Carbohydrates, Water, Protein, Physical Training, and Sport Performance

The need for carbohydrate is a foremost thought among athletes. Pasta dinners the night before games and other high-carbohydrate meals help maximize muscle glycogen stores while gels and sport drink during training or competition help fuel working muscle as well as maintain blood glucose levels. After training or competition, carbohydrate is invaluable to recover glycogen stores, maximize muscle net protein balance, and help fuel other repair mechanisms. Glucose is the primary carbohydrate fuel for working muscle, and its contribution to total energy increases relative to exercise intensity and decreases with prolonged duration secondary to waning muscle glycogen.

Many other factors will influence how much carbohydrate is used during exercise including an athlete's general diet, timing, and composition of the most recent meal and the consumption of a sport beverage during exercise. In addition to pre- and post-exercise considerations, interest in the role of the timing and type of carbohydrate in the post- workout recovery period is growing as a means of refueling and supporting recovery efforts and maximizing skeletal muscle protein synthesis potential.

MUSCLE GLYCOGEN AND BLOOD GLUCOSE

Muscle tissues (biopsies) taken before and after exhaustive exercise show that muscle glycogen content is reduced. Meanwhile, the difference between the level of glucose in the arteries supplying skeletal muscles and in the veins that drain them is greater when the muscles are engaged in physical activity. Furthermore, both hypoglycemia and muscle glycogen depletion have proved to be independently involved in reducing athletic performance and promoting fatigue. The total amount of muscle glycogen is approximately 300 to 500 g depending on an athlete's gender, size, and training status, while liver glycogen stores range between 60 and 120 g. Meanwhile, a blood glucose concentration of 70 to 110 mg/100 mL would approximate 4 to 6 g of glucose for a total blood volume of 5.5 L or the equivalent of 16 to 24 kcal.

DIETARY CARBOHYDRATE

The forms of carbohydrate commonly found in natural foods including grains, fruits, vegetables, and dairy are starches and sugars such as glucose, fructose, lactose, and sucrose. Manufactured sport bars, shakes, gels, etc, use glucose, fructose, maltodextrin, corn syrup, high-fructose corn syrup, starches, fruit pastes, and purees with the choice based on sensory and functional properties and cost. In addition, the type of carbohydrate chosen can have different properties in the digestive tract as well as varied glycemic and insulinemic effects. Furthermore, the combination of other nutrients, particularly amino acids, peptides, and protein, brings about additional considerations for recovery, net muscle protein synthesis, and soreness.

CARBOHYDRATE METABOLISM DURING EXERCISE

It has long been known that during exercise, the utilization of carbohydrate by skeletal muscle increases. However, because free glucose is found in relatively low levels in the blood and within muscle cells, increased glucose demands during exercise must be met by glycogen breakdown (glycogenolysis) and by an increased uptake of circulating glucose via the translocation of G1uT4 transporters to the sarcolemma in an insulin-independent manner. Glucose is metabolized via glycolysis yielding pyruvate, which can be converted to lactic acid (lactate) or enter mitochondria for aerobic metabolism. Increased exercise intensity leads to the recruitment of more type II muscle fibers that have lower 02 availability and less mitochondria than type I fibers and thus are more carbohydrate dependent and produce more lactic acid. The increased reliance on carbohydrate as an energy source when exercise intensity increases is demonstrated by an elevation in the respiratory exchange ratio and the level of lactic acid in the blood during high- intensity exercise. At roughly 50 to 65% Vo2peak, the percentage contribution made by farty acids to energy expenditure tends to peak and as intensity increases farther the reliance on carbohydrate does as well, especially muscle glycogen. Furthermore, a strong relationship exists between the depletion of muscle glycogen stores and/or hypoglycemia and the onset of fatigue during endurance exercise bouts in the range of 60 to 85% Vo2peak. As blood glucose levels approach 45 mg/100 mL, one may experience lightheadedness, lethargy, and nausea (neuroglycopenia) (68). For highly trained individuals, exercise at this intensity could be endured for more than 2 to 3 hours (72). This is a typical time frame for sports such as endurance cycling (e.g., tour stages and cycling centuries), marathons (42 km or 26.2 miles), triathlons (sprint or Olympic distance), and Nordic skiing.

CARBOHYDRATE INGESTION BEFORE EXERCISE

General daily recommendations for athletes are 8 to 10 g of carbohydrate per kilogram of body mass daily or □60% energy. Many athletes engage in carbohydrate loading (or glycogen supercompensation) to maximize glycogen stores, a practice that involves very high-carbohydrate intake (>70% daily caloric intake from carbohydrate), reduced training, and/ or cessation in the days leading to an endurance event or game. While the classic method of glycogen loading involved glycogen depletion with 1 or more strenuous exercise bouts and a very low-carbohydrate intake for a couple of days, more recent studies suggest a similar degree of glycogen optimization by simply tapering and ceasing exercise and consuming a high-carbohydrate diet. Thus, one potential benefit of ingesting carbohydrate in the hours prior to exercise would be to raise muscle glycogen levels prior to the onset of exercise.

