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IS THERE A NEED FOR PROTEIN INGESTION DURING EXERCISE?

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KEY POINTS

- Exercise increases muscle protein synthesis rates, allowing skeletal muscle tissue to adapt to the various types of exercise training.
- Protein ingestion following exercise augments muscle protein accretion by further increasing muscle protein synthesis rates over an extended period of time.
- The ingestion of dietary protein prior to and/or during exercise stimulates skeletal muscle protein synthesis rates during resistance or endurance type exercise.
- Allowing muscle protein synthesis rates to increase during exercise training may facilitate the skeletal muscle adaptive response to exercise training and improve training efficiency.
- The ingestion of protein with carbohydrate during exercise does not acutely improve exercise performance above carbohydrate ingestion alone, when ample carbohydrate is ingested.

INTRODUCTION

Skeletal muscle tissue has an enormous capacity to structurally adapt to changes in muscle use or disuse. This allows us to adapt to prolonged exercise training, thereby increasing performance capacity. This skeletal muscle plasticity becomes apparent when we compare the obvious differences in the structural adaptation to prolonged resistance versus endurance type exercise training, each resulting in a distinct phenotypic or body-type outcome. Simply compare the physique of a professional bodybuilder with that of a triathlete. This muscle plasticity is facilitated by the fact that skeletal muscle tissue turns over at a rate of 1-2% per day, with muscle protein synthesis rates ranging between 0.04% and 0.14% per hour throughout the day.

Muscle protein synthesis is regulated by two main anabolic stimuli, food intake and physical activity. Food intake, or rather protein ingestion, directly elevates muscle protein synthesis rates. The dietary protein derived amino acids act as key signaling proteins activating anabolic pathways in skeletal muscle tissue and provide building blocks for muscle protein synthesis. Ingestion of a meal-like amount of protein (15-20 g) elevates muscle protein synthesis rates for 2-5 h following meal ingestion (Moore et al., 2009b). The other main anabolic stimulus is physical activity. Physical activity (or exercise) directly stimulates skeletal muscle protein synthesis, an effect that has been shown to persist for up to 24 h after cessation of exercise (Burd et al., 2011). Of course, different types of exercise will stimulate the synthesis of different sets of proteins. Whereas resistance type exercise strongly stimulates the synthesis of muscle contractile (myofibrillar) proteins, endurance type exercise will have a greater impact on stimulating the synthesis of mitochondrial proteins (Moore et al., 2009b), thereby allowing exercise-specific muscle adaptation. Athletes, coaches, and scientists are well aware of the impact of both exercise and nutrition in facilitating the adaptive response to exercise training. Consequently, much work is being done to define dietary strategies that facilitate the adaptive response to prolonged exercise training and optimize training efficiency. This paper will discuss the potential benefits of protein ingestion during exercise as a means to support the adaptive response to exercise training.

EXERCISE AND FOOD INTAKE

A single bout of exercise increases skeletal muscle protein synthesis and, to a lesser extent, muscle protein breakdown rates, thereby improving muscle protein balance (Phillips et al., 1997). However, net muscle protein balance will remain negative until food is ingested. In other words, nutrition is required to allow proper muscle reconditioning and is a prerequisite for muscle hypertrophy to occur. It is, therefore, not surprising that a strong synergy exists between exercise and nutrition. When protein is ingested following a single bout of exercise, muscle protein synthesis rates are increased to a much higher level and for a more prolonged period of time when compared with a normal post-meal response (Moore et al., 2009b). Moreover, recent work from our laboratory shows that when exercise is performed prior to protein ingestion, more of the ingested protein is used to synthesize new muscle proteins (Pennings et al., 2010). As such, the metabolic fate of ingested protein largely depends on the level of physical activity that is performed prior to food consumption. The stimulating properties of exercise on the post-meal muscle protein synthetic response are long lived and persist over an extended period of time, as much as 24 h after performing a bout of exercise (Burd et al., 2011). The latter is in line with previous work showing that protein supplementation represents an effective dietary strategy to further augment the skeletal muscle adaptive response to more prolonged resistance type exercise training, resulting in greater gains in skeletal muscle mass and strength (Hartman et al., 2007).

A recent meta-analysis performed in our laboratory confirmed the benefits of protein supplementation and also showed that there is a large variability in the impact of nutritional modulation on the skeletal muscle adaptive response to prolonged resistance type exercise training (Cermak et al., 2012). Obviously there are still considerable challenges ahead to elucidate how dietary intake regimens can improve post-exercise muscle protein reconditioning. Many research groups are presently studying the various individual factors that may augment the acute post-exercise muscle protein synthetic response. Various studies have previously assessed the impact of the amount (Moore et al., 2009a) and type (Tang et al., 2009; Tipton et al., 2004; Wilkinson et al., 2007) of dietary protein ingested following an exercise bout on subsequent post-exercise muscle protein synthesis. Others have assessed the impact of co-ingesting free amino acids (Koopman et al., 2008), other macronutrients (Glynn et al., 2011; Koopman et al., 2007), and/or specific nutritional compounds (Smith et al., 2011) that may further enhance post-exercise muscle protein synthesis. It is beyond the scope of this manuscript to discuss all dietary factors that may augment post-exercise muscle protein synthesis. Therefore, we will focus on a single parameter that is likely of key importance in driving the muscle protein synthetic response to exercise: the timing of protein provision.

