Original Article

Effect of ingestion of essential amino acids and tea catechins after resistance exercise on the muscle mass, physical performance, and quality of life of healthy older people: A randomized controlled trial

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Background and Objectives: We evaluated the effectiveness of a 24-week nutritional ingestion program involving essential amino acid (AA) and tea catechin (TC) intake after performing resistance exercise in increasing the skeletal muscle mass, physical performance, and quality of life of healthy older people. **Methods and Study Design:** An open-label randomized controlled trial involving 84-healthy older individuals (age ≥65 years) without sarcopenia, diabetes, and kidney disease, was conducted. They were allocated to the exercise (n=28), exercise and essential AA ingestion (n=28), and exercise, essential AA, and TC ingestion groups (n=28). The participants underwent a 24-week program of resistance exercise (performed twice per week) along with essential AA and TC intake (3,000 and 540 mg, respectively). **Results:** Six participants could not complete the intervention after randomization. After the 24-week intervention period, the exercise, essential AA, and TC ingestion groups showed an increase in the skeletal muscle mass index, one-legged balance test, and physical quality of life score (skeletal muscle mass index, p=0.004; one-legged balance test, p=0.045; physical quality of life, p=0.020). After the 24-week intervention period, the exercise and essential AA ingestion group showed an increase in the skeletal muscle mass index and physical quality of life score (skeletal muscle mass index, p=0.014; physical quality of life, p=0.041). However, the exercise group did not show an increase in the skeletal muscle mass index. **Conclusions:** These results suggested that resistance exercise, essential AA, and TC intake in healthy older people could improve physical performance.

Key Words: essential amino acid, tea catechins, resistance exercise, physical performance, healthy older people

INTRODUCTION

Sarcopenia, characterized by a progressive decline in the skeletal muscle mass, strength, and performance associated with aging and physical inactivity ultimately increases the risk of developing adverse outcomes, such as physical disabilities.[1] A previous interventional study showed that the evidence in support of exercise or nutritional interventions for the treatment or prevention of individuals with or without sarcopenia, as defined by the Asian Working Group for Sarcopenia (AWGS) criteria, was limited.[2]

Skeletal muscle metabolizes proteins in response to exercise.[3] In particular, resistance exercise increases muscle protein synthesis for up to 24 h after exercise.[4] Muscle protein synthesis peaks immediately after exercise and reduces over time. Therefore, the intake of essential amino acids (AA) immediately after resistance exercise is important for muscle protein accumulation. In particular, leucine intake has been reported to stimulate muscle protein synthesis by activating the mammalian target of the rapamycin signaling pathway (mTORC).[5] Since muscle protein synthesis peaks after exercise, followed by a gradual time-dependent decrease, receiving leucine-enriched essential AA after exercise in a supplement form that is rapidly digested and absorbed, can be important in optimizing muscle protein accumulation.[6]

Resistance exercise also altered the post-exercise response of anabolic and catabolic responses to the muscle protein status. Recently, among the different forms of nutraceuticals, tea catechins (TC) have gained significant attention because of their health benefits.[7] A previous study reported on the effects of green TC on skeletal muscle health through the maintenance of a dynamic balance between protein synthesis and degradation and boosting of the synthesis of mitochondrial energy metabolism. The results revealed favorable muscle homeostasis and the mitigation of muscle atrophy with aging

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both *in vitro* and *in vivo* (in animals).[8] However, previous studies have not identified the additional benefit of TC ingestion after resistance exercise in enhancing the skeletal muscle mass, strength, physical performance, and quality of life (QOL) in older individuals. Here, we aimed to evaluate the effectiveness of a 24-week nutritional intervention program involving essential AA and TC intake after resistance exercise in increasing the skeletal muscle mass, muscle strength, physical performance, and QOL of healthy older people, using a randomized controlled design.

METHODS

Participants

This open-label study was approved by the Ethics Committee of Tokushima University (approval #3777, registry trial number: UMIN000040024). As per the Helsinki Declaration, we explained the study's content and possible risks to the participants, both verbally and in writing. Written informed consent was obtained from all the participants enrolled in this study. We recruited older individuals (n=99) aged ≥65 years from the Harima community in Hyogo, Japan. In the present study, to detect an increase in leg muscle strength of 3.3 kg (standard deviation, 1.5 kg) using nutritional supplementation combined with exercise in older individuals, compared with exercise alone, the sample size was based on the assumption of a similar response to supplementation in the present study, identified using repeated measures of ANOVA at a power of 80% with the alpha set at 0.05 (two-tailed).[9] Thus, 19 individuals were included in each group. To be conservative and to allow a potential dropout rate of 30%, we aimed to enrol 28 individuals per group.

