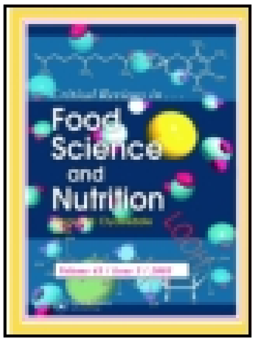

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REVIEW

Effects of dietary supplementation in sport and exercise: a review of evidence on milk proteins and amino acids

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ABSTRACT
Dietary supplements, especially protein, are used by athletes to achieve the exercise and training daily demands, and have been receiving research focus on their role regarding recovery and performance. Protein supplements are preferred over traditional protein sources because of their ease of availability and use. In addition to consuming a complete protein supplement, such as whey protein, the ingestion of a supplement containing only amino acids has been of interest for promoting skeletal muscle anabolism and high-quality weight loss. The aim of this study was to review the existing evidence on the effects of protein and amino acid supplementation on exercise. The preponderance of evidence suggests that protein supplementation, especially milk proteins, potentiate muscle protein synthesis, lean mass and exercise recovery. Unlike proteins, amino acids supplementation (branched-chain amino acids, glutamine or leucine) results from research are equivocal and are not warranted.

KEYWORDS
Athletic performance; dietary supplements; glutamine; leucine; whey protein

Introduction

Nutrition can play a crucial role in optimizing training sessions, as well as in recovery and metabolic adaptation to exercise (Bytomski 2018; Maughan et al. 2018). Both diet and exercise potentiate the cellular and enzymatic activity of energy systems and also modulate the individual's body phenotype, influencing lean mass and visceral and subcutaneous fat (Poortmans et al. 2012; Herring et al. 2013).

Athletes' nutritional needs vary greatly depending on the sport practiced, competitive period, time, intensity and type of exercise training, thus they should be able to obtain the appropriate macro and micronutrients through a food variety or dietary supplements (Bytomski 2018). Thus, within an appropriate dietary pattern, supplementation can provide a convenient alternative option to achieve nutritional requirements due to training schedules and gut comfort (Maughan et al. 2018).

Dietary patterns that include regular intake of high quality foods, with high-protein food, are important for balancing muscle protein breakdown (MPB) and synthesis (MPS). MPS Regulation and subsequent muscle growth can be complex, it is multifaceted and involves several dependent and independent factors, the mammalian rapamycin target protein (mTOR) is one of them (Duplanty et al. 2017). MPS induced effects of dietary protein are important to maintain or increase skeletal muscle mass (Hector and Phillips 2018). In addition of MPS, a positive nitrogen balance is necessary to promote exercise recovery, adaptation and muscle anabolism (Rogerson 2017; Van Vliet et al. 2017; Hector and Phillips 2018).

Dietary supplements are used by athletes at all levels of sport, reflecting the prevalence of their use in the wider society (Maughan et al. 2018). To achieve daily demands many people use dietary protein supplements. These supplements are easy sources of protein as they require less time for preparation and may cost less than traditional sources of food. Protein supplements are preferred over traditional sources of protein because of their ease of availability and use (Samal and Samal 2018). In addition to consuming a complete protein supplement, such as whey protein, the ingestion of a supplement containing only amino acids has been of interest for promoting skeletal muscle anabolism and high-quality weight loss (Hector and Phillips 2018).

Knowing the importance of protein in the diet of physically active individuals and the possible influence on exercise performance, the aim of this study was to review the existing evidence on the effects of protein and amino acid supplementation on sports and exercise.

Proteins

The protein building blocks are their respective amino acids. There are 20 types of amino acids in nature, animal species (including humans) can produce 12 of them, they are also called non-essential amino acids. The remainder is acquired through food, which are called essential amino acids (EAA) (World Health Organization 2007; Kubyshkin, Acevedo-

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Rocha, and Budisa 2018). Each protein is formed by a set of specific amino acids and thus perform differentiated functions such as: defensive, structural, regulatory and transport.

Oscillatory periods of serum availability and deprivation of protein consumption constitute the nitrogen balance network. The dynamic balance between muscle anabolic and catabolic states modulate the muscles metabolic contribution and alter the level of proteins bioavailability (Churchward-Venne, Burd, and Phillips 2012). Therefore, a maximized (or greater than breakdown) frequency of protein synthesis creates a positive nitrogen balance, which associated with hormonal and tension factors, are the key to the promotion of skeletal muscle hypertrophy. In contrast, if there is an insufficient supply of energy within a given period of time, muscle catabolism overlaps with anabolism, giving condition to the negative nitrogen balance which may be related to loss of muscle mass (Phillips 2009).

Both exercise and protein intake, in a single or associated way, are capable of stimulating MPS (Jäger et al. 2017). Thus, the main proteins metabolic role is in the period after exercise (recovery) (Trommelen and Van Loon 2016; Ives et al. 2017). This consumption will be adjusted according to the individual's characteristics, such as: gender, age, anthropometric profile, health status; and exercise program (duration, frequency and intensity) (Nowson and O'Connell 2015; Jäger et al. 2017).

Recent evidences point out that the offered protein characteristics (amino acid composition and digestibility, for example) seem to have a great influence in the recommendations of protein consumption (Van Vliet, Burd, and Van Loon 2015). Protein kinetics and postprandial MPS are similar between women and men (Morales, Tinsley, and Gordon 2017), but there is a reduction in the basal and postprandial response of MPS with aging, resulting in a lower anabolic stimulus (anabolic resistance) (Burd, Gorissen, and Van Loon 2013; Morales, Tinsley, and Gordon 2017; Morton and Phillips 2018).

The first registry of an association of high-protein diet and sport performance was in Greece, V b.C. At that time, diets were plant-based, with only a record of two athletes who improved their weight and strength after eating meat. Currently, it is known that protein recommendations for sedentary adults are 0.8 g/kg body weight per day. For trained individuals, it has been suggested 1.2–2.0 g/kg of dietary protein intake to support metabolic adaptation, repair, remodeling and for protein turnover (Thomas, Erdman, and Burke 2016).

In general, athletes should consume approximately from 15% to 30% of their calories from protein sources (Bytomski 2018). According to Thomas, Erdman, and Burke (2016), ingesting 20–30 g of total protein or approximately 10 g of EAA in a single dose is the key factor to reach the maximum MPS, thus the biological value of the protein consumed must be considered. Due to the high content of EAA, one of the most studied proteins are those derived from bovine milk.