TIMING OF PROTEIN INGESTION

Besides the amount and type of protein ingested during post-exercise recovery, the timing of protein ingestion has been identified as another key factor modulating post-exercise muscle protein anabolism. Levenhagen et al. (2001) were one of the first to report a more positive net protein balance after consuming a protein (containing) supplement immediately after exercise when compared with the provision of the same supplement 3 h into post-exercise recovery. As a consequence, it is now generally advised to ingest 20 g of a high-quality dietary protein immediately after the cessation of exercise as a means to optimize post-exercise reconditioning (Moore et al., 2009a). However, more recent work suggests that protein may even be consumed prior to and/or during exercise to further stimulate post-exercise muscle protein accretion (Beelen et al., 2008a, 2011b; Koopman et al., 2004; Tipton et al., 2001). Tipton et al. (2001) reported that a mixture of 6 g essential amino acids and 35 g sucrose ingested prior to exercise was even more effective in stimulating muscle protein synthesis than ingesting the same mixture immediately after exercise. The authors hypothesized that this may be attributed to the combination of increased amino acid levels at a time when blood flow is increased during exercise, thereby offering a greater stimulation of muscle protein synthesis by increasing amino acid delivery to the muscle. However, in a subsequent study the same research group failed to confirm these findings when examining the impact of 20 g of whey protein ingested prior to as opposed to 1 h after resistance type exercise on muscle protein balance measured over a 4-5 h recovery period (Tipton et al., 2007). It seems likely that the longer recovery period in the second study, at least partly compensated for any early benefits of protein provision prior to exercise, which allows post-exercise muscle protein synthesis rates to be elevated more rapidly due to the greater amino acid availability to the muscle. This suggestion is in agreement with recent observations that intense exercise induces intestinal damage due to a reduced blood flow to the gut, thereby impairing dietary protein digestion and absorption kinetics during early post-exercise recovery (van Wijck et al., 2011). Consequently, dietary protein ingestion prior to and/or during exercise may provide a more effective feeding strategy to improve amino acid availability during early post-exercise recovery.

In a series of studies we also assessed the impact of protein provision prior to and during exercise on muscle protein synthesis rates measured during exercise conditions (Beelen et al., 2008a, 2011b; Koopman et al., 2004). In the first study, recreational athletes ingested carbohydrate-containing drinks (0.15 g/kg body mass/h) with or without additional protein (0.15 g/kg body mass/h) prior to and during 2 h of resistance type exercise. Using contemporary stable isotope methodology, it was shown that protein co-ingestion prior to and during resistance type exercise substantially increases muscle protein synthesis rates during exercise (Beelen et al., 2008a). The capacity to increase muscle protein synthesis rates during exercise extends the time frame during which the skeletal muscle adaptive response can be facilitated.

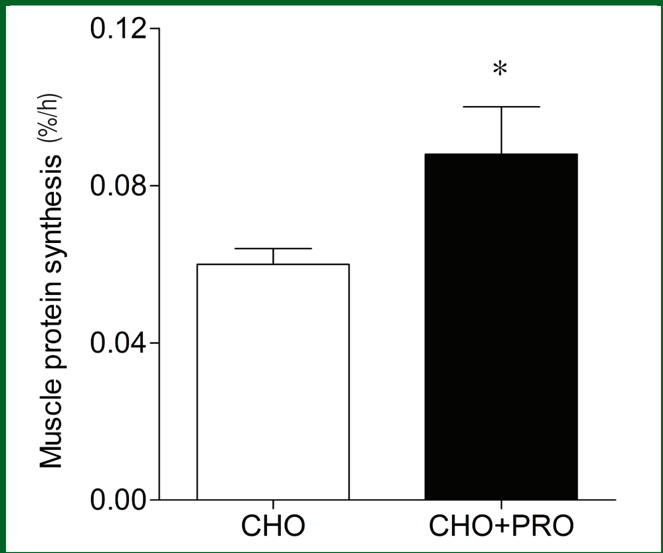

Figure 1: Dietary protein ingestion prior to and during resistance type exercise stimulates muscle protein synthesis during exercise. Fractional synthesis rate (FSR) of mixed muscle protein during exercise following carbohydrate (CHO) or carbohydrate plus protein (CHO+PRO) ingestion. Values represent means ± SEM. *significantly different from CHO. Figure redrawn from Beelen et al. (2008) Am. J. Physiol. 295; E70-77, American Physiological Society.

