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The Effects of BCAA-Enriched Essential Amino Acid Mixtures and Exercise on the Muscles: A Randomized, Single-Blind, Placebo-Controlled Trial

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Abstract

Background: Protein intake provides the essential amino acids (EAA) necessary for promoting muscle protein synthesis. Branched-chain amino acids (BCAA) belonging to the EAA in particular are known to have more potent effects. We developed BCAA-enriched essential amino acids (BEAA®) to improve muscle health and performance. Therefore, we aimed at comparing the effects of BEAA® and whey protein intake in combination with exercise on muscle mass and strength in humans. **Methods:** A randomized, single-blind, placebo-controlled, parallel-group study was conducted to evaluate the impact of BEAA® and exercise on the muscles in healthy participants. Seventy-five healthy male participants were enrolled and randomly divided into three groups; the BCAA-enriched essential amino acids (BEAA), whey protein (WHEY), and placebo (PLA) groups. The participants consumed either the food containing BEAA® 3 g, whey protein 20 g, or dextrin 3 g for 12 weeks. The participants exercised five times weekly, and the exercise load was gradually increased. The primary (muscle mass) and secondary (muscle strength) outcomes were evaluated. **Results:** Whole-body muscle mass and lower-limb muscle mass showed statistical significance in the BEAA group compared to the PLA group ($P < 0.05$), whereas there was no difference between the WHEY group and the PLA group. Regarding the knee joint extensor muscle strength, no significant differences were observed between the BEAA group and the WHEY group when compared to the PLA group. No adverse events attributable to the test foods were observed during the study period. **Conclusions:** Overall, BEAA® was

shown to increase muscle mass in healthy adult males when combined with exercise.

Keywords

Essential Amino Acid, Branched-Chain Amino Acid, BEAA, Whey Protein, Muscle Mass

1. Introduction

Skeletal muscle is a tissue in which protein synthesis and degradation are constantly repeated in vivo, and its mass is determined by the balance between muscle protein synthesis and degradation [1]. It is known that protein ingestion after exercise promotes muscle protein synthesis and inhibits its degradation, resulting in an increase in net muscle protein mass during the post-exercise recovery period [2] [3]. Whey protein is a popular form of protein intake, and 20 g of whey protein has been reported to maximally stimulate muscle protein synthesis in healthy young adults at rest and after resistance exercise [4]. The major "active" component of the muscle synthesis effect of whey protein intake is thought to be essential amino acids (EAAs) that cannot be synthesized by the body and must be obtained from the diet [5].

The protein ingested with the diet is broken down into free amino acids by digestive enzymes and then absorbed into the body, where it is transported to skeletal muscle via the bloodstream, contributing to muscle protein synthesis. Amino acids play a metabolic role in promoting muscle protein synthesis rather than simply functioning as protein components [6]. In particular, leucine, an essential amino acid (EAA), is known to activate the mammalian target of the rapamycin (mTOR) signaling pathway and most potently promotes muscle protein synthesis [6] [7]. When blood leucine is taken up into muscle cells by the amino acid transporter, it activates the downstream mTOR signaling pathway via the intracellular signal receptor mTOR complex 1 (mTORC1), thereby promoting protein synthesis. Leucine also stimulates pancreatic beta cells to promote insulin secretion, and the secreted insulin also activates the mTOR signaling pathway [6] [7]. Thus, leucine contributes to muscle protein synthesis by directly or indirectly activating the mTOR signaling pathway in muscle cells. In fact, numerous studies have shown that leucine or leucine-rich supplements enhanced muscle protein synthesis in healthy adults [7]. On the other hand, EAAs other than leucine are also thought to exert synergistic effects on muscle protein synthesis, especially valine and isoleucine, which belong to the branched-chain amino acids (BCAAs) such as leucine, and it was reported that the intake of all three BCAAs effectively activated mTOR signaling compared with leucine alone [8]. Therefore, BCAAs are thought to have a synergistic effect on leucine-induced muscle protein synthesis [8] [9].

In addition, EAAs other than BCAAs are known to have effects on muscle pro-

tein synthesis. In healthy adults, the ingestion of EAA mixtures with resistance exercise has been shown to increase mTOR activity more than BCAA ingestion [10]. In contrast, the intake of nonessential amino acids after exercise in healthy adults has no effect on muscle protein synthesis, suggesting that EAA is the only amino acid that functions as a signaling molecule to stimulate muscle protein synthesis [11]. Therefore, it is believed that the composition of ingested amino acids affects the net muscle protein content [11], and, in particular, the inclusion of all EAAs stimulates protein synthesis [12].

