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Physiologic and Metabolic Responses during Vigorous Exercise, Making Recovery Nutrition Indispensible

Sports dietitians frequently educate athletes on the significance of recovery nutrition. Aside from providing education, it is also imperative that dietitians are prepared to answer questions that reinforce recovery nutrition recommendations. Responding with scientific accuracy will strengthen one's credibility as a dietitian. Familiarity with the pathophysiology and biochemistry that occurs during strenuous exercise, which makes recovery nutrition indispensible, is important for the knowledge and benefit of the athlete. This article reports upon several basic physiological and metabolic responses that occur during vigorous exercise and are central to recovery nutrition.

Physiologic and Metabolic Changes during Strenuous Exercise

Laborious physical activity acts as a stressor to the athlete's body. Hormone fluctuations, muscle protein degradation, and depression of the immune system comprise only a few of the natural responses that occur during and after bouts of strenuous physical activity[1]. Knowing the nutritional recommendations that aid in an athlete's recovery is the final stage in understanding recovery nutrition. Prior to making recommendations, a full understanding of the causes of nutritional depletion and how it affects an athlete's body should be obtained through science and from literature. This will set the foundation for recovery nutrition recommendations.

Hormone Response

Catabolic hormones are released in response to vigorous workout periods and during the recovery process to provide glucose, protein, and fat as fuel. Although several catabolic hormones are released, such as cortisol, epinephrine, norepinephrine, and glucagon, cortisol will be highlighted most, due to its popularity and influential catabolic implications to athletes. In response to intense exercise and lowering levels of blood glucose, adrenal glands secrete cortisol, which stimulates glucose production by the liver. It also functions to metabolize fat, protein, and carbohydrates to provide fuel to the working muscles. Fat and protein breakdown and glycogen depletion continues to occur as catabolic hormones, such as cortisol, remain elevated for thirty to sixty minutes following a vigorous workout[1].

Volpe et al. exercised 12 men to exhaustion on stationary bikes. They found that "serum cortisol levels increased 44% at 12 minutes after exercise" and remained raised until 25 minutes following exercise, after which they began declining[2], as seen in Figure 1. Additionally, Hill and colleagues exercised men at intensities

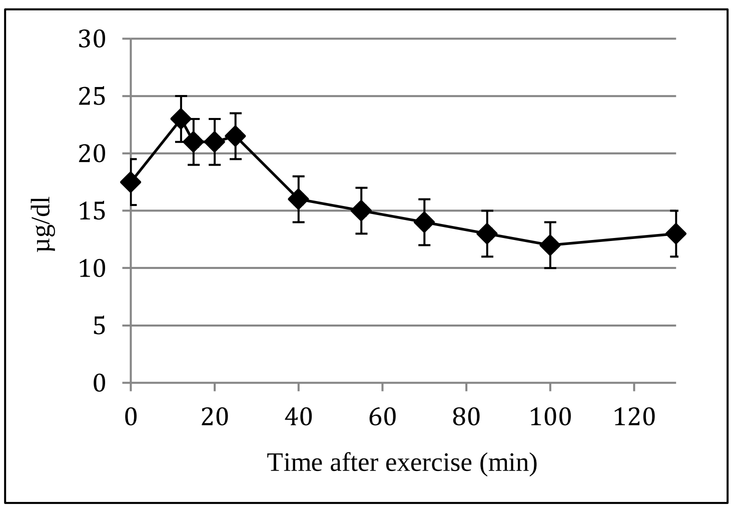

Figure 1 Changes in serum cortisol levels post-exercise in absence of recovery nutrition. Cortisol levels increased 44% at 12 minutes after exercise. Adapted from Volpe et al.

of 40, 60, and 80% maximal oxygen uptake (VO_{2max}). They found that moderate to intense physical activity, defined as 60 and 80% of VO_{2max} respectively, stimulated significant increases in cortisol levels from pre- to post-exercise measurements[3]. Rahimi et al. also found that resistance exercise promotes an increase in cortisol during and for at least 30 minutes following exercise[4]. During exercise, it is a natural and essential response that cortisol generate fuel by aiding in the metabolism of protein, glucose, and fat. Although this catabolic state is perfectly acceptable during exercise, it promotes a catabolic state after exercise, which is less desirable. The body now has the capability to receive exogenous sources of fuel post-exercise, which will decrease the reliance on catabolic hormones as a method for fuel.

