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# Effects of Branched Chain Amino Acid Supplementation on Post-Exercise Muscle Recovery and Muscle Growth

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## Abstract

BCAA supplements are composed of three main essential amino acids, including leucine, isoleucine, and valine. The concept of BCAA supplementation comes from the fact that essential amino acids cannot be made by the body and must be derived from food and diet, as amino acids are the building blocks of proteins and muscle. Thus, by increasing intake of these essential amino acids, BCAAs are believed to reduce the effects of exercise-induced muscle damage (EIMD) by increasing availability of these important compounds. However, BCAAs are not approved by the Food & Drug Administration (FDA) as the FDA does not regulate dietary supplements (*Workout supplements*, 2021). Some evidence supports BCAA's ability to reduce EIMD with chronic supplementation (>10 days) at high intakes (>200 mg/kg/day) at least twice daily, rather than showing immediate effects with short-term intake (Fouré & Bendahan, 2017). BCAAs ability to stimulate muscle growth remains unclear as there is conflicting evidence that suggests BCAA supplementation may cause some increases, yet less than that of other supplements such as whey protein (Jackman et al., 2017). Therefore, this review examines the effects of BCAAs, and whether the evidence supports these advertised benefits marketed by exercise supplement companies.

# I. Introduction

Creatine powder, pre-workout supplements, collagen capsules—these are just a some of the many different types of workout products that have populated the fitness industry. With an increased movement towards a healthy lifestyle and exercise, a growing demand among consumers has arisen for health-related products such as organic food, exercise equipment, and pre workout supplements in order to support exercise strength and performance. Among these health products, branched chain amino acid supplements (BCAAs) have been a trending pre-workout supplement by the public, adding to the ever-growing options for ways to recover faster, get stronger, and increase overall performance.

In 2016, the dietary supplement industry was valued at $122 billion and continues to rise (*Workout supplements,* 2021). One of the categories that comprises the dietary supplement market includes workout supplements. In a 2019 report overview, the global pre-workout supplement market size alone was valued at 12.6 billion USD and is projected to increase at a compound annual growth rate of 8.3% from 2020 to 2027 (*Pre-workout supplements market size: Industry report, 2027,* 2020). Many of these products make claims to bring desired results such as enhancing muscle strength, recovery, endurance, weight loss, and overall performance.

A pre-workout supplement that can easily be found in the market are BCAA supplements which consist of three essential amino acids called leucine, isoleucine, and valine. These amino acids account for almost 50% of the essential amino acids in foods and 35% of essential amino acids in muscle proteins (Fouré & Bendahan, 2017). BCAA supplements are a mixture of these compounds and have been used by both fitness enthusiasts and professional athletes. Because essential amino acids cannot be produced by the body and must be derived from external dietary sources (Hall et al., 2022), BCAA supplementation is marketed to increase the availability of these essential amino acids and contribute to accelerated muscle recovery and muscle mass with respect to exercise.

However, the validity of these claims has been debatable as to whether BCAA supplementation provides significant benefits, and there remains inconclusive research on the effectiveness of BCAAs to enhance muscle recovery and increase muscular strength, despite the increasing popularity of BCAAs among consumers. Thus, this review will focus on the current research of BCAA supplementation that are in favor of and contend with the various fitness claims and benefits that market this product's appeal.

## II. BCAAs For Reducing Muscle Recovery

One of the most common fitness claims that attracts consumers to the appeal of BCAA supplementation is its ability to reduce muscle soreness and accelerate recovery time after exercise. There have been several studies done that measure indirect biomarkers of muscle damage and muscle inflammation post-exercise when BCAA supplementation is ingested as compared to when not, with conflicting results and findings between studies. Variations between studies may be attributed to differences in experimental designs (e.g., dosage, supplementation timing, period), the markers used to measure muscle soreness and recovery (e.g., creatine kinase, lactate dehydrogenase), and the level of training experience participants have (Estoche et al., 2019). This review will consider the bodies of research that both reinforce and oppose BCAAs impact on muscle soreness and recovery.