Milk proteins

Milk proteins (casein and whey protein) are found in dairy products, such as milk, yogurt and cheese, or can be consumed as supplements in isolated or concentrated forms (Pasin and Comerford 2015). In the last decades there has been an expressive growth in the methods of protein isolates and hydrolysates preparation, both for clinical and nutritional purposes as well as for the improvement of food functional properties (Pacheco, Dias, and Baldini 2005). The corresponding studies are summarized in the Table 1.

Whey protein is a byproduct acquired in laboratory or industry. For decades, this fraction of milk was wasted by food industry. Since 1970 the properties of these proteins have been studied (Phillips 2004). Whey proteins are a group of heterogeneous and polymorphic proteins with fast and easy digestion and absorption. They have a high biological value, composed of β-lactoglobulin, α-lactalbumin, glycomacropeptide and especially high content of leucine (Smithers 2008; Laviolette et al. 2010; Chen et al. 2014).

There are several types of protein supplements commercially available, but whey protein concentrate (WPC) is the leading product. In WPC the concentration of protein varies between 25% and 89%, with the partial removal of carbohydrate (consequently reducing lactose) and fat. Whey protein isolate (WPI) contains a higher percentage of protein, varying between 90% and 95%, with fat and lactose in lower proportions, or even absent. And whey protein hydrolyzed (WPH), composed of the isolated and concentrated fraction, is formed by dipeptides and tripeptides of high nutritional value. The main characteristic of WPH is the good digestibility and low allergenic potential, containing up to 98% of peptides in the product (Carrilho 2013).

Casein constitutes the highest proportion of milk proteins, composed mainly of αs1, αs2, β, and κ-casein, with 8.77 g of leucine in 100 g and representing 80% of total milk proteins. Due to precipitating after acidification it promotes reduction of gastric emptying rate, being digested more slowly than whey protein and delaying the amino acids pool in the blood in the postprandial period (Calbet and Holst 2004; Reitelseder et al. 2010; Bendtsen et al. 2013; Holt et al. 2013).

Protein supplementation increases gains in lean body mass following exercise training in older and young adults (Morton et al. 2018). Dirks et al. (2017) assessed 24 weeks of progressive resistance-type exercise training (2 sessions per week) during which they were supplemented twice a day with milk protein (2×15 g) or placebo (2×7.13 g lactose). The researchers concluded that protein supplementation augments muscle fiber hypertrophy following prolonged resistance-type exercise training. Another study with milk protein indicates that resistance training is an effective way to increase muscle mass and strength, regardless of protein supplementation. Higher doses of protein-rich food may be recommended to promote muscle mass gains when performing resistance exercise in elderly sarcopenic individuals (Maltais, Ladouceur, and Dionne 2016). In addition, soluble milk proteins rich in leucine improved time to muscle failure and increase in skeletal muscle mass and strength, after 16 weeks of exercise training in healthy older men (Gryson et al. 2014).

Table 1. Effects of whey supplementation on exercise.

Study	Study type and sample	Supplementation protocol	Exercise protocol	Follow up period	Outcomes measures	Results
Andersen et al. (2005)	RCT with young healthy males ($N = 22$)	WHEY (16.6 g/day of whey protein + 2.8 g/day of casein + 2.8 g/day of egg protein + 2.8 g/day of glutamine) or PL (25 g/day of maltodextrin)	Training program: 3 days per week with 3–4 sets of inclined leg press, isolated knee extension and hamstring curls	14 weeks	Isokinetic peak torque, muscle CSA and vertical jump height	There was no statistically significant difference between groups
Kerksick et al. (2006)	Double-blind, RCT with healthy male ($N = 36$)	WHEYAA(40g/day of whey protein + 3 g/day of BCAA + 5 g/day of glutamine), WHEYCAS (40 g /day of whey protein + 8 g/day of casein) or PL (48 g/day of carbohydrate)	Training program: 4 days per week with 2 upper-body and 2 lower-body workouts	10 weeks	Anaerobic capacity, blood analysis (albumin, electrolytes, enzymes, globulin, glucose, hematocrit, hemoglobin, lipid profiles, total bilirubin, red blood cells, white blood cells), body composition (BMC, FFM, FM, LBM, weight), strength and training volume	*FFM and LBM:* significantly higher in the WHEYCAS group
Hartman et al. (2007)	RCT with healthy young males ($N = 56$)	WHEY (fluid milk:17.5 g/day of whey protein + 25.7 g/day of carbohydrate + 0.4 g/day of fat), SOY (soy milk: isoenergetic, isonitrogenous and macronutrient ratio-matched to the WHEY) or PL (maltodextrin, isocaloric drink)	Training program: 5 days per week with resistance exercise on a rotating whole-body split routine	12 weeks	Blood analysis (AA, glucose, insulin), body composition (BMC, FM, LBM, weight), strength and type muscle fiber CSA	*FM:* significantly lower in the WHEY group *LBM and type II muscle fiber CSA:* significantly higher in the WHEY group *Type I muscle fiber CSA:* significantly higher in the WHEY and SOY group
Holm et al. (2008)	Double-blind, RCT with postmenopausal females ($N = 29$)	WHEY (10 g/day of whey protein + 31 g/day of carbohydrate + 1 g/day of fat + 5 g/day of vitamin D + 250 mg/day of calcium) or PL (6 g/day of carbohydrate + 12 mg/day of calcium)	Training program: 3 days per week until 12 week, after 2 days per week with a progressive resistance exercises	24 weeks	Blood analysis (osteocalcin, parathyraid hormone, vitamin D), body composition (BMC, FM, LBM), fiber types, muscle CSA and strength	*BMC and strength*: significantly higher in the WHEY group
Laviolette et al. (2010)	Double-blind, RCT with patients with chronic obstructive pulmonary disease ($N = 22$)	WHEY (20 g/day of pressurized whey protein) or PL (20 g/day of casein)	Training program: 3 days per week, during 8 weeks, with 90 min each training session, that combined endurance and resistance exercises	16 weeks	Blood analysis (CRP, glutathione, IL-6, protein oxidation), cycle endurance test time, mid-thigh CSA and peripheral muscle function	*Cycle endurance test time:* significantly higher in the WHEY group
Reitelseder et al. (2010)	RCT with active young males ($N = 17$)	WHEY (0.30 g/kg of LBM), CASEIN (0.30 g/kg of LBM) or PL (a noncaloric control drink)	Acute heavy resistance exercise bout consisted of 10 sets with 8 repetitions at 80% of 1RM	1 day	Anabolic signaling pathways, blood analysis (AA, IGF-1, insulin, ketoisocaproate acid) and MPS	*Anabolic signaling, amino acids and MPS:* significantly higher in the WHEY and CASEIN group *Insulin:* significantly higher in the WHEY group
Burd et al. (2012)	RCT with eldery men ($N = 14$)	WHEY (20 g) or CASEIN (20 g)	Unilateral leg resistance exercise	1 day	Blood analysis (EAA, glucose, insulin) and MPS	*EAA, insulin and MPS:* significantly higher in the WHEY group
Farnfield et al. (2012)	RCT with healthy young males ($N = 16$) and healthy older males ($N = 15$)	WHEY (26.6 g/day) or PL (26.6 g/day of aspartame sweetener)	Training program: 3 days per week with exercises: leg presses, bench presses, seated rows, leg extensions, dumb-bell shoulder presses and sit-ups	12 weeks	Peak torque, phosphorylation of mTOR and strength	*Peak torque:* significantly higher in the WHEY group for young men *Phosphorylation of mTOR:* significantly higher in the WHEY group

(*continued*)

Table 1. Continued.

