CONFERENCE PAPER

Sports Med 2007; 37 (4-5): 337-340
0112-1642/07/0004-0337/$44.95/0

Protein Metabolism and Endurance Exercise

Martin J. Gibala

Department of Kinesiology, McMaster University, Hamilton, Ontario, Canada

Abstract

Prolonged endurance exercise stimulates whole-body protein turnover (synthesis and degradation) but it remains contentious whether this translates into an increased net protein oxidation or dietary requirement for protein. Skeletal muscle is the major energy consumer during exercise and the oxidation of branched-chain amino acids (BCAA) is increased several-fold, suggesting an increased requirement for fuel. Increased BCAA oxidation has been proposed to impair aerobic energy provision during prolonged exercise, but there is little evidence to support this theory. Endurance training blunts the acute exercise-induced increase in whole-body protein turnover and skeletal BCAA oxidation at a given work intensity. However, training also increases the maximal capacity for skeletal muscle BCAA oxidation, as evidenced by a higher maximal activity of the rate-determining enzyme branched-chain oxo acid dehydrogenase. Exercise-induced changes in protein metabolism are affected by nutritional status, with high carbohydrate availability (as typically practiced by endurance athletes) generally associated with reduced net protein utilisation. Ingestion of protein with carbohydrate improves net protein balance during exercise and recovery compared with carbohydrate alone, but it remains to be determined whether this practice facilitates the adaptive response to chronic training.

The predominant fuels catabolised for energy during endurance exercise are carbohydrates (CHO) and lipids. The oxidation of amino acids likely contributes ≤5% of total adenosine triphosphate provision,[1] although estimates range up to 20%,[2] and factors such as sex and CHO availability may influence the amount of energy derived from protein.[1,2] Despite this relatively minor role in terms of substrate oxidation, an acute bout of prolonged exercise induces profound changes in whole-body and skeletal muscle protein turnover (synthesis and degradation) and intermediary metabolism of amino acids.[1,2] Indeed, exercise-induced changes in protein metabolism are mechanistically linked to the regulation of fuel metabolism and may influence the adaptive response to chronic training. Space precludes a comprehensive discussion of this topic and so the present review addresses fundamental questions regarding protein metabolism that are relevant to endurance athletes.

1. Does an Acute Bout of Prolonged Endurance Exercise Increase Whole-Body Protein Utilisation?

Most studies that have measured whole-body protein turnover during prolonged exercise were performed in the morning after an overnight fast,[1,2] which does not represent everyday practice in competitive athletes. Endurance athletes typically ingest large amounts of CHO before and during exercise in order to optimise performance. Recently, Koopman et al.[3] assessed whole-body protein turnover during 6 hours of continuous moderate-intensity exercise (2.5 hours of cycling, 1 hour of running and another 2.5 hours of cycling), which was designed to simulate real life athletic competition. The elegant study involved infusion of three separate stable isotope tracers (L-[1-^{13}C] leucine, L-[$^2H_5$] phenylalanine and [$^{15}N_2$] urea) to evaluate changes in whole-body protein metabolism.[3] A detailed methodological discussion is beyond the scope of the present review; however, the authors suggested that the widely applied model based on infused L-[1-^{13}C] leucine overestimated protein oxidation and underestimated protein synthesis. In contrast to previous work by others,[1,2] Koopman et al.[3] concluded that protein utilisation was not increased during prolonged exercise compared with rest, provided that CHO was ingested at regular intervals.

2. Does an Increased Rate of Amino Acid Oxidation by Skeletal Muscle Impair Aerobic Energy Provision During Prolonged Exercise?

Irrespective of the precise effect on whole-body protein metabolism, an acute bout of prolonged exercise increases the rate of branched-chain amino acid (BCAA) oxidation by skeletal muscle, as evidenced by an increased activation of the rate-determining enzyme branched-chain oxo acid dehydrogenase (BCOAD).[4] The initial step in BCAA catabolism consumes 2-oxoglutarate, an intermediate in the tricarboxylic acid (TCA) cycle, which is the central common pathway involved in CHO and lipid catabolism. An increased rate of BCAA oxidation during prolonged exercise could potentially impair TCA cycle flux and aerobic energy provision by reducing the total muscle concentration of TCA cycle intermediates. Recently, Gibala et al.[5] tested this theory by combining measurements of muscle TCA cycle intermediates (TCAI), amino acids and key energy metabolites with direct measurements of limb oxygen uptake during a 90-minute bout of moderate-intensity exercise. Following a 3-fold expansion during the initial minutes of exercise, the muscle TCAI pool rapidly declined such that the value after 60 and 90 minutes was not different from the resting concentration. Despite the decline in muscle TCAI, the capacity for aerobic energy provision was not compromised, as evidenced by stable limb oxygen uptake during exercise and no change in muscle phosphocreatine content, which is a sensitive indicator of mitochondrial respiration. Thus, regardless of the effect of BCAA catabolism on muscle TCAI (which appears to be quantitatively small), Gibala et al.[5] concluded that changes in muscle TCA cycle intermediates are not causally related to the capacity for aerobic energy provision during prolonged exercise.