Based on these findings, we hypothesized that high content of BCAAs with excellent muscular synthesis ability and other EAAs would be highly effective when included in the formula. We also developed a free amino acid mixture with high BCAA content and a unique composition of other EAAs to improve muscle health and performance, which we named BCAA-enriched essential amino acids (BEAA®). BEAA® contains 83.7% of the total BCAAs (leucine, valine, and isoleucine), with the remaining 16.3% consisting entirely of EAAs (lysine, phenylalanine, threonine, methionine, histidine, and tryptophan).

Therefore, the purpose of this study was to examine the effects of BEAA® and whey protein intake in combination with exercise on muscle mass and strength in humans. A randomized, single-blind, placebo-controlled, parallel-group study with three groups of participants ingesting 3 g of BEAA®, 20 g of whey protein, and placebo was thus conducted.

2. Materials and Methods

2.1. Study Subjects and Setting

For this study, the principal investigator recruited paid volunteers according to selection and inclusion/exclusion criteria. The subjects were healthy adult males who met the following selection criteria and did not violate the exclusion criteria. The selection criteria were as follows: 1) healthy Japanese males aged 20 to 40 years old; 2) subjects whose BMI was under 30; 3) subjects capable of performing self-assessment and who voluntarily gave written informed consent. The exclusion criteria were as follows: 1) subjects who regularly used drugs associated with muscle and/or lipid metabolism; 2) those who had contracted or had a history of serious diseases (e.g., liver, kidney, digestive, heart, respiratory, endocrine, metabolic, skeletal muscle, and/or tendon disease); 3) those who were undergoing or could have received surgical treatment of the knee joints; 4) those with a pacemaker or artificial joint, etc.; 5) those who had had severe damage of the locomotive organs, such as fractures, tendon ruptures, or muscle strain, in the past 1 year; 6) those with physical disabilities such as severe low back pain and knee pain, which could have interfered with exercise; 7) those who had contracted or had a surgical history of digestive disease affecting digestion and absorption; 8) those who could not stop using supplements and/or functional foods (including food for specified health uses, foods with function claims, or nutritional supplements which contained amino acids and/or proteins); 9) subjects for whom exercise was

prohibited by doctors; 10) those who declared allergic reactions to foods; 11) those who could not stop drinking 2 days before each measurement; 12) those whose alcohol intake was more than approximately 20 g/day of pure alcohol equivalent or had a habit of drinking not less than 4 days a week; 13) those who were shift workers and/or midnight-shift workers; 14) those with a history of and/or current drug addiction and/or alcoholism; 15) those who were judged as unsuitable for the current study based on screening tests; 16) subjects who had donated over 200 mL of blood and/or blood components during the month prior to the current study or over 400 mL of blood and/or blood components during the three months prior to the current study; 17) those participating in or willing to participate in other clinical studies; and 18) those who were judged as unsuitable for the current study by the investigator for other reasons.

This study was subject to deliberation and approval (approval date: May 16, 2024) by the Ethical Committee of Kobuna Orthopedics Clinic (Chairman: Toshio Kawada) and was approved according to the "Declaration of Helsinki October 2013, WMA Fortaleza General Assembly (Brazil), as amended" and the "Ethical Guidelines for Life Science and Medical Research Involving Human Subjects" (2021). This research study was conducted under the supervision of a physician at the Urayasu Sekiguchi Clinic for Internal Medicine, Rheumatology and Arthritis. The research plan for this study has been registered in the clinical trial registration system operated by the University Hospital Medical Information Network Research Center, with the registration ID UMIN000054813 (name of the trial registration: Effect of test food consumption and Exercise on Physical Fitness—A Randomized, Single-blind, Placebo-controlled, Parallel-group Study).

2.2. Research Methods

This study was conducted as a randomized, single-blind, placebo-controlled, parallel-group study (allocation ratio: 1:1:1) for a total of 13 weeks, consisting of a pre-observation period (1 week) and an intake period (12 weeks), with no methodological changes after study entry. The statistical analyst used computer-generated random numbers to allocate the subjects according to a block randomization method (block size 4) with age, BMI, protein intake based on the Food Frequency Questionnaire (FFQg), whole-body muscle mass, and knee joint extensor muscle strength as the adjustment factors. The participants were assigned to the three allocated groups of placebo (PLA), whey protein (WHEY), and BCAA-enriched essential amino acids (BEAA) by the study food allocation manager, and a table (key code) describing the results was prepared.