Study	Study type and sample	Supplementation protocol	Exercise protocol	Follow up period	Outcomes measures	Results
Weinheimer et al. (2012)	Double-blind, RCT with overweight and obese middle-aged males and females ($N = 220$)	WHEY0 (0 g/day), WHEY20 (20 g/day), WHEY40 (40 g/day) or WHEY60 (60 g/day)	Training program: 2 days per week of resistance exercise + 1 day per week of aerobic exercise	36 weeks	Blood analysis (CRP, cholesterol, glucose, insulin, plasminogen activator inhibitor-1, triglycerides), blood pressure, body composition (FM, LBM, weight), VO_2max, strength and waist circumference	There was no statistically significant difference between groups
Weisgarber, Candow, and Vogt (2012)	Double-blind, RCT with untrained young adults ($N = 17$)	WHEY (0.30 g/kg body weight/day) or PL (0.2 g/kg body weight/day of cornstarch maltodextrin + 0.1 g/kg body weight/day of sucrose)	Training program: 4 days per week with 3 sets of 6–10 repetitions of 9 whole-body exercise with 90 min each training session	8 weeks	Body composition (BMC, FM, LBM, weight), muscle size, muscle thickness, strength and volume of training	*Volume of training:* significantly higher in the WHEY group
Witard, Jackman, et al. (2014)	Single-blind, RCT with healthy active males ($N = 48$)	WHEY0 (0 g), WHEY10 (10 g), WHEY20 (20 g) or WHEY40 (40 g)	Unilateral exercise: 8 sets of 10 repetitions of leg presses and leg extensions of 80% 1RM	1 day	Blood analysis (AA, glucose, insulin, urea), and MPS	*AA:* significantly higher in the WHEY10, WHEY20 and WHEY40 group *Insulin and MPS:* significantly higher in the WHEY20 and WHEY40 group *Urea and phenylalanine oxidation:* significantly higher in the WHEY40 group
Macnaughton et al. (2016)	Double-blind, cross-over RCT with healthy resistance-trained males ($N = 30$)	WHEY20 (20 g) or WHEY40 (40 g)	Acute bout resistance exercise 3 sets of 10 repetitions + 1 set to volitional failure in chest press, latissimus pull-down, leg curl, leg press and leg extension at 75% 1RM	1 day	Anabolic signaling pathways, blood analysis (leucine, phenylalanine, threonine) and MPS	*MPS*: significantly higher in the WHEY40 group
Maltais, Ladouceur, and Dionne (2016)	Double-blind, RCT with female basketball players ($N = 26$)	WHEY (13.5 g/day of milk protein with 7 g of EAA + 37.5 g/day of carbohydrate + 3.8 g/day of fat), SOY (12 g/day of protein with 7 g EAA + 39 g/day of carbohydrate + 5.3 g/day of fat), or PL (0.6 g/day of rice milk protein + 59.5 g/day of carbohydrate + 3.75 g/day of fat)	Training program: 3 days per week with 3 sets of 6–8 repetitions at 80% 1RM of 9 whole-body exercise with 1 h each training session	12 weeks	Body composition (LBM, weigh), chair stand, strength, timed up and go test and walking speed	There was no statistically significant difference between groups
Taylor et al. (2016)	Double-blind, RCT with female basketball players ($N = 14$)	WHEY (24 g/day) or PL (24 g of maltodextrin)	Training program: 3 days per week of upper- and lower-body resistance training + 3 days per week of 'explosive' exercises + 4 days per week of agility training	8 weeks	Agility, body composition (FM, LBM) and performance in bench press, broad jump, leg press and vertical jump	*Agility, LBM and performance in bench press:* significantly higher in the WHEY group
Dirks et al. (2017)	Double-blind, RCT with elderly individuals ($N = 34$)	WHEY (30 g/day of milk protein concentrate + 1 g/day of fat + 14.26 g/day of lactose + 0.84 g/day of calcium) or PL (14.26 g/day of lactose + 0.84 g/day of calcium)	Training program: 2 days per week of resistance exercise training	24 weeks	Body composition (ALM, BMC, FM, LBM, leg lean mass, weight), functional performance, myocellular characteristics and satellite cells content, strength and type muscle fiber CSA	*ALM , FM, LBM, leg lean mass and weight:* significantly higher in the WHEY group

(*continued*)

Table 1. Continued.

Study	Study type and sample	Supplementation protocol	Exercise protocol	Follow up period	Outcomes measures	Results
Englud et al. (2017)	RCT with mobility-limited older adults (*N* = 120)	WHEY (20 g/day of whey protein + 800 IU/day of vitamin D + 350 mg/day of calciuml) or PL (nonnutritive sweetened drink)	Training program: walking, lower-extremity strength exercises, balance and flexibility	24 weeks	Body composition (ALM, FM, intermuscular fat CSA, LBM, muscular density CSA, subcutaneous adipose tissue CSA, muscle CSA, weight), power and strength	*Intermuscular fat CSA:* significantly lower in the WHEY group *Muscular density CSA:* significantly higher in the WHEY group
Reidy et al. (2017)	Double-blind, RCT with healthy young males (*N* = 54)	WHEY (22 g/day of isolate whey protein), BLEND (22 g/day of 25% soy protein + 25% whey protein + 50% sodium caseinate) or PL (isocaloric maltodextrin)	Training program: 3 days per week with whole-body progressive resistance exercises	12 weeks	Body composition (LBM), myonuclear addition, satellite cell content and vastus lateralismyofiber-type-specific CSA	There was no statistically significant difference between groups

RCT: randomized clinical trial; CSA: cross-sectional area; BMC, bone mineral content; FFM: fat free mass; FM: fat mass; LBM: lean body mass; AA: amino acids; CRP: C-reactive protein; IL: interleukin; RM: repetition maximum; IGF-1: insulin-like growth factor-1; MPS: muscle protein synthesis; EAA: essential amino acids; mTOR: mammalian target of rapamycin; VO_2max: maximal oxygen uptake capacity; ALM: appendicular lean mass.