3. Does Endurance Training Alter Whole-Body or Skeletal Muscle Protein Metabolism During Prolonged Exercise?

Only one study has examined the effect of endurance training on whole-body and skeletal muscle protein metabolism using a longitudinal research design. McKenzie et al.[4] showed that 38 days of training attenuated leucine oxidation and BCOAD activation during 90 minutes of exercise at 60% of peak oxygen uptake, regardless of whether the comparison was made at the same absolute or relative work intensity. However, total BCOAD activity was higher after training, which suggested the total capacity for BCAA oxidation was increased. The authors interpreted these adaptations to predict that, under most circumstances, endurance training would decrease the relative contribution of amino acids to total substrate oxidation. The opinion that protein metabolism becomes more efficient after training is consistent with work by others[2] and implies that trained endurance athletes have no increased dietary requirement for protein. However, McKenzie et al.[4] noted that in the case of an elite endurance athlete who has an increased total BCOAD capacity, an intensive training programme could potentially increase the total amount of amino acid oxidation and hence the requirement for protein above a sedentary person or recreational athlete. Regardless, even assuming the theoretical maximum requirement calculated by Tarnopolsky[1] of 1.6g of protein per kg per day, endurance athletes can satisfy any increased need for protein by consuming 10–15% of their habitual diet from high-quality protein sources and adequate energy to meet training demands.

4. Does Protein Ingestion During Exercise Improve Endurance Performance?

Research has established that ingesting a CHO-electrolyte solution improves performance during prolonged exercise by providing fuel for working muscle and promoting fluid balance. Recently, it was suggested that adding a small amount of protein to a typical sports drink improved endurance capacity by ≈30% compared with the sports drink alone.[6,7] While these findings are intriguing, the practical applications of this work are hampered by the way the research was conducted. First, the rate of CHO delivered in the sports drink was less than what is considered optimal for endurance performance, and second, the performance test employed (exercise time to fatigue) did not mimic the manner in which athletes typically compete. A recent study[8] addressed these issues by having trained cyclists ingest a sports drink during exercise at a rate considered near-optimal for CHO delivery (60 g/hour) and perform a task that closely simulated athletic competition. In a randomised, double-blind manner, subjects performed an 80km cycling time trial on three occasions and ingested drinks that contained either 6% CHO, 6% CHO + 2% whey protein or a sweetened placebo at a rate of 1 L/hour. Average performance time was identical during the CHO and CHO + protein trials (135 minutes) and significantly faster (≈4%) compared with the placebo trial (141 minutes). This study[8] implied that when trained athletes ingested a sports drink during exercise at a rate considered optimal for CHO delivery, protein provided no additional performance benefit during an event that simulated 'real life' competition. Additional research will resolve this debate, but there is no established mechanism by which protein intake during exercise should improve acute endurance performance.

5. Does Protein Ingestion During Recovery from Endurance Exercise Affect the Muscle Adaptive Response?

Nutrition during the immediate post-exercise period may benefit the athlete in several ways, including the repair and synthesis of muscle proteins and the synthesis of muscle glycogen. Levenhagen et al.[9] showed that ingesting protein with CHO during recovery from endurance exercise facilitated leg uptake of amino acids and promoted leg protein accretion. This effect may be mediated through amino acid (particularly leucine) stimulation of signaling pathways that control muscle protein synthesis, although this has only been demonstrated after acute resistance exercise.[2] A more contentious issue is whether co-ingestion of protein with CHO enhances muscle glycogen synthesis during the first several hours of recovery from prolonged exercise. In this author's opinion, which is consistent with other researchers in the field,[10] most evidence suggests that feeding a high amount of CHO at frequent intervals (e.g. ≥1.2g CHO per kg bodyweight per hour) negates the benefits of added protein. However, co-ingestion of protein with CHO may enhance glycogen synthesis when the amount of CHO ingested is sub-optimal.[10] Thus, similar to the effect on endurance capacity, the purported beneficial effect of ingesting protein with CHO on glycogen storage may be due to higher energy intake *per se* rather than any proven physiological mechanism.

Acknowledgements

Martin J. Gibala is member of the Gatorade Sports Science Institute Science Advisory Board. Work cited from the author's laboratory was supported by the Natural Sciences and Engineering Research Council of Canada.

References

1. Tarnopolsky M. Protein requirements for endurance athletes. Nutrition 2004; 20 (7-8): 662-8
2. Rennie MJ, Bohe J, Smith K, et al. Branched-chain amino acids as fuels and anabolic signals in human muscle. J Nutr 2006; 136: S264-8
3. Koopman R, Pannemans DL, Jeukendrup AE, et al. Combined ingestion of protein and carbohydrate improves protein balance during ultra-endurance exercise. Am J Physiol Endocrinol Metab 2004; 287: E712-20
4. McKenzie S, Phillips SM, Carter SL, et al. Endurance exercise training attenuates leucine oxidation and BCOAD activation during exercise in humans. Am J Physiol Endocrinol Metab 2000; 278: E580-7
5. Gibala MJ, Gonzalez-Alonso J, Saltin B. Dissociation between muscle tricarboxylic acid cycle pool size and aerobic energy provision during prolonged exercise in humans. J Physiol 2002; 545: 705-13
6. Ivy JL, Res PT, Sprague RC, et al. Effect of a carbohydrate-protein supplement on endurance performance during exercise of varying intensity. Int J Sports Nutr Exerc Metab 2003; 13: 382-95
7. Saunders MJ, Kane MD, Todd KM. Effects of a carbohydrate-protein beverage on cycling endurance and muscle damage. Med Sci Sports Exerc 2004; 36: 1233-8
8. van Essen M, Gibala MJ. Failure of protein to improve time trial performance when added to a sports drink. Med Sci Sports Exerc 2006; 38: 1476-83
9. Levenhagen DK, Carr C, Carlson MG, et al. Postexercise protein intake enhances whole-body and leg protein accretion in humans. Med Sci Sports Exerc 2002; 24: 828-37
10. Burke LM, Keins B, Ivy JL. Carbohydrates and fat for training and recovery. J Sports Sci 2004; 22: 15-30

Correspondence: Dr *Martin J. Gibala*, Department of Kinesiology, McMaster University, Hamilton, ON L8S 4K1, Canada.
E-mail: gibalam@mcmaster.ca