The target number of subjects in this study was set at 25 per group (75 subjects in total) based on a report [13] that showed a muscle mass-increasing effect of EAA intake and exercise load.

In addition, the study subjects were advised not to use supplements or health foods (including food for specified health uses, functional foods, and nutritional supplements such as amino acids and protein), to lead the same lifestyle as before

the study, and not to drink alcohol excessively during the study period. In addition, the subjects were advised to avoid alcohol consumption for two days prior to all examinations, to refrain from strenuous exercise from the time they woke up on the day before all examinations until the end of the examinations, to go to bed early and not to stay up late on the day before all examinations, to go to bed by around midnight and get enough sleep in principle, and to quit smoking on the day of all examinations, from the time they woke up until the end of the examinations. For those undergoing examinations in the morning, no food or drinks were allowed from the time they woke up until the end of the clinical examination, and they had to refrain from eating or drinking for at least 8 hours from the night before. In addition, the research subjects were to use medicines only with the permission of the principal investigator or a research associate physician, except in cases of emergency.

2.3. Intake of Research Food

The BEAA group consisted of a powdered beverage containing BEAA® (Toyo Shinyaku Co., Ltd., Saga, Japan) mixed with a flavoring and sweetening agent. The PLA group's study foods were powdered beverages in which the BEAA® in the BEAA diet was replaced with dextrin so that they were visually indistinguishable from the BEAA diet; WHEY diets were designed to have a daily intake of 3.4 g and 27 g. Each daily portion of the study foods was packaged and distributed to the study subjects in plain aluminum bags of the same size to ensure the blinding of the study subjects.

The caloric and nutrient values per daily intake of the study foods are shown in Table 1.

Table 1. Analysis of nutrient composition values of test food.

Table column subhead	PLA	WHEY	BEAA
Energy (kcal)[a]	13.0	105.3	13.5
Protein (g)[b]	0.0	20.0	3.0
Fat (g)	0.0	1.0	0.0
Carbohydrate (g)	3.3	4.1	0.4
Salt equivalent (g)	0.000	0.124	0.002
ΣEAAs (g)	0.0	10.0	3.0
Total (g)	3.4	27.0	3.4

a) Calorie conversion factor: protein, 4; fat, 9; carbohydrate, 4. b) Nitrogen-to-protein conversion factor: 6.25 (PLA, WHEY), 8.82 (BEAA).

2.4. Exercise Load

The exercise load consisted of resistance exercise performed at a sports club or at home 5 times per week during the intake period. Exercise at the designated sports club was performed twice a week. At the first exercise session, the participants

were instructed by an exercise therapist on how to use the equipment, had their Repetition Maximum (RM) measured, and exercised at 60% to 80% of that intensity each time. The exercises were leg presses, leg extensions, and leg curls. Warm-up stretching and other exercises were performed before the exercise, and no other exercises were performed. The exercise intensity was set at 60% for 2 sets of 8 repetitions from week 0 onward, 60% for 2 sets of 10 repetitions from week 3 onward, 70% for 3 sets of 10 repetitions from week 6 onward, and 80% for 3 sets of 10 repetitions from week 9 onward. Exercise at home was performed once a week for set A and twice a week for set B, as a rule, after the preparatory exercise. Set A was all performed with dumbbells, and 1) squats, 2) front lunges (alternating left and right), 3) calf raises, and 4) side lunges (alternating left and right) were all performed on a different day from the exercise days at the sports club. The exercise load was calculated from week 0 onward and consisted of 2 sets of 8 repetitions (4 repetitions alternating between (2) and (4)) after week 0, 2 sets of 10 repetitions (5 repetitions alternating between (2) and (4)) after week 3, 3 sets of 10 repetitions (5 repetitions alternating between (2) and (4)) after week 6, and 3 sets of 12 repetitions (6 repetitions alternating between (2) and (4)) after week 9. Set B consisted of 1) pushups, 2) back kicks, and 3) arm curls with dumbbells (alternating left and right), all of which were allowed to overlap with the exercise days at the sports club. The exercise load included 2 sets of 8 repetitions (4 repetitions alternating left and right) after week 0, 2 sets of 10 repetitions (5 repetitions alternating left and right) after week 3, 3 sets of 10 repetitions (5 repetitions alternating left and right) after week 6, and 3 sets of 12 repetitions (6 repetitions alternating left and right) after week 9. The weight of the dumbbells used in sets A and B was 10 kg (5 kg × 2). Furthermore, the presence and frequency of exercises conducted at the sports club and at home were managed by recording them in a log.