Young athletes also benefited from post exercise consumption of milk, which promotes greater hypertrophy during the early stages of resistance training in novice weightlifters when compared with isoenergetic soy or carbohydrate consumption (Hartman et al. 2007). Corroborating with this the study of Kerksick et al. (2006) with 36 resistance-trained males that followed a 4 day-per-week split-body resistance training program for 10 weeks. In the study the participants received 48 g of carbohydrate (placebo) or 40 g of whey protein plus 8 g of casein or 40 g of whey protein plus 3 g of branched-chain amino acids (BCAA) plus 5 g glutamine per day. It has been demonstrated that the combination of whey and casein protein promoted the greatest increases in fat-free mass after 10 weeks of heavy resistance training.

Some authors compared WPI supplementation alone or micellar casein on MPS. They showed faster MPS with WPI compared to casein intake. However after 4–6 h the response in MPS was globally the same, despite temporal differences found on insulin and amino acids concentrations (Reitelseder et al. 2010; Burd et al. 2012). This effect is associated to rapid aminoacidemia stimulating early synthesis of intramuscular proteins by the mTOR signaling cascade (Dangin et al. 2001; Sancak et al. 2008). Regarding protein dose and MPS, one study compared a single dose of 25 g against doses of 2.5 g every 20 min after exercise in an attempt to reproduce the digestion of slow absorption protein. The single dose was shown to be more effective in increasing plasma amino acid levels (West et al. 2011), demonstrating that a greater amount of protein promotes a more pronounced aminoacidemia peak which reflected a better anabolic signaling.

In general, protein ingestion may suppress appetite, promote energy expenditure and support increase in muscle mass and decrease in body fat (Kinsey et al. 2016). Protein consumed before sleep has been suggested to offer an overnight supply of exogenous amino acids for anabolic processes (Joy et al. 2018). One of the first studies to evidence the anabolic effect of nighttime protein on whole body protein balance studied older men who were provided with 40 g of casein via a nasogastric tube versus a volume matched bolus of water (Groen et al. 2012). The potential incremental impact of exercise and casein supplementation on whole body and muscle protein balance was evaluated in young males. Participants were engaged in an evening resistance exercise session receiving 40 g of casein. Whole body protein synthesis rate and net protein balance were increased with the latter adjusted from a potentially net negative to positive balance (Res et al. 2012).

In another study participants were already engaged in unsupervised exercise training, they were provided 54 g of casein protein, either at night or in the morning for 8 weeks. Dietary protein intake was increased in both groups from 1.7–1.8 to 2.4 (g/kg body weight/day) and no differences in strength and body composition from the beginning to the end were observed (Antonio et al. 2017). In a 12-week study, the combination of evening resistance training and supplemental casein protein led to greater gains in strength and muscle mass rather than resistance training alone (Snijders et al. 2015). While the resistance training stimulus was consistent across all participants, two important aspects should be considered about this experimental design: (a) the protein supplemented group consumed significantly more total protein daily (1.9 vs. 1.3 g/kg body weight/day), when compared to control group that did not receive an isocaloric or isonitrogenous comparator; (b) training stimulus was during the evening followed by a low-protein meal (10 g protein, 37 g carbohydrate, 9 g fat) (Snijders et al. 2015). A recent study evaluated thirteen males that participated in a 10-week exercise and dietary intervention. Participants received 35 g of casein daily at night or day and were controlled by isocaloric diets and 1.8 g of protein/kg body weight/day. Total dietary protein intake, both supplementation and food, is part of a 24 h-nutrition approach in order to increase strength and hypertrophy. The results support the strategy of achieving specific daily protein levels versus specific timing of protein ingestion to increase muscle mass and performance (Joy et al. 2018).

Although total daily protein intake seems to be the most important factor in maximizing muscle adaptation along with resistance training (Schoenfeld, Aragon, and Krieger 2013), some studies do not support it. In a study with 48 healthy resistance-trained men and women divided into normal protein group (NP) with 2.3 g/kg/day of dietary protein, and high protein group (HP) with 3.4 g/kg/day of dietary protein, each subject was instructed to follow a heavy resistance program for 8 weeks training five days a week. The program was a 'split routine' in which different parts of the body were trained on consecutive days. There was a greater body weight gain in the NP group than in the HP group; however, the HP group experienced a greater decrease in fat mass and % body fat (Antonio et al. 2015).

The timing of amino acid/protein ingestion before and during exercise should also be considered in the context of stimulating MPS (Witard et al. 2016). Whereas many studies suggest that timing is important to MPS (Beelen et al. 2008; Holm et al. 2008, Farnfield et al. 2012, Churchward-Venne et al. 2013), other studies have found no significant difference among several ingestion times (Verdijk et al. 2009; Jäger et al. 2017). A reduction in training-induced effects was found to occur when protein ingestion was delayed compared with immediately protein intake following exercise (Andersen et al. 2005; Holm et al. 2006; Hartman et al. 2007).

Protein intake frequency has also demonstrated benefits for MPS. The consumption of 30 to 45 g protein/meal produced the greatest increase in leg lean mass and strength in young adults and elderly (Mamerow et al. 2014; Loenneke et al. 2016). Conversely, some recent acute metabolic studies do not support the notion that timing amino acid/protein ingestion makes difference in MPS with protein consumption before or after exercise (Burk et al. 2009; Witard et al. 2009; Witard, Jackman, et al. 2014; Jäger et al. 2017). Accordingly, a longitudinal study reported similar increases in lean mass after 12 weeks of resistance training among groups of older adults that consumed a protein blend supplement either before or after each exercise session (Candow et al. 2006). Taken together, these data suggest that skeletal muscle is, at the very least, comparatively responsive to amino acid/protein ingested pre or post-exercise.

Besides frequency and timing, protein dose seems to be important and may influence the MPS rate. A study with young adults compared the intake of 0 g (placebo), 10 g, 20 g or 40 g of whey protein, with a session of unilateral leg press and knee extension exercises (8 sets of 10 repetitions each, at 80% one-repetition maximum). The subjects were then allocated to one of the study groups, receiving the proposed supplementation and rested for 4 h. Regarding dosages, the groups that received 20 g and 40 g of whey protein presented a 49% and 56% positive difference in MPS, respectively, when compared to the placebo group. There are no differences on the MPS rate between placebo and 10 g groups, which also occurred between doses of 20 g and 40 g. The results of this study indicate that the MPS peak in young adults is reached after 20 g dose, thus supplementation does not need to exceed this quantity (Witard, Jackman, et al. 2014).

