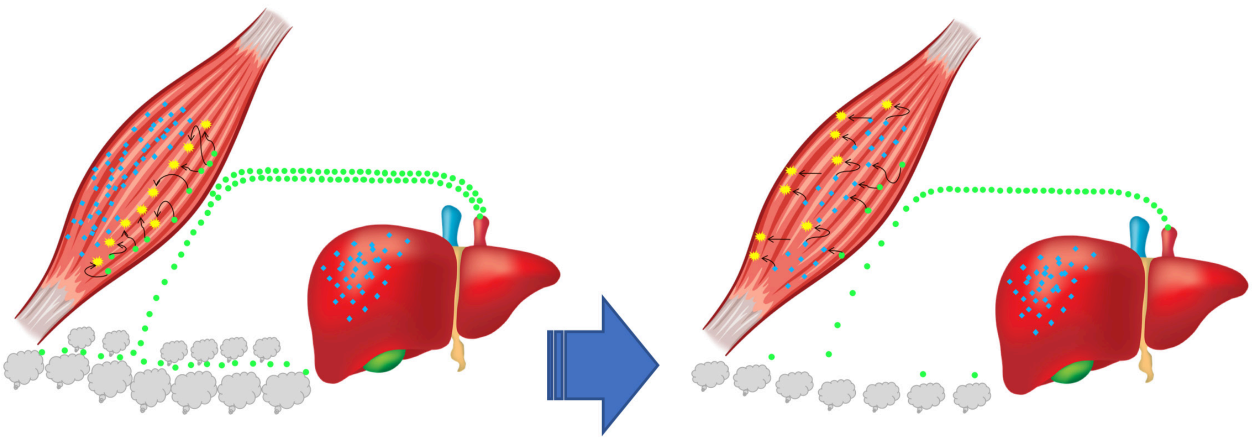

Fig 1. Carbohydrate cycling concept: cycle carbohydrates through muscle glycogen storage prior to energy utilization. Illustrated: skeletal muscle, adipose tissue (clouds), liver. Green dots represent glucose, blue diamonds represent stored glycogen, and yellow bursts represent energy utilization.

The concept of reverse engineering our *sports nutrition* recommendations for long-term health might best start with replacing high glycemic, rapidly absorbed carbohydrates, that are currently available in popular beverages, with low glycemic, slowly absorbed carbohydrates. This reconceptualization of the carbohydrate quality widely consumed in popular beverages to reduce the glycemic response, and promote endogenous carbohydrate use for energy, may be a good first step in promoting long-term skeletal muscle health, reducing obesity, and lowering metabolic disease risk factors.

ANHI ABBOTT NUTRITION HEALTH INSTITUTE

anhi.org | 2018 117th Abbott Nutrition Research Conference:
Carbohydrates Through the Life Cycle and Across Tissues

181414b(1)/November 2018 LITHO IN USA

Abbott

References:

1. Ormsbee MJ, Bach CW, Baur DA. Pre-exercise nutrition: The role of macronutrients, modified starches and supplements on metabolism and endurance performance. *Nutrients.* 2014;6(5):1782-1808.

2. Dashty M. A quick look at biochemistry: Carbohydrate metabolism. *Clin Biochem.* 2013;46(15):1339-1352.

3. Burke LM, van Loon LJC, Hawley JA. Postexercise muscle glycogen resynthesis in humans. *J Appl Physiol* (1985). 2017;122(5):1055-1067.

4. Coyle EF, Coggan AR, Hemmert MK, Lowe RC, Walters TJ. Substrate usage during prolonged exercise following a preexercise meal. *J Appl Physiol* (1985). 1985;59(2):429-433.

5. Taylor R, Magnusson I, Rothman DL, et al. Direct assessment of liver glycogen storage by 13C nuclear magnetic resonance spectroscopy and regulation of glucose homeostasis after a mixed meal in normal subjects. *J Clin Invest.* 1996;97(1):126-132.

6. Mul JD, Stanford KI, Hirshman MF, Goodyear LJ. Exercise and regulation of carbohydrate metabolism. *Prog Mol Biol Transl Sci.* 2015;135:17-37.

7. Baur DA, Vargas Fde C, Bach CW, Garvey JA, Ormsbee MJ. Slow-absorbing modified starch before and during prolonged cycling increases fat oxidation and gastrointestinal distress without changing performance. *Nutrients.* 2016;8(7):392.

8. Alghannam AF, Gonzalez JT, Betts JA. Restoration of muscle glycogen and functional capacity: Role of post-exercise carbohydrate and protein co-ingestion. *Nutrients.* 2018;10(2):253.

9. Roberts MD, Lockwood C, Dalbo VJ, Volek J, Kerksick CM. Ingestion of a high-molecular-weight hydrothermally modified waxy maize starch alters metabolic responses to prolonged exercise in trained cyclists. *Nutrition.* 2011;27(6):659-665.

10. Jeukendrup A. A step towards personalized sports nutrition: Carbohydrate intake during exercise. *Sports Med.* 2014;44(Suppl 1):25-33.

11. Jentjens RL, Achten J, Jeukendrup AE. High oxidation rates from combined carbohydrates ingested during exercise. *Med Sci Sports Exerc.* 2004;36(9):1551-1558.

12. Montfort-Steiger V, Williams CA. Carbohydrate intake considerations for young athletes. *J Sports Sci Med.* 2007;6(3):343-352.

13. Marcelino H, Veyrat-Durebex C, Summermatter S, et al. A role for adipose tissue de novo lipogenesis in glucose homeostasis during catch-up growth: A Randle cycle favoring fat storage. *Diabetes.* 2013;62(2):362-372.

181414b(1)/November 2018 LITHO IN USA