## BCAAs Effect on Creatine Kinase & Lactate Dehydrogenase

A 2021 meta-analysis looked at studies that measured plasma markers of muscle damage, such as lactate dehydrogenase (LDH) and creatine kinase (CK), as well as subjective soreness using the visual analog scale (VAS) after resistance exercise in trained males. A significant gender effect has been shown to affect serum levels of CK in women (i.e. women tend to have lower CK levels than men), thus this article focused on studies with male participants to account for any gender effect (George et al., 2016). 278 participants were included, with the resistance exercise intervention consisting of multi-joint exercises such as barbell, back squat, drop jump, and a combination squat and split jump. Volume of exercise was designed between 3 sets to volitional exhaustion and 5 to 20 repetitions, with exercise intensity between 70% 1-RM to 100% 1-RM (Khemtong et al., 2021). BCAA supplementation was given to experimental groups for a period ranging from 1 to 28 days using various strategies: at pre-load only, on exercise day only, at preload and exercise day, on exercise day and recovery period, and at all preload, exercise day, and recovery period.

Key findings showed that a positive effect was found for BCAA supplementation on CK levels in participants at <24, 24, and 48 h post exercise, when compared to control groups. However, there was high variability between studies for the results at 24 and 48 h. Results also demonstrated a positive effect of BCAA supplementation on muscle soreness at <24 h, measured by the visual analog scale (VAS), with low variability between results. BCAAs did not show effect on LDH levels at 24 h or 48 h post exercise (Khemtong et al, 2021).

Serum CK and LDH are enzymes specific to muscle and can be elevated in response to exercise or trauma, thus the levels of these biomarkers can be used as an indirect measure of muscle damage (Jankovic, 2022). LDH plays an important role in the production of lactate in muscle cells, with high levels of lactate associated with muscle soreness. Thus, LDH can act as an indirect biomarker of muscle soreness (Farhana & Lappin, 2021).

This meta-analysis did not demonstrate a reduction effect of BCAA supplementation on LDH levels, suggesting that BCAA supplementation does not have a significant impact on muscle soreness associated with the production of LDH. However, BCAAs demonstrated a reduction effect on CK levels, and have shown this particular result in other studies when BCAA supplementation is taken over a long period of time, in comparison to a short period of time (Hormoznejad et al., 2019). These results suggest that BCAA supplementation does not affect muscle damage but can help resolve inflammation associated with CK by increasing cell regeneration. Thus, while showing no significant reduction in LDH, BCAAs have the potential to reduce short-term perceived muscle soreness and accelerate recovery time by reducing elevated CK levels after resistance exercise.

## Peak Performance & Muscle Soreness

While both LDH and CK levels have commonly been used as indirect biomarkers of muscle soreness and recovery, other studies have utilized performance-based measurements to assess the effect of BCAA supplementation. In a 2019 double-blind, parallel-design study conducted by José M. Estoche and colleagues, BCAA supplementation was observed to have no significant impact on the number of repetitions nor the rate of perceived exertion (RPE) between the BCAA supplementation group and the placebo-controlled group. Additionally, both muscle soreness, using the visual analog scale (VAS), and countermovement jump (CMJ) were measured at baseline, 30 min, 24 h, and 48 h after exercise. Muscle CMJ was utilized as a measurement of maximum jumping height & peak power output/body ratio to determine if BCAAs had an impact on muscle performance and recovery. Similarly, these results showed no significant difference between the BCAAs and placebo group (Estoche, 2019). Considering these findings, while BCAA supplementation may have a reduction effect on elevated CK levels that occur post-exercise, other measures such as RPE, VAS, number of repetitions, and peak power output have not shown significant improvement from BCAA supplementation when compared to placebo-controlled groups. These discrepancies between researchers suggest an influence on post-exercise, physiological changes (i.e. CK levels) but do not translate into a physical, noticeable effect on muscle performance, recovery, and soreness. Further controlled and consistent evaluation of BCAAs effects is necessary to determine whether these supplements provide beneficial effects to consumers.