It has been suggested that the observed impact of protein co-ingestion (with carbohydrate) on mixed muscle protein synthesis rates during exercise is merely restricted to intermittent, resistance type exercise (Beelen et al., 2008a; Fujita et al., 2009). It is attractive to assume that muscle protein accretion occurs during the short rest periods between sets of exercise. Consequently, it has been debated whether dietary protein administration prior to and/or during exercise can also stimulate muscle protein synthesis rates during continuous endurance type exercise activities. Prior work has clearly shown that protein co-ingestion during prolonged endurance type exercise improves whole-body protein balance (Koopman et al., 2004). Moreover, whereas whole-body protein balance remained negative when only carbohydrates were ingested, dietary protein co-ingestion was shown to improve whole-body protein balance by increasing protein synthesis as well as decreasing protein breakdown, resulting in a positive protein balance during 5 h of prolonged endurance exercise. As measurements on a whole body level do not necessarily reflect skeletal muscle tissue, a follow-up study was performed to assess muscle protein synthesis rates during endurance exercise while ingesting carbohydrate or carbohydrate plus protein. Interestingly, this study showed that muscle protein synthesis rates were higher during exercise when compared to pre-exercise fasting protein synthesis rates (Beelen et al., 2011b). However, no significant differences were observed in muscle protein synthesis rates between the carbohydrate and carbohydrate plus protein trial, despite clear differences in whole-body protein balance. Future studies are warranted to assess muscle protein synthesis rates during more prolonged exercise, as longer exercise trials (>3-5 h) will allow differences in fractional protein synthesis rates to become apparent. Clearly, more work is needed to address the relevance of the potential to stimulate muscle protein synthesis during resistance as well as endurance type exercise activities, thereby elongating the time frame for muscle protein synthesis rates to be increased.

WINDOW OF OPPORTUNITY

So what is the preferred timing of protein supplementation when trying to optimize the adaptive response to successive exercise sessions? Though this seems a simple question, the answer is complicated. Exercise stimulates muscle protein synthesis rates for several hours after a single bout of exercise. Protein ingestion further augments the post-exercise muscle protein synthetic response. As such, it is not surprising that protein supplementation during prolonged resistance type exercise training generally leads to greater gains in skeletal muscle mass and/or strength. It is generally advised to provide 20-25 g of a high-quality protein immediately after an exercise session to maximize the muscle protein synthetic response during acute recovery (Beelen et al., 2011a). However, as discussed previously, the window of opportunity to allow muscle protein synthesis rates to be elevated is not limited to the few hours of acute post-exercise recovery. Muscle protein synthesis is already stimulated during exercise when protein is provided prior to and/or during exercise. So it might be wise, especially in the case of more prolonged endurance type exercise bouts (>3 h) to ingest some protein prior to and during exercise. The latter may prevent excess muscle protein breakdown and elevate muscle protein synthesis throughout the exercise session. This dietary strategy might facilitate muscle reconditioning and improve training efficiency, especially for those spending many long hours in training.

However, this still provides a simplistic idea of the role of nutrition and exercise training in skeletal muscle reconditioning. The skeletal muscle adaptive response to exercise is not limited to the exercise session itself and the subsequent hours of acute post-exercise recovery. It has been reported that basal muscle protein synthesis rates and the muscle protein synthetic response to food intake are increased up to 24 h after a resistance type exercise session (Burd et al., 2011). Such findings imply that the window of opportunity to modulate the skeletal muscle adaptive response to exercise is much larger and also depends on overall training and training status (Wilkinson et al., 2008).

The window of opportunity likely also extends to overnight recovery during sleep, but for obvious methodological issues, this has rarely been studied. Recently, we evaluated the impact of exercise performed in the evening on muscle protein synthesis during subsequent overnight recovery (Beelen et al., 2008b). Though an increase in muscle protein synthesis rate was observed during the first few hours of acute post-exercise recovery, muscle protein synthesis rates remained unexpectedly low during overnight sleep. Clearly, although dietary protein ingestion after exercise stimulates muscle protein synthesis during the acute stages of post-exercise recovery, the elevated synthesis rates were not maintained during subsequent overnight sleep. Using various models we have now established that protein administration prior to sleep (via ingestion, Res et al., 2012) or during sleep (via nasogastric tube feeding, Groen et al., 2011) is followed by proper dietary protein digestion and absorption, increased plasma amino acid availability, and stimulated net muscle protein accretion throughout overnight sleep. Therefore, the night provides another interesting extension of the window of opportunity during which the adaptive process can be facilitated. It will be challenging to define whether there is an actual limited ‘window of opportunity’ for nutritional interventions to improve skeletal muscle adaptation. Clearly, it is too early to provide a definite answer on the impact of the distribution of dietary protein provided throughout the day and night to maximize the exercise training response.