2.5. Evaluation Items

The primary endpoints were whole-body muscle mass and lower-limb muscle mass, and the secondary endpoint was knee joint extensor muscle strength. Muscle mass was evaluated twice before and 12 weeks after intake by using the Dual Energy X-ray Absorptiometry (DXA) method. Knee joint extensor muscle strength was evaluated by using the Tension Meter D (TKK-5710E; Takei Kiki Kogyo Co., Ltd.) three times before, six weeks after, and twelve weeks after intake. There were no changes in outcomes after the study began. In addition, physical characteristics (height, weight (BMI), blood pressure, and pulse rate) and protein intake based on the FFQg were assessed prior to the start of intake and at each examination to confirm the background of the study subjects.

The study subjects were given a food diary and a research logbook and were asked to complete them daily throughout the intake period, beginning one week prior to the start of intake. The survey items included 1) the intake of study foods, 2) the presence or absence of physical changes, 3) bedtime, 4) the presence or absence of changes in living conditions, 5) the use of medicines (medicines exclud-

ing nutritional drinks, new designated quasi-drugs, and new range quasi-drugs), and 6) dietary contents (*i.e.*, the contents of meals (including meals, snacks, banned foods, supplements, health food supplements, drinks, alcohol, etc.)).

2.6. Statistical Analysis

The population for analysis was defined as a Per-Protocol Set (PPS). Repeated measures analysis of variance was performed to confirm the interactions between groups and time points. When a significant difference was confirmed, Dunnett's multiple test was used to compare the group with the PLA group on the actual measured values and the change from the period before treatment. All tests were two-tailed with a significance level of 5%. Statistical analysis was performed by using IBM SPSS Statistics 28. The study subjects' characteristics are presented as means ± standard deviations, and other data are presented as means ± standard errors. No additional analyses were performed.

3. Results

3.1. Analysis Subjects

The number of subjects included in this study was 75. A total of 75 participants were recruited with no dropouts after randomization, and 25 subjects in each group were assigned to receive the intervention. During the study period, two subjects in the BEAA group dropped out of the study because they met the discontinuation criteria (*i.e.*, the subject exhibited behaviors that significantly compromised their credibility as a research participant), bringing the total number of subjects who completed the study to 73. In addition, 6 subjects were found to fall under the rejection criteria after the completion of the study; thus, 67 subjects were included in the analysis. The reason for rejection was that the subjects were found to have violated the precautions during the study period (three subjects in the PLA group, two subjects in the WHEY group, and one subject in the BEAA group). The analysis was performed as originally assigned for each group.

The period from recruitment to the end of the follow-up for the study subjects was June 2024 to January 2025, and the study was terminated when all subjects had completed the follow-up. Table 2 shows the background of the study subjects for the analysis in this study, and Figure 1 shows a flowchart of the process from inclusion to analysis.

Table 2. Subject characteristics.

	PLA	WHEY	BEAA
	(n = 22)	(n = 23)	(n = 22)
Age (years)	32.2 ± 4.5	32.8 ± 5.6	31.3 ± 5.0
Height (cm)	171.3 ± 4.5	170.8 ± 4.4	172.6 ± 5.2
Weight (kg)	67.0 ± 7.7	67.0 ± 7.2	68.4 ± 7.8

Continued

BMI (kg/m^2)	22.8 ± 2.4	23.0 ± 2.5	23.0 ± 2.8
Habitual dietary protein (g/day)	62.1 ± 18.3	68.7 ± 34.5	66.2 ± 14.0

Values are expressed as means ± SDs. No significant difference was observed.