CARBOHYDRATE DURING EXERCISE

Carbohydrate consumption during exercise increases the availability of carbohydrate to working muscle fibers, which can have a positive influence on endurance performance as well as intermittent high-intensity performance, the latter of which could be applicable to sports such as football, ice hockey, and soccer. Carbohydrate type is an important consideration as glucose, maltose, sucrose, amylopectin, and maltodextrins are oxidized at higher rates than fructose, amylose, and galactose.

Whether or not carbohydrate ingestion can slow the rate of muscle glycogen breakdown remains debated. Some research involving cyclists suggests no effect while studies involving treadmill running have suggested that carbohydrate ingestion may actually slow the rate of glycogen breakdown, especially in type I fibers. Regardless, carbohydrate ingestion during endurance exercise can extend performance time prior to fatigue.

CARBOHYDRATE AFTER EXERCISE

Ingesting carbohydrate, either in liquid or solid form shortly after training or competition, is crucial to maximizing muscle glycogen recovery. Timing is critical. If carbohydrate is ingested within 30 minutes or so after exercise, enhanced glucose uptake occurs as a result of the increased G1uT4 translocation during exercise. On the contrary, if carbohydrate delivery is delayed by 2 hours, the rate of glycogen recovery is slowed by 50%. Irrespective of post-exercise timing, maximal glycogen resynthesis is realized if 1.2 g of carbohydrate per kilogram per hour is consumed every 15 to 30 minutes for up to 5 hours, while maximal glycogen levels are restored within 24 hours if dietary carbohydrate intake levels of 8 g of carbohydrate per kilogram per day are achieved. A carbohydrate intake of 9 to 10 g of carbohydrate per kilogram per day is suggested for athletes who are completing intense exercise bouts on consecutive days.

The glycemic and insulinemic effect of different carbohydrates is an important consideration. High—molecular weight carbohydrates have become popular in more recent years based on purported faster absorption and more potent insulinemic effect than simpler sugars such as glucose. For instance, when well-trained men endured glycogen-depleting exercise and then consumed 75 g of a commercial processed high—molecular weight, low osmolality carbohydrate with fast digestive kinetics (Vitargo; SweCarb, Skeppsbron, Sweden) or a glucose/maltodextrin solution (low—molecular weight, high osmolality) immediately after and at 30, 60, and 90 minutes (58) post exercise, it was reported that the high—molecular weight, processed carbohydrate solution, led to a 68% faster glycogen recovery within the first 2 hours of recovery. Higher glycemic index foods may allow for a more rapid glycogen recovery versus lower glycemic index foods. Meanwhile, the coingestion of carbohydrate (4 g/kg body mass) with caffeine (8 mg/kg body mass) has been reported to result in a greater accumulation of glycogen during recovery from exhaustive exercise . The addition of protein to carbohydrate has also been reported to enhance muscle glycogen recovery.

However it has been shown that more frequent supplementation, such as every 15 to 30 minutes, results in rates of synthesis 25-30% higher than when supplementing every 2 hours. The amount of carbohydrate necessary to maximize glycogen storage when supplementing frequently is 1.5 g/kg body weight/hr. The amount of carbohydrate and protein found to be most effective ranges between 1.2 and 1.5 g CHO/kg body weight and .4-.6 g PRO/kg when provided immediately post exe4cise at 2-hour intervals.

<u>PRACTICAL APPLICATIONS/GENERAL RECOMMENDATIONS</u>

- The general recommendation for carbohydrate intake among athletes is 6 to 10 g/kg body weight (1). For endurance athletes training aggressively or competing daily, a carbohydrate intake at the high end is better suited.
- Athletes need to experiment with timing and type of carbohydrate to identify what works best for them.

<u>PRE-EXERCISE CARBOHYDRATE</u>

- General recommendation for carbohydrate intake 3 to 4 hours prior to exercise for an adult is 2 g/kg or roughly 200 to 350 g. This would be appropriate to raise glycogen stores at the onset of exercise and potentially enhance performance especially if there was an extended fasting period prior (e.g., sleep).
- Many athletes choose foods that they have tolerated well in the past and that have minimal indigestible material (e.g., fiber). This meal should be lower in fat to allow for an optimal rate of emptying from the stomach and should provide fluids to optimize hydration status.

DURING EXERCISE

• During endurance exercise bouts, athletes should strive to ingest 30 to 60 g of carbohydrate per hour of performance to maintain blood glucose levels and optimize glucose / uptake and oxidation. This can be achieved by drinking 600 to 1,200 / mL of a 6 to 8% carbohydrate store drink per hour.

POST-EXERCISE

• Immediately after training or competition, it is recommended that athletes ingest at least 1.5 g of carbohydrate per kilogram of body weight.

• Ingesting 1.2 g of carbohydrate per / kilogram of body weight every 30 / minutes over a 5-hour period can promote maximal glycogen resynthesis.

• Maximal glycogen levels can restored within 24 hours at dietary carbohydrate intake levels of 8 g /of carbohydrate per kilogram per dy.

• Waiting to ingest carbohydrate /for a couple of hours after strenuous exercise will dramatically reduce the rate of glycogen recovery.