Muscle Degradation

A catabolic environment generated by strenuous exercise promotes muscle damage that results in net protein loss and decreased protein synthesis by increasing branched chain amino acid (BCAA) (*i.e.* leucine, isoluecine, and valine) oxidation. Most amino acids are metabolized in the liver, where BCAAs are metabolized in the muscle. BCAAs comprise about 35% of the essential amino acids in muscle protein and are required for protein synthesis[5]. They can promote anabolism by increasing the rate of protein synthesis and opposing the rate of protein

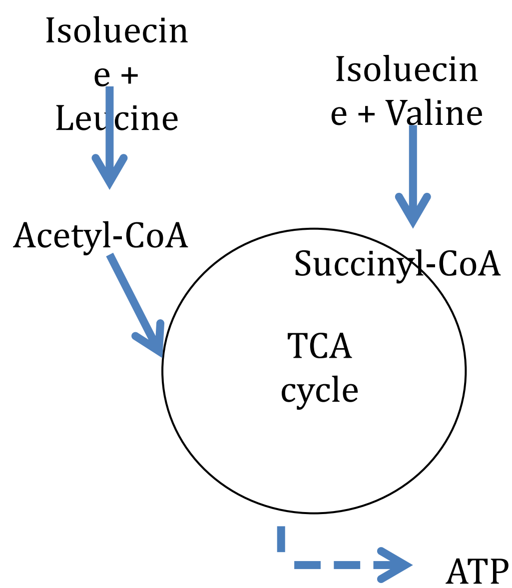

Figure 2 BCAAs are broken down to supplement the TCA cycle as it increases in rate to generate more ATP for the exercising body.

catabolism. It is hypothesized that the anabolic effects of BCAAs are mediated through insulin. They have also been shown to participate in the activation of mTOR[6]. However, BCAAs are oxidized during exercise and supplement the tricarboxylic acid (TCA) cycle, as seen in Figure 2. BCAA-derived acetyl-CoA increases TCA cycle activity to produce adenosine triphosphate (ATP), which provides energy to the exercising body. In order to spare further BCAA breakdown and an overall net protein loss post-exercise, exogenous nutrition is needed to supply the TCA cycle and reverse BCAA catabolism.

Furthermore, muscle contraction promotes 5' adenosine monophosphate-activated protein kinase (AMPK) activation, which increases fatty acid oxidation and muscle glucose uptake. AMPK activation disrupts the mammalian target of rapamycin (mTOR) signaling pathway, which is responsible for regulating and initiating key signaling cascades in protein synthesis, as seen in Figure 3. mTOR also plays a fundamental role in cell proliferation and muscle hypertrophy, acting as a regulator of protein synthesis by sensing and incorporating signals from nutrients, such as carbohydrates and amino acids[7]. Disruption of this pathway increases the likelihood of autophagy, a catabolic process that involves the degradation of cellular components[7]. Although disruption of this pathway is a natural and transient response to exercise, recovery nutrition can be used to promote mTOR signaling and activity following exercise, leading to protein synthesis and cellular growth.

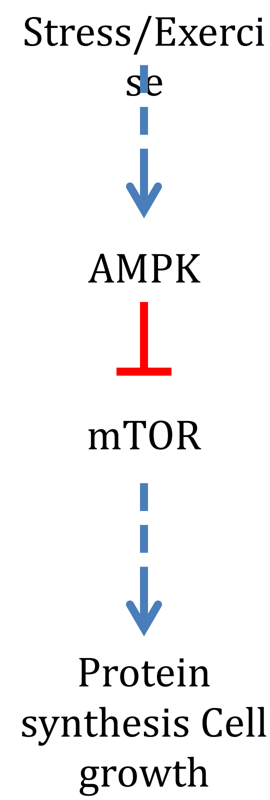

Figure 3 Exercise promotes AMPK release, which disrupts the mTOR signaling pathway, leading to the inhibition of protein synthesis.

Immune Function

In addition to muscle damage, intense physical activity temporarily suppresses immune cell function, increasing an athlete's susceptibility to minor infections. Moderate to vigorous physical activity increases plasma concentrations of inflammatory cytokines (*e.g.* TNF-α), anti-inflammatory cytokines (*e.g.* interleukin (IL)-1), and acute phase proteins (*e.g.* C-reactive protein) all of which can manipulate leukocyte functions[8]. Hormonal changes that occur during exercise, such as increases in cortisol and epinephrine are known to negatively alter immune response by suppressing type 1 T-cell cytokine production, which is critical in promoting cell-mediated immune responses[8]. Leukocytes are critical in helping the body defend itself against infectious disease and foreign matter. Additionally, the circulation of natural killer (NK) cells has been found to decrease below one half of pre-exercise levels for up to 24 hours following vigorous exercise, after which they return to normal levels[8]. NK cells oppose viruses and infection, thus a decrease in circulating NK cells can further compromise the athlete's immune system. Depressed immune function is most prominent when moderate to vigorous exercise lasts longer than 1.5 hours and is performed without nutritional intake[8]. Encouraging recovery nutrition can resist an athlete's susceptibility of becoming sick.