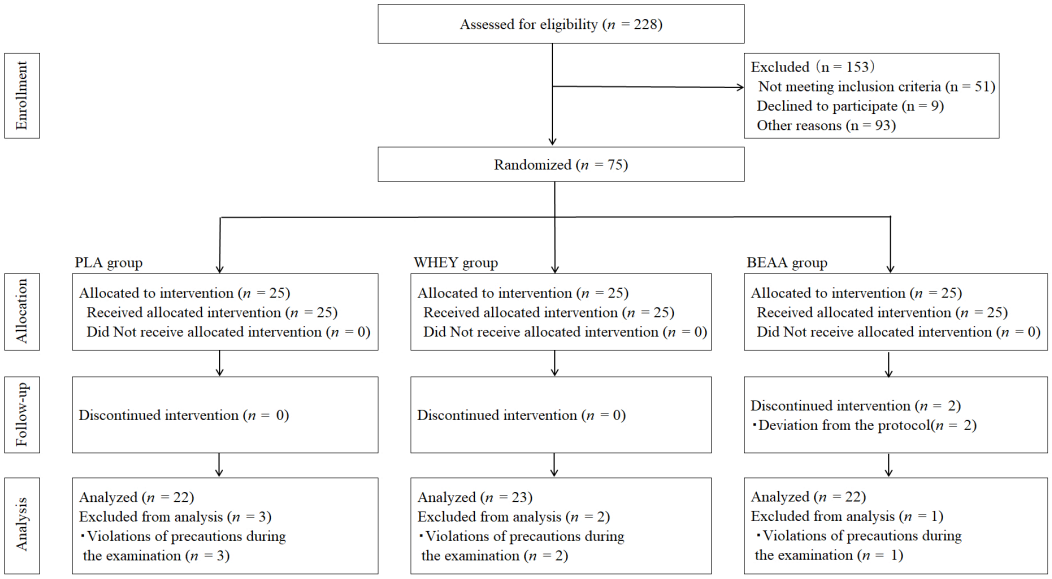

Figure 1. Flow diagram of progress through phases of single-blind, randomized, placebo-controlled, parallel-group study.

3.2. Analysis Results

The results of whole-body muscle mass and lower-limb muscle mass are shown in Table 3. An interaction between group and time point was observed for whole-body muscle mass and lower-limb muscle mass. The BEAA group showed a significant difference ($P < 0.05$) in whole-body and lower-limb muscle mass after 12 weeks of intake compared with the PLA group, while the WHEY group showed no increase in muscle mass compared with the PLA group.

The results for knee joint extensor muscle strength are shown in Table 4. There was no interaction effect on knee extensor strength.

There were no significant differences in protein intake among groups at 6 and 12 weeks of intake [55.3 ± 16.5 g/day in the PLA group, 55.0 ± 16.0 g/day in the WHEY group, and 56.0 ± 15.6 g/day in the BEAA group at 6 weeks of intake; PLA group 51.6 ± 14.9 g/day, WHEY group 54.3 ± 14.9 g/day, BEAA group 54.7 ± 12.8 g/day at 12 weeks of intake].

3.3. Adverse Events

During the period of the study, no serious adverse events occurred. All confirmed events were ruled out as causally related to the study foods by the investigators.

4. Discussion

The purpose of this study was to examine the effects of BEAA® intake in combination

Table 3. Test results for whole-body muscle mass and lower-limb muscle mass.

Group			Baseline			12 Weeks				P-value (Interactions between Groups and Time Points)
Whole-body muscle mass (kg)	PLA (n = 22)	Measured	45.9	±	0.7	48.7	±	0.8		P = 0.028
		Changes from baseline				2.8	±	0.3		
	WHEY (n = 23)	Measured	46.3	±	0.9	49.2	±	1.0		
		Changes from baseline				2.9	±	0.4		
	BEAA (n = 22)	Measured	46.3	±	1.0	50.3	±	1.0		
		Changes from baseline				4.1	±	0.4	*	
Lower-limb muscle mass (kg)	PLA (n = 22)	Measured	14.9	±	0.3	16.1	±	0.3		P = 0.008
		Changes from baseline				1.2	±	0.1		
	WHEY (n = 23)	Measured	14.8	±	0.3	16.1	±	0.4		
		Changes from baseline				1.4	±	0.1		
	BEAA (n = 22)	Measured	14.8	±	0.3	16.7	±	0.3		
		Changes from baseline				1.9	±	0.2	*	

Values are expressed as means ± SEs. *Significantly different from the placebo group ($P < 0.05$).

Table 4. Test results for knee joint extensor muscle strength.