This study excluded patients with sarcopenia (according to the criteria of the AWGS2019 [n=10]),[2] and those with type 2 diabetes and chronic kidney disease on diet therapy (n=5). After the assessments, the 84 participants were randomly divided into three groups: the resistance exercise intervention group (Ex group: n=28), the essential AA intake after resistance exercise group (Ex+AA group: n=28), and the essential AA and TC after resistance exercise group (Ex+AA+TC group: n=28). This three-arm age-and sex-based stratified randomized controlled study was performed over a 24-week period.

None of the participants had previously participated within 1 year of the commencement of this study, in a structured resistance-exercise program with the intake of food enriched with AA or TC.

Intervention design

The Ex+AA+TC group intervention consisted of the ingestion of an AA and TC test meal after completing the resistance exercise program. The Ex + AA+TC group intervention effects were evaluated against the Ex group (control group), in which the participants completed the same exercise program, but without receiving AA and TC, and the Ex+AA group, in which the participants ingested the same AA, but without TC intake. The intervention period was 24 weeks, with participants completing their assigned protocol twice a week.

Exercises

The exercise session included a 20-min warm-up exercise and a 40-min resistance exercise.[10] The resistance exercise intervention program included bodyweight resistance and resistance elastic band exercises. Bodyweight-resistance lower-body exercises included rising and sitting from a chair and leg extensions. Resistance elastic band exercises (THERABAND, The Hygenic Corporation, Akron, OH, USA) included upper and lower body exercises. The resistance load (50–70% of the one-repetition maximum) was modified in a standardized fashion over the 24-week program. The detailed resistance exercise regimen is presented in Appendix S1. Pole walking (Pole stick, Furutani Corporation, Tokyo, Japan) was performed for warm-up exercises.

AA and TC

The AA test meal was provided to participants in the EX +AA and Ex+AA+TC groups. The AA test meal contained 17.6 kcal of energy and 3,000 mg of essential AA acids (1,200 mg of leucine, 500 mg of lysine, 330 mg of valine, 320 mg of isoleucine, 280 mg of threonine, 200 mg of phenylalanine, 100 mg of methionine, 50 mg of histidine, 20 mg of tryptophan), per 4 g of powder of one intake serving.

The TC test meal was provided to participants in the Ex+AA+TC group. The TC test meal contained 19 kcal of energy and 540 mg of catechins, per 6 g of powder of one intake serving.

On the 1st day of the study, the test meal was ingested within 30 min after the end of the resistance exercise.

Nutritional management

The total protein intake for participants in all three experimental groups was adjusted to a level of at least 1.2 g/kg/day, and increased during the intervention period.[11] Nutritional management was provided by a nutritionist and was based on the Japanese Dietary Reference Intakes and individual results of the nutrition survey, which was performed before the intervention.[12] The detailed nutritional management regimen is presented in detail in Appendix S2.

Assessment of body composition, muscle strength, and physical performance

Body weight, body mass index, and skeletal muscle mass were measured using a body composition analyzer (In Body bioelectrical impedance analyzer, In Body Japan, Tokyo, Japan) and a multi-frequency bioelectrical impedance analysis (BIA). The skeletal muscle mass index (SMI) was calculated by dividing the upper- and lower-limb skeletal muscle mass by the height squared. The muscle strength measurements included the grip strength and the knee extension strength. Physical performance measurements included gait speed and the one-legged stand balance test. Grip strength and knee extension strength were measured using handheld dynamometers (T. K. K 5401, Takei Scientific Instruments, Niigata, Japan; μ-tus F-100, Anima, Tokyo, Japan). Sarcopenia was defined using the AWGS 2019 criteria, as follows: low hand grip strength or slow gait speed, and low SMI.[2] Body composition, muscle strength, and physical performance data were collected pre- and post-intervention.

Assessment of health-related QOL

The health-related QOL of the surveyed participants was estimated using the Medical Outcomes Study 36-Item Short-Form Health Survey (SF-36).[13] The SF-36 is one of the most widely used health-related QOL measures and is a standardized questionnaire consisting of 36 questions/items measuring the physical component summary score (physical QOL) and the mental component summary score (mental QOL) in relation to health concepts. Higher scores correspond to better self-perceived health. Physical and mental QOL data were collected pre- and post-intervention.