Thus, Macnaughton et al. (2016) verified the influence of lean mass on MPS responses of trained men. Participants were divided into two groups: (1) lean mass $\leq$65 kg, (2) lean mass $\geq$ 70 kg, both performing full body resistance exercise. Authors showed that the ingestion of 40 g of protein during recovery stimulates a higher MPS response than 20 g of protein intake, although the amount of lean body mass did not influence the response to MPS (Macnaughton et al. 2016).

Amplified response in MPS may not be directly related to a phenotypic result as skeletal muscle mass (Mitchell et al. 2015). Weisgarber, Candow, and Vogt (2012), analyzed the effects of whey protein supplementation before and during exercise on 17 untrained young adults. The intervention group consumed 0.3 g/kg body weight of protein ($\sim$26 g) and placebo group 0.2 g maltodextrin with 0.1 g sucralose per kg body weight. After eight weeks of follow-up, where exercise and supplementation were performed for four days a week, there was a significant increase in muscle volume in both groups (supplemented and placebo) but there was no difference on muscle mass and strength, analyzed by dual X-ray absorptiometry (DXA). Authors reported that an absence of effect may be caused by daily protein intake, amount of protein supplementation, age of volunteers and length of the intervention, suggesting studies of longer follow-up. Therefore another study evaluated twice a day whey protein supplementation associated with resistance and aerobic exercises for 36 weeks in a group of overweight and obese volunteers. Protein supplementation (0, 20, 40 and 60 g of whey protein) have not promoted changes in body composition by DXA analysis (Weinheimer et al. 2012).

In addition to body composition and nutritional status, age is also a relevant factor for both metabolism and the rate of ingestion and absorption of protein. A recent study with elderly people resulted in improvements in body composition, subcutaneous and intramuscular fat and strength after six months of exercise. Nutritional supplementation (20 g whey protein + vitamin D) resulted in lower intramuscular fat and higher muscle density compared to placebo. These results suggest that nutritional supplementation and exercise training provide benefit to elderly people with reduced mobility (Englund et al. 2018). However, a study that evaluated a healthy young population for 3 months receiving 22 g of soy protein or whey protein or maltodextrin, found no difference in relation to muscle hypertrophy, proposing that while protein intake is adequate during muscle overload, adaptations in muscle growth and function are not influenced by protein supplementation (Reidy et al. 2017).

Even with some discordant results, whey protein supplementation, including the young population, has been reported as a factor of body composition improvement and athletes' performance (Taylor et al. 2016). A recent meta-analysis demonstrated that protein supplementation increases strength and lean mass when associated with resistance training. However, these results are less effective in elderly individuals and when the total amount of dietary protein is higher than 1.6 g/kg/day (Morton et al. 2018). As seen consistently in this session, milk proteins seem to be well evidenced in the literature to stimulate MPS in association with exercise and may result in lean mass gain.

Amino acids

In addition to dietary protein, amino acid supplements such as BCAA (leucine, isoleucine and valine) are quite popular and are often used by well-trained athletes. Among the amino acids, BCAA is the most frequently purchased (Pereira 2012). Amino acids generally have potential therapeutic effects, such as: healing, immune system improvement, avoiding sarcopenia in elderly and malnourished patients, and in the treatment of renal and hepatic diseases (Sipahi et al. 2013; Tsien et al. 2015; Khan et al. 2016; Rondanelli et al. 2016).

Branched-chain amino acids (BCAA)

BCAA account for about one third of muscle proteins, with leucine being the most investigated since the 1990s due to its oxidation rate being greater than the other two (Mero 1999). Some premises for BCAA use are that these amino acids, mainly leucine, promote MPS and insulin secretion, increase performance, decrease the degree of exercise-induced muscle injury and central fatigue (Howatson et al. 2012). The corresponding studies are summarized in the Table 2.

It has been proposed that BCAA supplementation decreases tryptophan uptake by central nervous system, reducing protein loss and retarding fatigue (Choi et al. 2013; Dunstan et al. 2017). Studies in rodents have shown good evidence to reduce symptoms of central fatigue, but this effect in humans is equivocal (Knechtle et al. 2012; Choi et al. 2013; Cordeiro et al. 2017). Another proposed reason for BCAA supplementation is the promotion and maintenance of post-exercise glutamine concentration which, in turn, would be involved in the attenuation of immunosuppression observed after the end of exercise (Cruzat, Krause, and Newsholm 2014).

One of the limitations of assessing BCAA effects is the association with other nutrients in some interventions, such as carbohydrates and other amino acids. A study that evaluated the combined supplementation of BCAA with arginine and carbohydrate versus placebo in treadmill tests until exhaustion, found that there was a reduction in the sensation of fatigue and increased plasma levels of BCAA in the intervention group (Hsu et al. 2011). However, another study evaluating BCAA supplementation alone, after a treadmill test, where the individuals also performed the endurance test until fatigue, have shown no differences in the sensation of fatigue and on blood lactate (Uchida et al. 2008). When the combination of BCAA and carbohydrate was compared with carbohydrate supplementation alone, authors have found neither significant improvement between the evaluated groups of blood markers recovery nor better results in strength after three days of intense training (Kephart et al. 2016). In contrast, a double-blind study of elite taekwondo athletes found that after three consecutive rounds, combined BCAA, arginine and citrulline supplementation may decrease athletes' central fatigue (Chen et al. 2016). The same combination of supplementation (BCAA, arginine and citrulline) also showed positive results regarding the decline prevention in performance in tennis athletes after a match, where this benefit was mainly attributed to BCAA (Yang et al. 2017).

Concerning BCAA action in MPS, Jackman et al. (2017) investigated the effect of 5.6 g BCAA or a placebo drink after resistance exercise in 10 young men. The authors observed a positive effect of BCAA supplementation on mTOR phosphorylation signaling and MPS after exercise (Jackman et al. 2017). In contrast, investigating the efficacy of BCAA supplementation in relation to performance, muscle pain and indirect markers of muscle loss, BCAA proved to be ineffective (Areces et al. 2014; Fouré et al. 2016). A current review brings criticism regarding BCAA supplementation, since the premise of BCAA consumption stimulating MPS or producing an anabolic response in humans is unwarranted, marketing a nutritional supplement industry of several million dollars (Wolfe 2017). In this case, the industry conflict of interest could be outweighing the real benefits of this type of food supplement. Although some athletes have a fairly high intake of BCAA because of their high energy and protein intake or supplementation, the effect of BCAA on performance is still unclear (Gleeson 2005). Also BCAA is not specifically mentioned in current guidelines (Thomas, Erdman, and Burke 2016; Maughan et al. 2018). The last one in which it was cited was the 2009 American College of Sports Medicine (ACSM) position, where it was listed as: ergogenic aids that do not perform as claimed (Rodriguez, DiMarco, and Langley 2009). The heterogeneity of the studies and the lack of methodological quality, do not corroborate to a conclusive evidence of the use of BCAA as an ergogenic supplement for sport.