Group			Baseline			6 Weeks			12 Weeks			P-value (Interactions between Groups and Time Points)
Knee joint extensor muscle strength (kg)	PLA (n = 22)	Measured	41.49	±	2.99	49.10	±	2.71	52.73	±	2.65	P = 0.462
		Changes from baseline				7.61	±	1.46	11.24	±	1.35	
	WHEY (n = 23)	Measured	45.79	±	2.35	51.18	±	2.22	56.69	±	1.93	
		Changes from baseline				5.40	±	2.10	10.90	±	2.35	
	BEAA (n = 22)	Measured	46.96	±	3.25	53.08	±	3.19	61.57	±	2.62	
		Changes from baseline				6.12	±	2.67	14.61	±	2.55	

Values are expressed as means ± SDs. No significant difference was observed.

with exercise on muscle mass and strength in humans. The results of the study were as follows: BEAA® increased muscle mass in the BEAA group significantly more than in the PLA group in terms of whole-body muscle mass and lower-limb muscle mass from before the intervention to 12 weeks after intake, indicating that BEAA® increases muscle mass. On the other hand, there was no significant difference in muscle strength in the BEAA group compared with the PLA group.

Leucine is one of the BCAAs and is believed to initiate the synthesis of muscle protein and contribute to the increase in muscle mass by activating the mTOR signaling pathway most effectively [10]-[14]. On the other hand, BCAAs other than leucine are also known to play important roles in muscle synthesis. Valine and isoleucine have also been reported to stimulate the mTOR signaling pathway, although not as much as leucine [15]. Isoleucine also promotes glucose uptake in muscle and improves muscle energy efficiency [16]-[18].

In addition, EAAs other than BCAAs are known to have effects on muscle protein synthesis. In fact, the effects of leucine alone and BCAAs are limited to transient muscle protein synthesis through the activation of the mTOR signaling pathway, and it is believed that administration of all EAAs is required to obtain a long-term increase in muscle protein synthesis and improvement in muscle mass and strength in humans [19]. Thus, BCAAs, including leucine, play a central role in muscle protein synthesis; furthermore, other EAAs are thought to complement the function of BCAAs, thereby enabling efficient muscle protein synthesis as a whole.

In skeletal muscle, amino acid intake and resistance exercise are known to enhance muscle protein synthesis via the mTOR signaling pathway. In the absence of resistance exercise, the ingestion of amino acids as protein only sustains the enhancement of muscle protein synthesis for about 1.5 hours [20] [21]. On the other hand, resistance exercise activates the mTOR signaling pathway via mechanical stress, and the stimulation of muscle protein synthesis has been reported to last as long as 24 - 48 hours after exercise [22] [23]. Therefore, in order to increase muscle mass more efficiently, it is considered important to provide a stronger and sustained input of stimulation to the mTOR signaling pathway with the combination of amino acid intake and resistance exercise [20]-[24].

The form of amino acid intake is known to influence the efficiency of muscle protein synthesis, with free amino acid intake promoting muscle protein synthesis more than protein intake [25]-[27]. According to previous reports, rapidly digested proteins are thought to promote muscle protein synthesis, while slowly digested proteins are thought to regulate skeletal muscle mass by inhibiting muscle protein degradation [28]. Since free amino acids are absorbed directly in the small intestine without digestion, they are thought to increase plasma amino acid concentrations more rapidly and efficiently than proteins. In fact, it has been reported that plasma amino acid concentrations increase rapidly and show higher peaks in healthy subjects when free amino acids are ingested [29]. The rapidly increased

amount of plasma amino acids, particularly BCAAs, is taken up directly by skeletal muscle and is thought to provide a stronger input of stimuli to the mTOR signaling pathway and promote muscle protein synthesis [28]-[30]. This suggests that free amino acid intake may effectively promote muscle protein synthesis.

Since BEAA® is a free amino acid mixture, its digestion and absorption may be more rapid and efficient than those of whey protein. Therefore, plasma amino acid concentrations increase rapidly and to higher concentrations, which may provide a stronger boost to muscle protein synthesis via the mTOR signaling pathway in skeletal muscle. Therefore, it is also possible that muscle protein synthesis was more enhanced in the BEAA group than in the WHEY group, contributing to an overall increase in muscle mass. In conclusion, BEAA® may be useful for increasing muscle mass in healthy individuals due to its high BCAA content and superior absorption kinetics.

In addition, there was no increase in muscle mass or strength in the WHEY group compared with the PLA group in this study. This may be due to insufficient insulin levels in the WHEY group. In a previous report, insulin was the reason for the lack of muscle protein synthesis even after 42 g of protein was consumed [31]. Plasma insulin is thought to promote muscle protein synthesis by stimulating the uptake of specific amino acids and the mTORC1 receptor of the mTOR signaling pathway [32] [33]. Indeed, it has been reported that elevated plasma insulin concentrations increased net muscle protein balance when plasma amino acid concentrations were high [34] [35]. In addition, increases in plasma insulin concentrations are known to be induced by EAAs themselves [36], of which leucine is considered one of the most potent stimulants [37].