Nutritional survey

A nutritional survey was administered to document the total daily energy intake and total intake of protein adjusted by the ideal body weight (IBW) (g/kg IBW/day). The IBW was calculated by multiplying an ideal BMI of 22.0 kg/m^2 with a person's actual height (m) squared. The nutrient intake was calculated using the Fifth Revised Edition of the Standard Tables of Food Composition in Japan and the 2015 Japanese Dietary Reference Intakes by using nutrition calculation software (Excel Eiyou version 8.0, Kenpakusha, Tokyo, Japan).[12]

The nutritional survey was conducted using a weighing method documenting the 5 consecutive days pre-and post-intervention of the study. In addition, when there were missing responses, individual interviews were conducted with participants regarding their food intake status. The total energy and protein intake data were collected pre- and post-intervention. The nutritional status was determined using the Mini-Nutritional Assessment-Short Form (MNA-SF) and calf circumference. An MNA-SF score <12 was suggestive of a risk or possibility for malnutrition.[2,14] In the supine position, the knee joint was flexed at 90° with the feet and ankles relaxed; the flexible tape was wrapped perpendicularly around the leg axis, and the maximum calf circumference was recorded at 0.1 cm increments. The MNA-SF scores and calf circumference measurements were collected pre-intervention.

Physical activity survey

The participants wore triaxial accelerometer wearable devices (EZ-063 CALORIZM; Tanita, Tokyo, Japan) during the 7-day pre-intervention period, except when sleeping or taking a bath, and the daily total step count was determined for each participant. The total step count was collected pre-intervention.

Statistical analyses

Between-group differences in the distributions of physical characteristics were evaluated before the intervention, using an independent group non-paired one-way ANOVA or the χ^2-test. Between-group differences in outcome measures (skeletal muscle mass, muscle strength, physical performance, nutritional intake, and health-related QOL) pre-and post-interventions, were evaluated using a paired t-test. Changes in the measured outcome measures (skeletal muscle mass, muscle strength, physical performance, nutritional intake, and health-related QOL) were evaluated between the groups (Ex, Ex+AA and Ex+AA+TC) and time (pre- and post-intervention) using a repeated measure two-way ANOVA, using group and time as the independent and repeated factors, respectively. To identify the main effects and interactions, multiple comparisons were performed using the Tukey post-hoc analysis. The rate of change (Δ) in measured outcomes, pre- to post-intervention, were compared using an unpaired one-way ANOVA. All statistical analyses were performed using IBM SPSS statistical 22 software (IBM Corp., Armonk, NY, USA), with the level of significance defined as a p-value <0.05.

RESULTS

Six participants were unable to complete the intervention after randomization because of the withdrawal of their consent (Ex group: n=2; Ex+AA group: n=3; Ex+AA+TC: n=1; Figure 1). The final analysis of the Ex, Ex+AA, and Ex+AA+TC groups consisted of 26, 25, and 27 participants, respectively. The physical characteristics of the participants pre-intervention are listed in Table 1, with no between-group differences identified.

The comparison of outcome measures pre- and post-intervention is presented in Table 2 and Supplementary Appendix S3. After the 24-week intervention period, the Ex+AA+TC (n=27) showed an increase in the SMI, grip strength, knee extension strength, gait speed, one-legged stand balance test, and physical QOL score (SMI, p=0.004; grip strength, p=0.038; knee extension strength, p=0.013; gait speed, p=0.008; one-legged stand balance test; p=0.045, physical QOL; p=0.020). After the 24-week intervention period, the Ex+AA group (n=25) showed an increase in the SMI, grip strength, knee extension strength, gait speed, and physical QOL score (SMI, p=0.014; grip strength, p=0.019; knee extension strength, p=0.020; gait speed, p=0.002; physical QOL, p=0.041). After the 24-week intervention period, the Ex group (n=26) showed an increase in the grip strength, knee extension strength, gait speed, and physical QOL score (grip strength, p=0.007; knee extension strength, p=0.017; gait speed, p=0.012; physical QOL, p=0.016). A significant group by time interaction was not identified for muscle mass, muscle strength, physical performance, nutritional intake, and health-related QOL. The pre- to post-intervention changes in the skeletal muscle mass, muscle strength, and physical performance are presented in Figure 2. There were no between-group differences in the percent change from pre- to the post-intervention period at 24 weeks in the SMI, grip strength, knee extension strength, gait speed, and one-legged stand balance test.