CARBOHYDRATE TYPE

• Despite lower glycemic and insulinemic responses with fructose versus glucose, at this time, it does not seem that there is a performance benefit to using either if fructose is well tolerated.

• Glycernic index of a pre-exercise food(s) can clearly impact metabolic response; however, the impact on exercise performance is unresolved.

• Waxy maize starch (amylopectin) can offer lower insulinemic responses compared with glucose if used prior to exercise but result in similar carbohydrate oxidation rates and performance during prolonged endurance exercise. Also, waxy maize starch can be used after exercise to facilitate fast muscle glycogen recovery in a manner similar to glucose and rnaltodextrin if ingested in the post-exercise period.

• Commercial processed high— molecular weight carbohydrates may enhance post-exercise insulin levels and the rate of glycogen resynthesis, which could be beneficial for short-term recovery periods prior to subsequent performance.

• Amylose and resistant starches are not recommended as an exclusive carbohydrate source viable carbohydrate option before, during, or after exercise.

Table 3
Nutritional content of commercially available carbohydrate-electrolyte beverages

Beverage (per 8 oz)	Calories	Carbohydrate (g)	Carbohydrate (%)	Sodium (mg)
Gatorade	50	14	6	110
Powerade	70	19	8	55
All Sport	70	19	8	55
HydraFuel	66	16	7	25
Cytomax	66	13	5	53
Exceed	70	17	7	50
10-K	60	15	6	55
Quickick	67	16	7	100
1st Ade	60	16	7	55
Pedialyte	25	6	2.5	253
Coca-Cola	103	27	11	6
Orange juice	104	25	10	6
Water	0	0	0	Low

Table 2
Rate of fluid loss and required fluid replacement

	Percent of body mass lost (in lbs)						
	1%	2%	3%	4%			
Body mass (lbs)	**Pounds of body mass lost**						
140	1.4	2.8	4.2	5.6			
160	1.6	3.2	4.8	6.4			
180	1.8	3.6	5.4	7.2			
200	2	4	6	8			
220	2.2	4.4	6.6	8.8			
240	2.4	4.8	7.2	9.6			
260	2.6	5.2	7.8	10.4			
280	2.8	5.6	8.4	11.2			
300	3	6	9	12			
320	3.2	6.4	9.6	12.8			
340	3.4	6.8	10.2	13.6			
			Sweat rate				
Time (min)	0.5 L/h	1 L/h	1.5 L/h	2 L/h	2.5 L/h	3 L/h	3.5 L/h
	Amount of fluid lost (in lbs) according to sweat rate						
30	0.6	1.1	1.7	2.2	2.8	3.3	3.9
60	1.1	2.2	3.3	4.4	5.5	6.6	7.7
90	1.7	3.3	5.0	6.6	8.3	9.9	11.6
120	2.2	4.4	6.6	8.8	11.0	13.2	15.4
150	2.8	5.5	8.3	11.0	13.8	16.5	19.3
180	3.3	6.6	9.9	13.2	16.5	19.8	23.1
	Cups of fluid needed to replace body mass loss						
30	1	2	3	4	5	6	7
60	2	4	6	8	11	13	15
90	3	6	10	13	16	19	22
120	4	8	13	17	21	25	30
150	5	11	16	21	26	32	37
180	6	13	19	25	32	38	44

Athletes and coaches should monitor fluid losses during prolonged exercise bouts in hot/humid environments to determine the rate at which fluid is lost as sweat from the body because many factors can influence an individual's sweat rate. Minimally, consuming 100 mL (.5 cups) of fluid every 10 minutes has been shown to help offset fluid losses and is recommended as a baseline recommendation.

PRACTICAL APPLICATIONS FOR PROTEIN

Although it is not possible to make conclusive recommendations regarding protein intake for optimal performance, the following observations and recommendations are made considering the current body of literature:

1. Athletes wishing to enhance lean mass from resistance exercise should never train fasted nor remain fasted in the immediate post-exercise period. Assuming total energy needs are being met, training-induced gains in strength and lean mass can be significantly improved when athletes are given proper pre- and post-exercise (i.e., pre-workout) nutrient combinations.

2.Essential amino acids ingested before resistance exercise lead to a greater increase in muscle protein accretion than when they are ingested after exercise. In contrast, whole whey proteins ingested before or after resistance exercise lead to similar effects on amino acid uptake, regardless of the timing of ingestion. Consume a post-workout nutrient mixture that contains approximately 2 parts carbohydrates to 1 part protein, where protein intake constitutes 0.25—0.50 grams per kilogram of body mass. For team sport athletes, a 3:1 ratio is recommended. For endurance athletes, a 4:1 ratio is recommended. A similar macronutrient combination should also be consumed every 1—2 hours thereafter for at least 6 hours after exercise (i.e., a total of 3—4 post-exercise "meals" should be consumed within the 6-hour post-exercise window) to maximize adaptive responses in muscle. If caloric intake is a concern, then essential amino acids can be used instead of whole protein, with an intake of 0.15—0.30 grams of essential amino acids per kilogram of body mass. One scoop of high- quality whey protein contains approximately 10—12 g essential amino acids.

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