PROTEIN AS AN ERGOGENIC AID

Dietary protein ingestion during and/or immediately after each exercise bout facilitates muscle reconditioning and may help to improve training efficiency. However, over the last few years there have also been suggestions that protein ingestion during exercise may directly improve performance during competition. Ivy and co-workers (2003) were the first to publish a paper in which they reported increased performance capacity in trained cyclists following ingestion of carbohydrate plus protein during prolonged cycling. Nine cyclists were recruited and cycled to exhaustion while ingesting drinks containing carbohydrate, carbohydrate plus protein, or flavored water. The authors reported that ingestion of a carbohydrate solution with added protein enhanced endurance performance when compared to the ingestion of the carbohydrate solution only. However, the reason for this improvement in performance remained unclear. Since then, additional studies have been published (Ivy et al., 2003; Saunders et al., 2004, 2007) reporting significantly greater time to exhaustion following ingestion of carbohydrate plus protein during more prolonged endurance type exercise tasks (Figure 2). More recent studies have been unable to confirm these findings (Lee et al., 2008; Martinez-Lagunas et al., 2010; Romano-Ely et al., 2006; Saunders et al., 2009; Valentine et al., 2008).

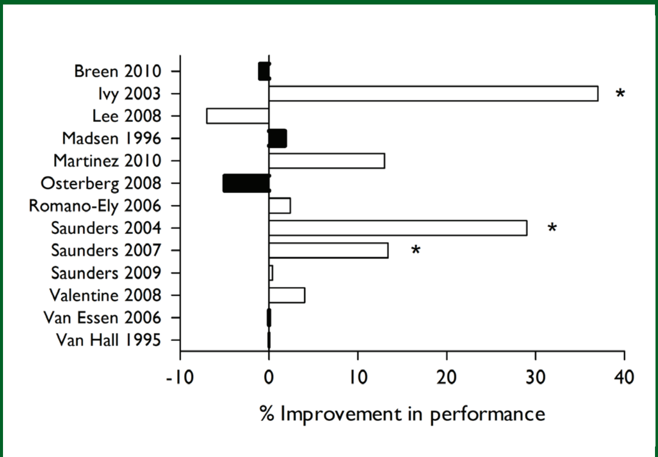

Figure 2: Overview of studies investigating the impact of dietary protein ingestion during endurance type exercise on subsequent performance capacity. Performance capacity was assessed either as time to exhaustion (red) or as time trial performance (blue) in the various studies. * : significant improvement in performance reported following protein co-ingestion during exercise.

Clearly, some studies reported substantial (10-30%) improvements in time to exhaustion, implying that protein co-ingestion during exercise may represent an effective dietary strategy to improve performance capacity. However, there are no apparent mechanistic explanations for the observed impact of protein co-ingestion on time to exhaustion. It is, therefore, unlikely that such large increases in time to exhaustion will translate into similar improvements in exercise performance in a more practical sports setting that simulates normal athletic competition. When evaluating the impact of sports drinks on exercise performance it is generally preferred to assess time trial performance. Time trials have shown a greater validity than time to exhaustion trials because they provide a good physiological simulation of actual performance and have been shown to correlate well with actual performance (Currell & Jeukendrup, 2008). Consequently, several studies have investigated the proposed acute ergogenic benefits of carbohydrate plus protein ingestion on time trial performance. However, none of these studies have detected any acute performance enhancing effects of protein co-ingestion during exercise (Breen et al., 2010; Madsen et al., 1996; Osterberg et al., 2008; van Essen & Gibala, 2006). In short, there is no convincing evidence to suggest that co-ingestion of dietary protein during exercise directly improves performance capacity when sufficient carbohydrates are ingested.

NUTRITIONAL RECOMMENDATIONS FOR THE ATHLETE

1. Provide sufficient protein (20-25 g) with each main meal
2. Co-ingest some protein before and during prolonged exercise
3. Ingest 20-25 g protein immediately after exercise
4. Consume protein prior to sleep

SUMMARY

Dietary protein ingestion following exercise stimulates post-exercise muscle protein synthesis, stimulating net muscle protein accretion, and facilitating the skeletal muscle adaptive response to prolonged exercise training. Recent studies show that protein ingestion prior to and/or during exercise already stimulates muscle protein synthesis before the exercise session is finished. Therefore, protein ingestion prior to and/or during prolonged exercise training sessions may inhibit muscle protein breakdown, stimulate muscle protein synthesis and further augment the skeletal muscle adaptive response to exercise training. Protein co-ingestion during exercise does not acutely improve performance capacity, but may improve exercise training efficiency.

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