Leucine

Leucine plays a role in the promotion of synthesis and inhibition of protein degradation via mechanisms involving the mTOR complex (Bandt 2016), besides influencing the short-term control of the protein synthesis translation step, having a synergistic effect with insulin (Yang et al. 2012). Although postprandial plasma insulin stimulates the uptake of amino acids, it may not promote exacerbation of MPS rates (Groen et al. 2016; Abdulla et al. 2016). The corresponding studies are summarized in the Table 3.

Currently, Stark et al. (2012) hypothesized that 3–4 g is the lower limit of leucine capable of maximizing the protein synthesis process (leucine threshold). In order to observe the leucine-induced effect on MPS, Venne et al. (2012) applied 0.7 g doses shortly after resistance exercise demonstrating that isolated amino acids were sufficient to stimulate MPS. In an older randomized study evaluating MPS and breakdown with co-supplementation of leucine and carbohydrate containing protein, a 0.3 g/kg body weight of leucine was shown to increase nitrogen balance when compared to the supplemented group with carbohydrate (Koopman et al. 2005). The consumption of 20–25 g of high biological value protein per meal, containing at least 8.5–10 g of essential amino acids or 1.5 g of leucine, promoted MPS stimulus, whether or not

Table 2. Effects of BCAA supplementation on exercise.

Study	Study type and sample	Supplementation protocol	Exercise protocol	Follow up period	Outcomes measures	Results
Uchida et al. (2008)	Double-blind, cross-over RCT with healthy males ($N = 17$)	BCAA (77 mg/kg body weight) or PL (64 g of maltodextrin)	Endurance test: running at 90% of the anaerobic threshold until exhaustion	1 day	Blood analysis (glucose, lactate, NH$_3$), perceived exertion, time to exhaustion, total distance performed	There was no statistically significant difference between groups
Hsu et al. (2011)	Double-blind, cross-over RCT with healthy males ($N = 14$)	BCAA (2 g of BCAA + 0.5 g of arginine + 12,1 g of carbohydrate) or PL (10 mg of sweetener)	Treadmill maximum effort test	1 day	Blood analysis (AA, CK, glucose, glycerol, insulin, lactate, NH$_3$, testosterone-to-cortisol ratio) and fatigue score	*Fatigue score:* significantly lower in BCAA group *Glucose, insulin testosterone-to-cortisol ratio:* significantly higher in the BCAA group
Howatson et al. (2012)	RCT with rugby and football male competitors ($N = 12$)	BCAA (20 g/day) or PL (aspartame based artificial sweetener)	Damaging exercise consisted of 100 consecutive drop-jumps	12 days	Blood analysis (CK), calf circumference, muscle soreness, MVC, thigh circumference and vertical jump	*CK, muscle soreness:* significantly lower in BCAA group *Recovery of MVC:* significantly higher in the BCAA group
Knechtle et al. (2012)	Trial with ultra-marathon athletes ($N = 28$)	BCAA (50 g of an amino acid concentrate including 20 g of BCAA) or PL (food and fluids ad libitum)	100 km ultra-marathon	1 day	Race time, renal function and skeletal muscle damage	There was no statistically significant difference between groups
Areces et al. (2014)	Double-blind, RCT with experienced runners ($N = 46$)	BCAA (5 g) or PL (isocaloric, composed by cellulose and dextrose)	Marathon race	1 week	Pain, power, running pace, speed, urine myoglobin concentration	There was no statistically significant difference between groups
Chen et al. 2016	Double-blind, cross-over RCT with taekwondo athletes ($N = 12$)	BCAA (0.17 g/kg body weight of BCAA + 0.05 g/kg body weight of arginine + 0.05 g/kg body weight of citrulline) or PL (0.27 g/kg body weight of starch)	3 simulated matches of taekwondo	1 day	Blood analysis (AA, glucose, glycerol, lactate, NEFA, NH$_{3,}$, NOx, urea) motor reaction time and perceived exertion	*BCAA, motor reaction time, NOx:* significantly higher in the BCAA group *Tryptophan/BCAA ratio:* significantly lower in BCAA group
Fouré et al. (2016)	Double-blind, RCT with young healthy males ($N = 26$)	BCAA (100 mg/kg body weight/day) or PL (microcrystalline celulose)	Maximal isometric leg extension	10 days	Muscle soreness and MVC	There was no statistically significant difference between groups
Kephart et al. (2016)	RCT with healthy resistance-trained males ($n = 30$)	BCAA (6 g of BCAA + 2 g of of non-sugar carbohydrates/day) or PL (40 g of sugar/day)	Training program: 10 sets of 5 repetitions of back squat at 80% 1RM	3 days	Blood analysis (lymphocyte, monocyte, myoglobin, neutrophil, white blood cells), isokinetic peak torque, muscle soreness, strength and training volume	*Monocyte:* significantly lower in BCAA group
Jackman et al. (2017)	Cross-over RCT with young resistance-trained males ($n = 10$)	BCAA (5.6 g of BCAA + 3.1 g of carbohydrate) or PL (4.6 g of carbohydrate)	4 sets of 10 repetitions on leg press at 70% 1RM + 4 sets of 10 repetitions on leg extension at 75% 1RM	1 day	Anabolic signaling proteins, blood analysis (AA, glucose, insulin, urea) and MPS	*BCAA, MPS*: significantly higher in the BCAA group *Phenylalanine:* significantly lower in BCAA group
Yang et al. (2017)	Cross-over RCT with tennis players males ($n = 9$)	BCAA (0.17 g/kg body weight + 6.67 UI/g of vitamin E + 0.05 g/kg body weight of arginine + 0.05 g/kg body weight of citrulline) or PL (starch + 100 UI of vitamin E)	1 simulated match of tennis	1 day	Blood analysis (AA, glucose, glycerol, lactate, NEFA, NH$_{3,}$ NOx, urea) heart rate, motor performance and perceived exertion	*BCAA, motor performance, NOx:* significantly higher in the BCAA group *Heart rate, perceived exertion, tryptophan/BCAA ratio:* significantly lower in BCAA group

BCAA: branched-chain amino acids; RCT: randomized clinical trial; PL: placebo; NH$_{3:}$ ammonia; AA: amino acids; CK: creatine kinase; MVC: maximal voluntary contraction; NEFA: non-esterified fatty acid; NOx: reduced nitric oxide; RM: repetition maximum; MPS: muscle protein synthesis.