DISCUSSION

In the present study, post-exercise intervention with essential AA (Ex+AA, Ex+AA+TC) significantly increased the skeletal muscle mass. In addition, tea catechin intake resulted in significantly improved performance of one-legged balance tests, such as balance ability. Muscle strength and gait speed were considered as the standard intervention. Exercise therapy is recommended based on the consensus on maintenance and increase of muscular strength and gait speed in older people. However, our

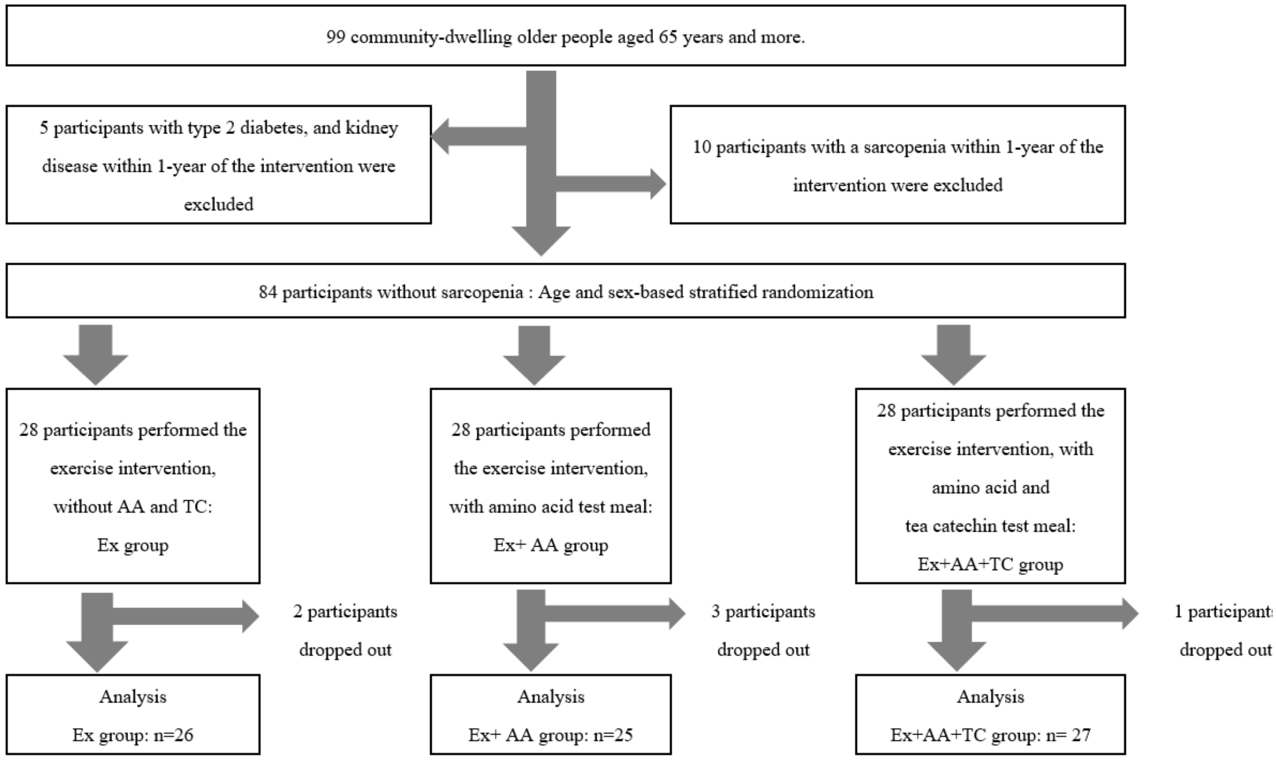

Figure 1. Flow chart of study participants. The participants without sarcopenia were randomly allocated to the exercise (Ex group; n=28), exercise and essential amino acid ingestion (Ex+AA group; n=28), and exercise, essential amino acid, and tea catechin ingestion groups (Ex+AA+TC group; n=28).

results revealed that the Ex-group did not show an increase in the skeletal muscle mass and one-legged balance test, suggesting that resistance exercise with the ingestion of essential AA and TC in healthy older people may lead to improved muscle mass and balance ability. In addition, no participant in this study was found to be undernourished, and the intervention study was conducted with the participants in a good nutritional condition. Therefore, the rate of change in each outcome obtained in this study reflected the supplementation effects of the essential AA and TC. A previous study showed that the nutritional supplementation effects were modulated by the individual's nutritional status, with poor nutritional status (e.g., sarcopenia and malnutrition),[10] lowering the benefits of nutrition on muscle mass and strength. Therefore, it is important to note that the benefits of combining a resistance exercise program with the ingestion of AA and TC are specific to healthy older people without any history of malnutrition and/or sarcopenia, and with a good nutritional status.