## BCAA Supplementation Regimen & Dosage

One of the challenges of BCAA supplementation is determining the most effective supplementation regimen in order to optimize the benefits of BCAAs, if present. There are multiple methods to the timing of BCAA intake, whether it be prior to exercise, the day of exercise, after exercise, or any combination of these. Another variable factor of supplementation strategy is the comparison between chronic use and short-term use of BCAAs. Several studies have observed that BCAA supplementation can alleviate low-to-moderate muscle damage, particularly when taken at high daily intakes at high daily frequency over a long period of time prior to the exercise session (Fouré & Bendahan, 2017). A review on the efficiency of BCAA supplementation to alleviate muscle damage analyzed multiple studies which measured exercise induced muscle damage outcomes, including peak force loss, serum biomarkers of muscle damage (e.g., CK, LDH, and myoglobin) and delayed onset muscle soreness. Considering the studies with positive and neutral quality ratings, BCAA supplementation had the greatest benefit with a high intake (>200 mg/kg/day) at a frequency of of 2 or more times per day with a long duration of supplementation over 10 days (Fouré & Bendahan, 2017).

In comparison, a low frequency (less than 2 intakes per day) and a low daily intake (less than 200 mg/kg/day) during a moderate time period (4-10 days) was not enough to affect the CK, LDH, and myoglobin levels post-exercise. Similarly, no significant effects resulted from high frequency and high daily intakes of BCAAs when taken over a short period of time (Fouré & Bendahan, 2017). This source emphasizes the specific supplementation strategies necessary to reduce outcomes of exercise-induced muscle damage, such as peak force loss. By taking BCAA supplementation on the suggested regimen, a peak force loss less than 15% can be expected (Fouré & Bendahan, 2017). Thus, BCAA supplements taken days to weeks prior to exercise may act as a proactive reduction of skeletal muscle tissue damage caused by low-to-moderate exercise intensity by enhancing mitochondrial synthesis and preventing oxidative damage. Overall, it is evident that the combination of frequency, amount, and duration of BCAA supplementation is vital to potentially activating the beneficial effects of BCAAs.

## III. BCAAs Effect on Protein Synthesis & Muscle Growth

Another advertised benefit associated with BCAA supplements is its claim to enhance muscle growth and increase muscle mass. In humans, new protein is constantly being produced while old protein is broken down for reutilization. This cycle of continuous protein synthesis and breakdown is referred to as muscle protein turnover (Santos & Nascimento, 2019). In the circumstance when protein synthesis occurs at a greater rate than protein breakdown, the body is in an anabolic state of net protein synthesis that supports muscle growth and hypertrophy. Conversely, when muscle protein breakdown exceeds protein synthesis, the body is in a catabolic state of protein degradation that leads to muscle loss. The metabolic goal of BCAA supplementation is to optimize protein synthesis by providing the body with a surplus of these 3 essential amino acids—leucine, isoleucine, and valine—as this has been a widely marketed benefit by the BCAA supplement industry.

When fasting, which begins approximately 2-3 hours after a meal, the body enters a postabsorptive state. During the postabsorptive state, plasma essential amino acids (EAA) drop below postprandial levels if no additional protein is consumed. Thus, plasma essential amino acid maintenance draws upon protein turnover from skeletal muscle, which is the body's major protein reservoir. Thus, the rate of protein breakdown exceeds protein synthesis by about 30%. This amount of protein breakdown occurs due to 25% of EAAs being released into plasma and uptake by other tissues, and 5% being oxidized in muscle. The remaining 70% are reused to sustain protein synthesis in muscle. The idea that BCAA intake during the postabsorptive state increases muscle protein synthesis and decreases the 30% rate of protein breakdown is based on the idea that external intake of BCAAs will increase the availability of essential amino acids for synthesis, rather than oxidation or release into the plasma (Santos & Nascimento, 2019).