Table 3. Effects of leucine supplementation on exercise.

Study	Study type and sample	Supplementation protocol	Exercise protocol	Follow up period	Outcomes measures	Results
Koopman et al. (2005)	Double-blind, cross-over RCT with healthy untrained males (*N* = 8)	LEU + CHO + PRO (0.1 g/kg body weight of leucine + 0.3 g/kg body weight of glucose/maltodextrin (50% each) + 0.2 g/ kg body weight protein hydrolysate), CHO + PRO or CHO	8 sets of 8 repetitions on horizontal leg press and leg extension at 80% of 1RM	1 day	Blood analysis (glucose, insulin, LEU, phenylalanine, tyrosine), FSR, protein balance and protein breakdown	*Insulin and positive protein balance:* significantly higher in the LEU + CHO + PRO group *FSR:* significantly higher in the LEU + CHO + PRO group and CHO + PRO group *Protein breakdown:* significantly lower in LEU + CHO + PRO group and CHO + PRO group
Venne et al. (2012)	RCT with young adult males (*N* = 24)	LEU (6.25 g whey protein with total LEU equivalent to PRO group), PRO (25 g whey protein) or EAA (6.25 g whey protein with total EAA equivalent to PRO group for all EAA except leucine)	10 RM of leg press and leg extension with dominant leg	1 day	Blood analysis (AA, glucose, insulin, LEU), exercise volume, MPS, mRNA expression AA transporter and muscle signaling	*Insulin (2 h post) and MPS (3–5 h post):* significantly higher in the PRO group *LEU and muscle signaling:* significantly higher in the LEU and PRO group
Church et al. (2016)	Double-blind, cross-over RCT with resistance-trained males (*N* = 9)	LEU (3 g), ursolic acid (3 g) or PL (3 g cellulose)	3 sessions of 4 sets of 8-10 repetitions on the angled leg press and leg extension at 75–80% of 1RM	1 day	Blood analysis (IGF-1, insulin, LEU, ursolic acid), skeletal muscle IGF-1 and mTORC1	*LEU (2 h post):* significantly higher in the LEU group *Skeletal muscle IGF-1:* significantly higher in the LEU group *Ursolic acid:* significantly higher in the ursolic acid group
Ispoglou et al. (2016)	Double-blind RCT with retired males and females (*N* = 36)	LEU20 (0.21 g/kg body weight/day of EAA with 20% LEU), LEU40 (0.21 g//kg body weigh/day of EAA with 40% LEU) or PL (lactose isocaloric)	None	12 weeks	6 min walk test, blood AA, body composition (BF, BMC, BMD, FM and LTM), handgrip, functional performance and strength	*6 min walk test*: significantly higher in the LEU20 and LEU40 group *Functional performance:* significantly higher in the LEU20 group *LTM:* significantly higher in the LEU40 group
Stragier et al. (2016)	RCT with older males and females (*N* = 25)	LEU (20 g/day of protein with 2.5 g of leucine + 7 g/day of maltosweet) or PL (27 g/day of maltosweet)	Training program: 2 sessions per week (1 hour each) at least 48 h apart	24 weeks	Muscle architecture, muscle thickness, MVC and strength	There was no statistically significant difference between groups
Aguiar et al. (2017)	Double-blind RCT with healthy young (*N* = 20)	LEU (3 g/day) or PL (3 g/day of cornstarch)	Training program: 2 sessions per week with 3 sets of 8–12 repetitions of leg press and leg extension	8 weeks	Muscle CSA of rectus femoris, muscle CSA of vastus lateralis and strength	There was no statistically significant difference between groups

RCT: randomized clinical trial; LEU: leucine; CHO: carbohydrate; PRO: protein; RM: repetition maximum; FSR: fractional synthesis rate; EAA: essential amino acid; AA: amino acids; MPS: muscle protein synthesis; PL: placebo; IGF-1: insulin-like growth factor-1; mTORC1: mammalian target of rapamycin complex 1; BF: body fat; BMC: bone mineral content; BMD: bone mineral density; FM: fat mass; LTM: lean tissue mass; MVC: maximal voluntary contraction; CSA: cross-sectional area.

followed by exercise. When stratified by body weight, the relative value of consumption margins 0.25 g protein/kg body weight (Moore et al. 2011), but the magnitude of the protein apparatus expression involved in MPS is greater when associated with training (Moore et al. 2009).

Different studies have shown positive effects of leucine supplementation on inflammatory-myogenic regenerative processes (Rowlands et al. 2016) and lean mass (Ispoglou et al. 2016) with resistance training. Adaptations are thought to occur by the activity stimulation of the protein synthetic machinery and the provision of an exogenous source of amino acids for incorporation into new proteins. Of all nutrients, leucine possesses the most marked anabolic characteristics in acting as a trigger element for the protein synthesis initiation and as a substrate for newly synthesized protein (Wilkinson et al. 2013; Thomas, Erdman, and Burke 2016). However, there are some divergent studies, where leucine increased growth factors in skeletal muscle, but have not increased signaling of mTOR significantly, in response to resistance exercise in trained men (Church et al. 2016). In this sense, Aguiar et al. (2017) evaluated the effects of leucine supplementation in changes in muscle mass and strength during an 8-week resistance training program in young and sedentary individuals. Authors demonstrated that leucine supplementation (3.0 g/

Table 4. Effects of glutamine supplementation on exercise.