These results suggested that essential AA and TC intake after resistance exercise in healthy older people improves physical performance, such as balance ability. To our knowledge, there are no previous randomized controlled trials where exercise was combined with essential AA and TC; this study is the first such report on muscle mass and physical performance in healthy older people. Previous interventional studies have shown that the evidence in support of exercise or nutritional interventions for the prevention of sarcopenia is limited. The findings of this study would increase the evidence concerning the prevention of sarcopenia because the participants were healthy older people without sarcopenia, as defined by the AWGS 2019 criteria.[2]

In this study, the Ex+AA+TC group showed improvements in the one-legged balance test post-intervention. This was supported by the results of a randomized controlled trial, in which exercise combined with TC intake showed improved physical performance compared to exercise alone. Conversely, a previous study reported that the prognosis for recurrent falls and daily living performance in older people was worse when balance ability and physical performance declined compared to muscle mass decline.[15]

Additional TC intake after exercise was very important for preventing falls, as low balance ability is associated with incidental falls in older people. In the present study, physical performance, such as balance ability, was improved in the combined intervention group with the addition of TC intake, and the results of the intervention obtained in this study would greatly contribute to the improvement of daily life performance of older people. However, there were no between-group differences in the percent change from pre- to post-intervention periods in the skeletal muscle mass, muscle strength, physical performance, and health-related QOL. In this study, the intervention effect of additional TC intake could not be clearly shown in the outcome measures.

In the present study, muscle strength, such as grip strength, knee extension strength, and gait speed, increased significantly in all experimental groups. The Ex+AA and Ex+AA+TC groups showed significant increases in the SMI, while the Ex group did not show an increase in the SMI. Previous studies have reported that

Table 1. Physical characteristics of the participants, pre-intervention

	Ex group (n=26)	Ex+AA group (n=25)	Ex+AA+TC group (n=27)	*p* value			F value
				Ex vs AA	Ex vs Ex+AA+TC	Ex+AA vs Ex+AA+TC	
Age (years)	70.9±4.1	70.6±4.7	70.0±3.7	0.969	0.653	0.800	0.312
Male/Female (n)	4/23	3/22	3/23	0.766	0.725	0.959	-
BMI (kg/m^2)	22.5±3.1	22.4±3.2	22.1±2.6	0.991	0.879	0.935	0.193
Calf circumference (cm)	34.1±2.6	34.3±1.9	33.8±2.7	0.927	0.999	0.914	0.281
MNA-SF (score)	12.5±1.2	12.5±1.2	13.0±1.0	0.981	0.163	0.235	1.87
Total step (count/day)	5829±1610	5970±1669	5809±1779	0.953	0.985	0.991	0.069

BMI; Body mass index; MNA-SF; Mini nutritional assessment short-form.
Mean value±standard deviation. The results of a non-paired one-way ANOVA or $\chi 2$-test showed no differences in the characteristics of the three groups pre-intervention.

Table 2. Comparison of outcome measure, pre- and post-intervention

	Ex group (n=26)				Ex+ AA group (n=25)			
	Pre-intervention	Post-intervention	*p* value	T value	Pre-intervention	Post-intervention	*p* value	T value
SMI (kg/m^2)	6.34±0.77	6.38±0.74	0.139	1.54	6.26±0.55	6.35±0.52	0.014	2.65
Grip strength (kg)	25.0±4.5	25.8±4.4	0.007	2.97	25.0±4.2	25.5±4.3	0.019	2.51
Knee extension strength (kg)	20.8±4.4	21.5±4.3	0.017	2.55	23.7±6.9	24.4±6.7	0.020	2.49
Gait speed (m/sec)	1.30±0.17	1.33±0.15	0.012	2.72	1.30±0.12	1.34±0.13	0.002	3.56
One-legged stand balance test (sec)	62.9±37.8	64.8±37.6	0.087	1.78	86.0±39.2	88.4±35.9	0.198	1.32
Total energy intake (kcal/kg IBW/day)	33.0±7.0	32.8±5.0	0.828	-0.219	33.5±6.8	33.9±5.9	0.744	0.330
Total protein intake (g/kg IBW/day)	1.20±0.29	1.16±0.29	0.554	-0.600	1.20±0.42	1.18±0.33	0.833	-0.214
Physical QOL (score)	45.9±9.1	50.0±5.7	0.016	2.59	44.4±9.6	49.5±5.2	0.041	2.17
Mental QOL (score)	54.7±9.2	51.3±5.3	0.104	-1.69	52.0±7.7	49.3±5.7	0.193	-1.34