## Muscle Protein Response to Intravenous Infusion of BCAA Supplements

An extensive review by Robert Wolfe found no studies that quantified muscle protein synthesis in human participants in response to oral intake of BCAAs. However, it examines two studies in which BCAAs were administered intravenously (IV) to 10 postabsorptive individuals and assessed its effects. The forearm balance method was used to measure the response of an IV infusion of BCAAs for 3 hours in 10 post-absorptive (i.e., fasting) individuals. This consists of measuring the uptake and release of essential amino acids, specifically leucine and phenylalanine. The rate of disappearance and rate of appearance of both leucine and phenylalanine were calculated. The rate of disappearance of phenylalanine is used as an indicator of muscle protein synthesis since this specific EAA is only taken up by skeletal muscle from plasma for protein synthesis, thus a high rate of disappearance from plasma would signify that muscles are undergoing protein synthesis through uptake of phenylalanine and other amino acids (Matthews, 2007).

The 3 hour infusion of BCAAs raised plasma concentrations of all 3 BCAAs, while reducing concentrations of the other EAAs. Muscle protein synthesis decreased (37+/− 3 to 21 +/− 2 nmol/min/100 ml), showing statistical significance ($p < 0.05$). Muscle protein breakdown also decreased by a similar amount, meaning that the catabolic state in the post-absorptive individuals remained. An anabolic state for protein synthesis did not result (Wolfe, 2017).

A second study that extended the time of IV infusion to 16 h in 8 normal volunteers showed similar results. BCAA plasma concentration increased 5 to 8 times, and muscle protein synthesis decreased (36 +/− 5 to 27 +/−2 nmol/min/100 ml) in comparison to the control saline infusion (Wolfe, 2017).

From these studies, BCAA supplementation given via IV demonstrated muscle protein breakdown exceeded muscle protein synthesis, resulting in a catabolic state that favored muscle breakdown instead of growth. Furthermore, a sustained decrease in muscle turnover would be expected to cause decreased muscle mass and muscle strength if maintained. Claims that dietary supplementation of BCAAs enhances muscle protein synthesis in humans are unnecessary and warrant further exploration to support such statements.

## Outcomes of Oral BCAA Intake on Muscle Protein Processes

Conversely, a randomized controlled trial consisting of ten young, resistance-trained males was conducted by Jackman et. al. and demonstrated that isolated, oral intake of 5.6 g of BCAAs showed a 22% higher rate of muscle protein synthesis over the 4 hour period following resistance exercise and drink ingestion compared to the placebo group (Santos & Nascimento, 2019). Moreover, phenylalanine rate of appearance was about 6% lower in the BCAA group compared to the control group after supplementation, indicating that the BCAA group had a lower rate of protein breakdown (Jackman et al., 2017).

Researchers also used Western blotting of muscle biopsies collected pre, 1-, and 4-h post drink to measure the phosphorylation of the mechanistic target of rapamycin complex-1 (mTORC1) signaling proteins in muscle. Key findings showed increased activation of the mTORC1 signaling pathway at 1 h after drink ingestion in the BCAA group compared to the placebo group. When mTORC1 is phosphorylated, this triggers the protein complex's signaling pathways and stimulates protein synthesis (Takahara et al., 2020; Hall, 2022). Thus, the measurement of phosphorylated mTORC1 in muscle biopsies acts as a surrogate marker for the rate of protein synthesis. However, when the effects of BCAA supplementation is compared to whey protein supplementation over a similar duration, BCAAs demonstrate about a 50% smaller increase in muscle protein synthesis than whey protein intake, despite containing similar amounts of BCAAs (Jackman et al., 2017).

While BCAA supplementation may show some increases in muscle protein synthesis pathways and activation after resistance exercise, the benefits remain relatively small when taking into account the effects of other protein sources or supplements, such as whey protein. Moreover, a surplus of BCAA supplementation may cause undesirable effects by reducing both muscle protein synthesis and breakdown, resulting in an overall decrease in protein turnover. If maintained, this may contribute to a decrease in muscle mass. However, it is worth noting that the studies which described these findings administered BCAA supplementation through intravenous infusion (Wolfe, 2017), which is not as practical of a measurement for the effect of oral BCAA intake and warrants further research specifically on BCAAs supplementation and its impact on protein synthesis and muscle mass through oral ingestion. Overall, there remains inconsistent research which cannot fully support the claims that BCAAs have a substantial impact on muscle development and protein synthesis that is worth the multi-billion dollar industry of BCAA supplementation.