Study	Study type and sample	Supplementation protocol	Exercise protocol	Follow up period	Outcomes measures	Results
Krzywkowski et al. (2001)	Double-blind, cross-over RCT with elite athletes ($N = 10$)	GLU (3.5 g) or PL (3.5 g of maltodextrin)	2h of bicycle exercise at 75% of VO_2 max	1 day	Blood analysis (catecholamines, glucose, GLU, growth hormone, IL, insulin, leukocytes, lymphocytes, monocytes, neutrophils)	*Glutamine:* significantly higher in the GLU group *Neutrophils:* significantly lower in GLU group
Antonio et al. (2002)	Double-blind, cross-over RCT with resistance-trained males ($N = 6$)	GLU (0.3 g/kg body weight) or PL (glycine 0.3 g/kg body weight) mixed with calorie-free fruit juice or placebo (calorie-free fruit juice only)	Training program: 2 sets of leg presses at 200% of body weight + 2 sets of bench presses at 100% of body weight	1 day	Number of maximal repetitions in leg press and bench press	There was no statistically significant difference between groups
Hiscock et al. (2003)	Double-blind, cross-over RCT with healthy males ($N = 8$)	GLU (3.5 g), PRO (13.7 g of protein from sodium caseinate, containing 1.23 g protein bound glutamine) or PL (3.5 g of maltodextrin)	2 h of cycle ergometry at 75% of VO_2 max	1 day	Blood analysis (GLU and IL-6)	*GLU:* significantly higher in the GLU and PRO group *IL-6:* significantly higher in the GLU group
Sasaki et al. (2013)	RCT with male university judoists ($N = 26$)	GLU (3 g/day) or PL (missing information)	2.5h of judo training/day + 1 h of weight training/day	2 weeks	Blood analysis (Ig, musculoskeletal enzymes, neutrophils, phagocytic activity, ROS, opsonic activity and white blood cells)	*ROS:* significantly higher in the GLU group
Legault, Bagnall, and Kimmerly (2015)	Double-blind, cross-over RCT with healthy participants ($N = 16$)	GLU (0.3 g/kg body weight/day + maltodextrin 0.3 g/kg body weight/day) or PL (maltodextrin 0.6 g/kg body weight/day)	Training program: 8 sets of 10 repetitions of eccentric contractions of leg	3 days	Peak torque and muscle soreness	*Peak torque:* significantly higher in the GLU group only for men *Muscle soreness:* significantly lower in GLU group
Song et al. (2015)	RCT with athletes ($N = 24$)	GLU (10 g/day) or PL (missing information)	Heavy training program	6 weeks	Blood analysis (lymphocytes (CD4 and CD8), IgA, IgG, IgM and NK)	*Lymphocytes (CD8):* significantly lower in GLU group
Zheng, Chen, and Zhou (2018)	Double-blind, cross-over RCT with healthy untrained young males ($N = 13$)	GLU (0.6 g/kg body weight + sugar-free lemon drink) or PL (sugar-free lemon drink alone)	Treadmill exercise to exhaustion at 40% of VO_2 max	1 day	Blood analysis (basophils, eosinophils, Ig, lymphocytes (CD3, CD4, CD8, CD19), monocytes, neutrophils NK, platelet, red and white cells), core body temperature, heart rate, gastrointestinal temperature, forehead temperature, perceived exertion, time to fatigue, weight	*Lymphocytes (CD3 and CD8):* significantly higher in GLU group

RCT: randomized clinical trial; GLU: glutamine; PL: placebo; VO_2 max: maximum oxygen consumption; IL: interleukin; ROS: reactive oxygen species; Ig: immunoglobulin; NK: natural killer.

day) have not increased muscle strength or muscle cross-sectional area to those who adopted adequate dietary protein intake (Aguiar et al. 2017). Likewise, the addition of leucine to protein supplementation was not able to potentiate muscle hypertrophy on elderly submitted to 12 weeks of resistance training (Stragier et al. 2016). Leucine stimulates muscle protein synthesis and suppresses protein breakdown (possibly through insulin), as it is demonstrated in short-term mechanistic, but few or almost none long-term trials show efficacy (Maughan et al. 2018). Thus, there is a lack of evidence that the leucine use is really effective.

Glutamine

Glutamine is the most abundant free amino acid in plasma and muscle tissue, with 80% of the total being present in the latter. It is used at high concentrations by rapidly dividing cells, such as enterocytes and leukocytes, to provide energy and also in nucleotide synthesis (Poortmans et al. 2012; Cruzat, Krause, and Newsholm 2014). Glutamine synthesis is catalyzed from the activity of *glutamine-synthetase*, which occurs in several organs, such as skeletal muscle, lungs, liver, brain and adipose tissue (Cruzat et al. 2007). The corresponding studies are summarized in the Table 4.

In special situations, such as exercise-induced stress, great changes occur in glutamine flux, reducing concentration in tissues and plasma. Among the mechanisms that lead to this decrease in glutamine concentrations, increased concentration of cortisol, which stimulates both the muscle glutamine efflux and the glutamine uptake by the liver (Silveira, Grittes, and Navarro 2011; Pereira 2012). Together with the decrease in hepatic glycogen stores and the increase in cortisol concentration, they promote greater stimulation of hepatic gluconeogenesis from glutamine (Cruzat et al. 2007).

Some authors suggested that reduced glutamine plasma concentration due to prolonged or exhaustive exercise could be responsible for the immune system suppression associated with the increased infection rate observed in the overtraining syndrome (Rogero, Mendes, and Tirapegui 2005). However, some studies indicated that glutamine plasma concentration may be maintained constant during and after exercise, and did not result in impairment in several aspects of immune function in post-exercise. Even though glutamine is essential for lymphocyte proliferation, there is no sufficiently reduction on plasma concentration after exercise (Hiscock and Pedersen 2002; Gleeson 2008). Thus, it is suggested that the decrease in glutaminemia is not primary cause of the overtraining syndrome, but that changes in plasma glutamine concentration may represent a good indicator of this syndrome (Kreher and Schwartz 2012).

Both ACSM and International Olympic Committee (IOC) mentioned glutamine as an ergogenic aid that may not perform as claimed, such as preliminary studies concerning these ergogenic aids are inconclusive as performance enhancers (Rodriguez, DiMarco, and Langley 2009; Maughan et al. 2018). Also glutamine's claim of immune system boost in athletes is not supported for well-controlled clinical trials. Recently IOC pointed out that glutamine supplementation before and after exercise does not alter immune perturbations and the mechanism for therapeutics effects still requires investigation (Maughan et al. 2018). It is clear that the recommendation for the use of glutamine still requires a range of studies that support this purpose.

Conclusion

The recommendations of protein consumption need to take into account the individual's age and level of physical activity. Dietary protein supplementation with at least 20 g and until 40 g seems to augment changes in muscle mass and strength associated with physical exercise. Whilst the whey protein effects were shown to be consistent over time, the results of leucine, glutamine and BCAA are limited, supporting the requirement for further comprehensive research in this area.

Hot topics

* The current recommendations of protein consumption are higher than previously recommended for healthy and active people;* The effect of protein supplementation on MPS in elderly is lower than in young people due to anabolic resistance.* Protein supplementation, especially milk proteins, ranging 20–40 g seems to be enough to stimulate MPS and consequently with exercise increased strength and lean mass;* BCAA, leucine or glutamine supplementation despite being widely used, there is still a lack of evidence to justify its use in sports and exercise.

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