	Ex+AA+TC group (n=27)			
	Pre-intervention	Post-intervention	*p* value	T value
SMI (kg/m^2)	6.18±0.78	6.29±0.79	0.004	3.14
Grip strength (kg)	25.2±3.6	25.6±3.7	0.038	2.19
Knee extension strength (kg)	21.1±4.4	21.9±4.7	0.013	2.68
Gait speed (m/sec)	1.45±0.16	1.48±0.16	0.008	2.86
One-legged stand balance test (sec)	65.6±34.6	69.6±32.9	0.045	2.11
Total energy intake (kcal/kg IBW/day)	34.1±5.5	33.6±3.9	0.661	-0.444
Total protein intake (g/kg IBW/day)	1.19±0.36	1.24±0.24	0.623	0.497
Physical QOL (score)	45.6±6.9	49.2±4.1	0.020	2.41
Mental QOL (score)	52.6±8.8	49.8±6.0	0.090	-1.75

SMI; skeletal muscle mass index; IBW; ideal body weight; QOL; quality of life.
Mean value±standard deviation. Paired t-test, pre vs post intervention.

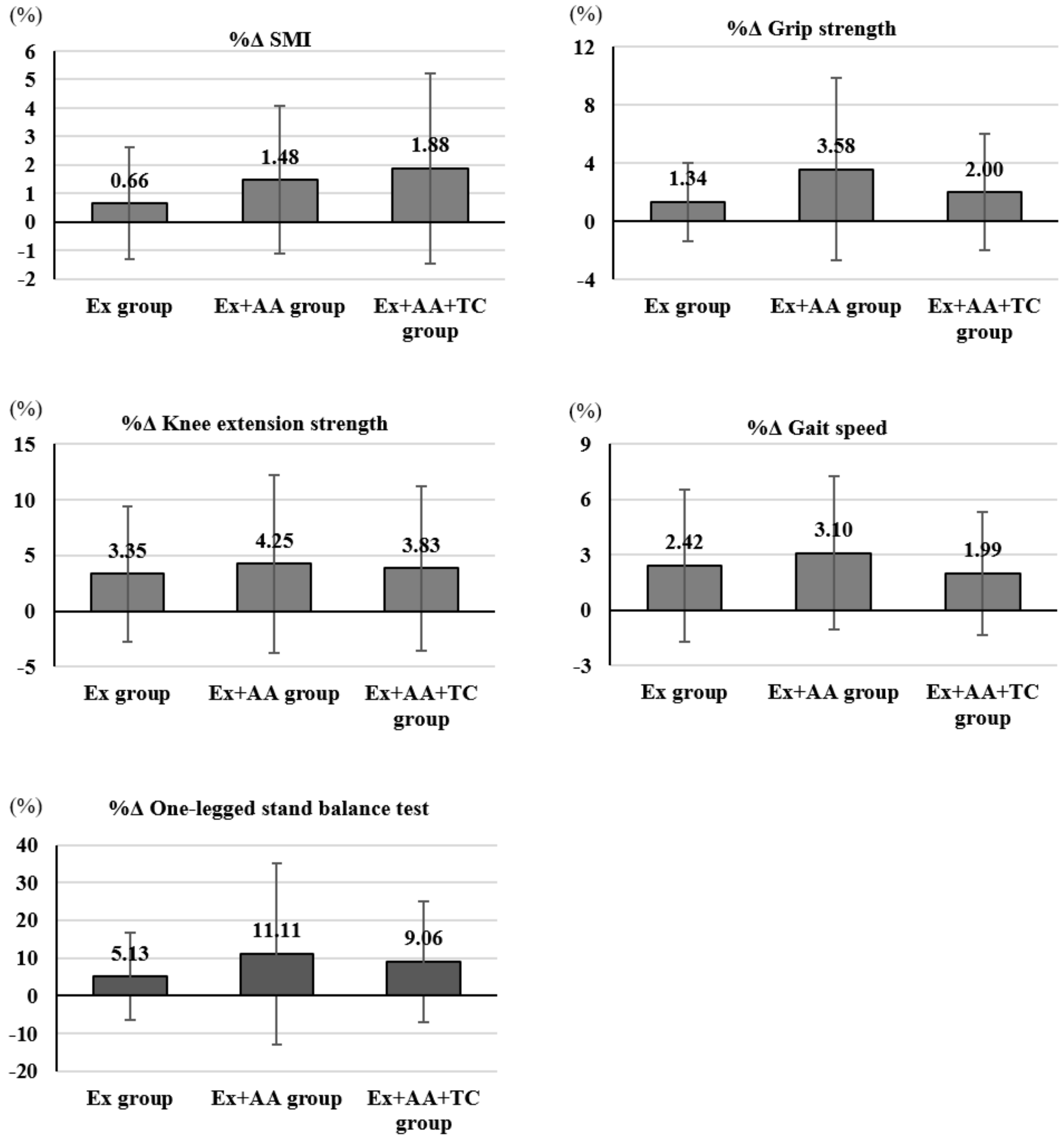

Figure 2. Comparison of skeletal muscle mass, muscle strength, and physical performance, pre- and post-intervention.

resistance exercise and AA together might have been effective in enhancing the muscle strength and the combined variables of the skeletal muscle mass.[16,17]

In this study, we observed an increase in the SMI because of post-exercise intake of essential AA on muscle protein synthesis. As exercise alone did not increase muscle mass compared with pre-intervention, it was suggested that the combined intervention with nutritional therapy, which increased muscle protein synthesis and inhibited muscle protein degradation after exercise, may have contributed to the prevention of sarcopenia.

The PROT-AGE study recommended that the intake of essential AA could be effective for improving the skeletal muscle mass in older people.[11] In particular, leucine intake has been reported to stimulate muscle protein synthesis by activating the mTORC.[5] In addition, a recent study reported an increase in muscle protein synthesis and muscle mass in older people with a 3,000-mg essential AA intake.[16,17] Furthermore, there is evidence of progressive age-associated attenuation of the sensitivity to leucine for high protein synthesis activity in skeletal muscles. A previous study reported that muscle protein synthesis in older people peaked at approximately 1–3 h after resistance exercise and at 1–2 h after ingestion of essential AA.