Preventing Catabolism and Promoting Anabolism

The absence of recovery nutrition keeps the body in a negative protein balance. Muscle hypertrophy relies on the ingestion of nutrients shortly after exercise[9]. A dietitian's recommendations for recovery nutrition can determine how an athlete's body is going to respond and recover after a strenuous workout. The invaluable promotion of recovery nutrition to minimize muscle catabolism will take into account if nutrients are used promptly and appropriately. John

Ivy and colleagues termed “metabolic window” as an approximate period of time following a workout where recovery nutrition becomes indispensible[1]. Following strenuous exercise, muscle sensitivity to nutritional stimuli is enhanced for approximately 30–60 minutes[10]. During this “window,” the fatigued body can blunt its catabolic hormone response and prevent further muscle protein degradation by utilizing nutrition to replenish depleted muscle stores and expedite muscle repair and growth.

Following exercise, nutritional supplementation in the right combination is effective in helping an athlete recover. Carbohydrate intake, following exercise, has been shown to increase insulin levels[1]. This is vital for the athlete because insulin is an anabolic hormone. When carbohydrates are consumed, this causes a rise in insulin levels, which promotes the uptake of nutrients, such as glucose, into the muscles. However, insulin itself cannot fully stimulate muscle protein synthesis in the absence of amino acids. Carbohydrate intake alone does not provide a net gain in muscle protein and likewise, protein ingestion without carbohydrates does not stimulate an anabolic state to sufficiently promote muscle protein synthesis and amino acid uptake by the muscles. Thus, the combination of protein and carbohydrate has been shown to be more valuable than either macronutrient independently[10].

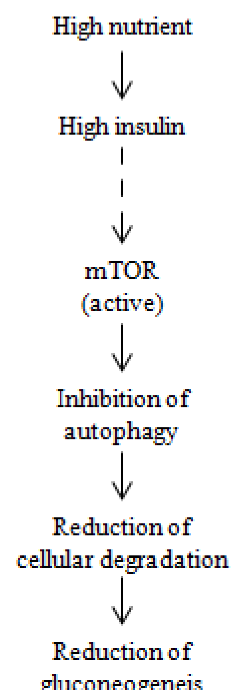

Figure 4 Intake of nutrients causes a rise in insulin levels, which helps to prevent the continued breakdown of cells and glycogen.

A balanced post-exercise meal of carbohydrates and protein, consumed during this “metabolic window,” enhances muscle glycogen storage and protein synthesis[1]. It decreases the body’s reliance on endogenous nutrients and, thus, the need for catabolic hormones to remain elevated. The nutritional promotion of the mTOR signaling pathway can also be mediated via carbohydrate and protein intake as seen in Figure 4. Providing the body with exogenous nutrients decreases the body's dependence further breakdown of nutrients within the body. This promotes a faster recovery for the athlete and preserves muscle breakdown following exercise. It also helps to maintain integrity of the immune system by lowering blood cortisol levels, which are known to manipulate the body's ability to fight infection and foreign material.

Recovery Nutrition Recommendations

It is recommended that a ratio of grams of carbohydrates to grams of protein be ingested after rigorous exercise within the "metabolic window" and preferably again two hours later[10]. This ratio can be 2:1 for resistance exercises and 4:1 for glycogen depleting exercise such as long distance running. Consuming a balanced snack or meal after the "metabolic window" closes can result in 85 percent less protein synthesis when compared with eating during the window's approximate 45 minute opening[1]. Consumption of high glycemic index carbohydrates has been shown to result in higher muscle glycogen levels 24 hours after vigorous exercise when compared with the same amount of low glycemic index carbohydrates[11]. Examples of post-exercise meals can include homemade items such as a peanut butter and jelly sandwich, Greek yogurt and granola, and a piece of fruit with a cheese stick. Sports dietitians have a tremendous opportunity to positively influence an athlete's recovery process. As science-based recommendations are made, an athlete can trust that he or she is making the best effort towards a faster recovery in preparation for the next workout.

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