## IV. Discussion

It's possible that protein synthesis and muscle growth did not increase with BCAA supplementation due to the need for all 9 essential amino acids, as well as the 11 non-essential amino acids, to be present in order for increased anabolic processes and muscle protein synthesis to occur. If only the 3 EAAs are consumed—leucine, isoleucine, valine—the amount of other amino acids that are needed for protein synthesis did not change, which is rate limiting for the anabolic process. Thus, the body resorts to its major protein reservoir, skeletal muscle, in order to acquire the remaining amino acids (Santos & Nascimento, 2019). If maintained, this may result in overall muscle loss. Despite high levels of the BCAAs, the absence of the remaining essential and non-essential amino acids is a rate limiting factor that is needed for anabolic, protein-synthesizing processes to occur. Therefore, it can be reasoned that it is more beneficial to choose supplements containing all amino acids in order to amplify muscle protein synthesis and increase muscle mass and growth.

In regards to BCAAs impact on muscle soreness, there are several markers that have been used to measure speed of recovery and soreness when compared to placebo-controlled groups. Many studies have looked at physiological biomarkers such as CK levels and LDH levels post-exercise, while others measure number of repetitions to exhaustion, VAS, and peak power output. Due to the variance in indirect markers of muscle soreness and recovery, this tends to lead to conflicting results between these different modes of measurement, making it difficult to concretely say whether BCAA supplements improve recovery and reduce soreness. However, evidence has shown that there are potential benefits for alleviating low-to-moderate muscle damage when taking BCAAs at higher intakes (>200 mg/kg/day) at least twice daily over a longer period of time (10 days), especially prior to exercise (Fouré & Bendahan, 2017). This may explain the need for longer-lasting supplementation in order to reduce peak force loss and exercise-induced muscle damage with BCAAs, which many previous studies have not done. This proposes the possibility that BCAAs effects are more gradual, rather than immediate. With these findings in mind, further studies should focus on chronic BCAA intake prior to exercise-induced muscle damage to determine if this method of intake is more effective, rather than short-term intake after or before exercise. Researchers should take special consideration into the method, frequency, amount, and duration of BCAA supplementation.

## V. Conclusion

Based on current research, BCAAs may have the benefit of accelerating muscle recovery by reducing CK efflux after exercise and reducing muscle inflammation associated with elevated levels of CK. Consistent with previous literature, BCAA intake had no effect on lactate dehydrogenase, a biomarker for muscle damage, and conflicting findings are unable to determine whether muscle soreness is reduced with BCAA supplementation. Further research should be conducted to determine BCAAs effectiveness at reducing muscle soreness and recovery time.

Studies utilizing intravenous infusion of BCAAs supplementation demonstrated a decrease in muscle protein synthesis in postabsorptive individuals, resulting in a catabolic state that can lead to undesired muscle loss if maintained. Contrarily, other evidence supports the benefits of BCAA when taken orally, as opposed to IV infusion, to increasing muscle protein synthesis at a rate 22% greater than a placebo. Yet, this increase in protein synthesis with oral BCAA supplementation is still 50% less than the rate of protein synthesis with whey protein supplementation. Considering both studies, those attempting to increase muscle growth should focus on consuming supplements containing a complete mix of both essential and nonessential amino acids, such as whey protein, rather than products containing only a select few amino acids.

Overall, the current research suggests that BCAAs have the potential to facilitate muscle recovery through reduction of elevated CK levels following resistance exercise and possibly alleviating muscle soreness. However, further controlled research is needed to determine whether BCAAs accelerate recovery time, improve performance, as well as increase protein synthesis and muscle growth. In coming years, demand for exercise supplements will continue to rise. Thus, as consumers of these products, it’s important to be aware of the effects of these supplements, whether beneficial or not, especially since exercise supplements are not regulated nor approved by the Food & Drug Administration. Greater consistent, accurate evidence will help the public as well as health and fitness professionals resolve whether BCAA supplements are effective and worth the multi-billion dollar industry. Therefore, being knowledgeable about the validity of the various health and fitness claims made by the exercise supplement industry is important for making conscious decisions about the supplements that the general public invests in as well as puts into their bodies.

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