[3-5] Although we identified the benefit of our essential AA ingestion in increasing muscle mass and strength, the physiological mechanisms by which a single dose of ingested essential AA, combined with resistance exercise, influences muscle protein synthesis, should be clarified. Leucine activates the mTORC signaling pathway, which is associated with protein anabolism through the regulation of mRNA translation.[4] To maximize muscle protein synthesis in older people, the intake of 3,000 mg of essential AA is recommended, of which 1,200 mg of leucine should be ingested once.

TC contain approximately 80 mg per serving (120 mL) of green tea drink sold in Japan. In this study, the Ex+AA+TC group received 540 mg of highly concentrated TC. Conversely, the functionality of highly concentrated TC has attracted attention as a component that inhibits muscle protein degradation.[7] The previous study suggested that oxidative stress levels decreased after performing eccentric exercise upon supplementation with green TC.[18] Moreover, another study reported that green TC intake reduced the loss of soleus muscle force during a period of hindlimb suspension in mice.[19] It has been reported that catechin suppresses the expression of ubiquitin ligase of muscle atrophy-related genes.[20] It has also been confirmed that catechin enhances phosphorylation of Akt, which translocates the transcription factor FoxO3a out of the nucleus, inhibits degradation of the skeletal muscle mass, and attenuates the apoptotic pathway associated with the progression of muscle atrophy.[21] In contrast, the intake of essential AA with high leucine content after exercise enhances muscle protein synthesis, while the intake of TC inhibits muscle protein degradation. Thus, the positive enhancement of the dynamic equilibrium of muscle protein accumulation may contribute to the improvement of physical performance in older people. Therefore, although this study was an interventional study in humans, we showed that a combined intake of essential AA and TC after exercise enhances muscle protein synthesis could inhibit muscle protein degradation and increase muscle protein accumulation in the skeletal muscle. Therefore, the introduction of nutritional interventions tailored to the dynamics of muscle protein metabolism after exercise has important implications for the increase in physical performance.