Ingestion in free amino acid form is likely to contribute to an increase in muscle mass, as these amino acids are easily utilized directly by muscles, thus increasing blood insulin concentrations sufficiently. On the other hand, why protein is less absorbable, and the plasma amino acid concentration increases slowly. Here, this may have prevented enough increase in insulin release; thus, an increase in muscle mass was not observed. Therefore, it is possible that the ingestion of whey protein together with sugar could have induced a strong insulin secretory response, allowing the ingested amino acids to be used efficiently for muscle protein synthesis and confirming an increase in muscle mass [38]-[40]. In fact, it has been reported that the ingestion of a mixture of sugar and protein after resistance exercise further increased plasma insulin concentration and had a stronger muscle protein synthesis effect than the ingestion of amino acids alone [41] [42].

In this study, no significant differences were observed in knee joint extensor muscle strength. Muscle strength is exerted by muscle contraction, whose patterns are classified as isometric, shortening, or stretching, depending on the magnitude of the force and the length of the muscle [43]. Muscle training specifically improves muscle strength corresponding to the activity condition and muscle contraction style, and it is known that the increase in muscle strength in other muscle contraction styles is low compared with the increase in exerted muscle strength

[44]. The exerted muscle strength in the resistance exercise performed in this study was shortening or stretching muscle strength. On the other hand, the measured item, knee joint extensor muscle strength, allowed for the evaluation of muscle strength in muscle contraction during static exercise without joint movement (isometric muscle strength). Therefore, it is possible that the effect of the increase in muscle strength associated with the increase in muscle mass due to the combination of BEAA® ingestion and the resistance exercise performed in this study was not expressed in isometric muscle strength, while it was expressed in shortening or extensor muscle strength. The muscle strength exerted does not depend solely on the muscle cross-sectional area, but it is also greatly influenced by the level of motor nerve excitation, such as motor unit mobilization and impulse firing frequency [45]. In this study, exercise training was performed with dynamic muscle contractions, and muscle strength measurements were performed with static muscle contractions, which are clearly different modes of motor nerve mobilization; it is possible that we did not reach the point of finding significant differences in exerted muscle strength. In future research, it is necessary to examine the effects of BEAA® ingestion on muscle strength by using different resistance exercise protocols and methods of measuring muscle strength.

In this study, the safety of BEAA® was also confirmed. The results showed that no adverse events attributable to the ingestion of BEAA®-containing foods were observed, suggesting that there are no safety issues with the long-term ingestion of BEAA®-containing foods.

However, several limitations exist in this study. First, it was conducted on healthy adult males between the ages of 20 and 40, so the effects in other age groups and genders are unknown. In addition, although resistance exercise was performed as the exercise load in this study, it is possible that the contribution of BEAA® to muscle protein synthesis may differ under training conditions with a higher exercise load or no exercise load. Future research is needed to examine the effects of BEAA® on muscle mass gain by conducting studies with a wider range of study subjects and under different exercise load conditions. Furthermore, no increase in muscle mass was observed with the intake of 20 g of whey protein compared with the intake of placebo. Previous studies have shown that although there is no significant difference between the intake of 40 g of whey protein and 20 g of whey protein, there is a trend towards increased muscle protein synthesis with a higher dosage [4]. Therefore, comparison of higher dosages remains a subject for future research.

5. Conclusion

BCAA-enriched essential amino acid (BEAA®) was shown to increase muscle mass in healthy adult males when combined with exercise.

Author Contributions

Conceptualization, T.K. and K.T.; methodology, Y.H.; validation, S.M.; formal

analysis, K.A. and S.M; investigation, Y.U.; writing-original draft preparation, Y.H and K.A., and writing-review and editing, T.M.; visualization, K.A. and Y.U.; supervision, K.T. and N.S.; project administration, T.O. and T.K. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethical Committee of Kobuna Orthopedics Clinic (approval date: 12 March 2022; approval number: MK-2205-01).

Informed Consent Statement

Informed consent was obtained from all participants involved in the study.

Data Availability Statement

The data used in this manuscript are not publicly available because of commercial restriction, but are available on reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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