Our study had several limitations that should be noted. First, the mechanisms of TC and balance ability were unclear. Future studies are required to investigate the effects of TC on muscle degradation and oxidative stress markers to provide further understanding and insight into the prevention of sarcopenia. Second, although we estimated muscle mass using BIA measurements, a strong positive correlation between dual-energy X-ray absorptiometry- and BIA-based measurements of muscle mass has been reported previously, confirming the validity of BIA measurements of muscle mass among older individuals.[22] Finally, as our intervention period was relatively short at 24 weeks, future studies are required to clarify the benefits of prolonged exercise and protein supplementation intervention in increasing muscle mass and strength.

In conclusion, our results demonstrated a positive effect of TC ingestion in healthy older people after undergoing resistance exercise. Especially, TC ingestion improved physical performance, as measured by the balance ability. Our study focused on healthy older people without sarcopenia, as defined by the AWGS 2019 criteria, and the findings will increase the knowledge regarding the prevention of sarcopenia.

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AUTHOR DISCLOSURES

The authors declare no conflicts of interest.

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REFERENCES

1. Chen LK, Liu LK, Woo J, Assantachai P, Auyeung TW, Bahyah KS et al. Sarcopenia in Asia: consensus report of the Asian Working Group for Sarcopenia. J Am Med Dir Assoc. 2014;15:95-101. doi: 10.1016/j.jamda.2013.11.025.
2. Chen LK, Woo J, Assantachai P, Auyeung TW, Chou MY, Iijima K et al. Asian Working Group for Sarcopenia: 2019 consensus update on sarcopenia diagnosis and treatment. J Am Med Dir Assoc. 2020;21:752-8. doi: 10.1016/j.jamda.2019.12.012.
3. Shad BJ, Thompson JL, Breen L. Does the muscle protein synthetic response to exercise and amino acid-based nutrition diminish with advancing age? A systematic review. Am J Physiol Endocrinol Metab. 2014;311:803-17. doi: 10.1152/ajpendo.00213.2016.
4. Katsanos CS, Kobayashi H, Sheffield-Moore M, Aarsland A, Wolfe RR. A high proportion of leucine is required for optimal stimulation of the rate of muscle protein synthesis by essential amino acids in the elderly. Am J Physiol Endocrinol Metab. 2006;291:381-7. doi: 10.1152/ajpendo.00488.2005.
5. Paddon-Jones D, Short KR, Campbell WW, Volpi E, Wolfe RR. Role of dietary protein in the sarcopenia of aging. Am J Clin Nutr. 2008;87:1562-6. doi: 10.1093/ajcn/87.5.1562S.
6. Jordan LY, Melanson EL, Melby CL, Hickey MS, Miller BF. Nitrogen balance in older individuals in energy balance depends on timing of protein intake. J Gerontol A Biol Sci Med Sci. 2010;65:1068-76. doi: 10.1093/gerona/glq123.
7. Luk HY, Appell C, Chyu MC, Chen CH, Wang CY, Yang RS et al. Impacts of green tea on joint and skeletal muscle health: prospects of translational nutrition. Antioxidants (Basel). 2020;9:1050. doi: 10.3390/antiox9111050.
8. Wang L, Wang Z, Yang K, Shu G, Wang S, Gao P et al. epigallocatechin gallate reduces slow-twitch muscle fiber formation and mitochondrial biosynthesis in C2C12 cells by repressing AMPK activity and PGC-1α expression. J. Agric. Food Chem. 2016;64:6517-23. doi: 10.1021/acs.jafc.6b02193.
9. Devries MC, Phillips SM. Creatine supplementation during resistance training in older adults-a meta-analysis. Med Sci Sports Exerc. 2014;46:1194-203. doi: 10.1249/MSS.0000000000000220.
10. Mori H, Tokuda Y. Effect of whey protein supplementation after resistance exercise on the muscle mass and physical function of healthy older women: A randomized controlled trial. Geriatr Gerontol Int. 2018;18:1398-404. doi: 10.1111/ggi.13499.
11. Bauer J, Biolo G, Cederholm T, Cesari M, Cruz-Jentoft AJ, Morley JE et al. Evidence-based recommendations for optimal dietary protein intake in older people: a position paper from the PROT-AGE Study Group. J Am Med Dir Assoc. 2013;14:542-59. doi: 10.1016/j.jamda.2013.05.021
12. National Institute of Health and Nutrition. 2010. Dietary reference intakes for Japanese -2010-: the summary report from the scientific committee of “dietary reference intakes for Japanese”. Ministry of Health, Labour and Welfare, Toyama Building Official Web Site. [cited 2012/07/05.] Available from URL: http://www0.nih.go.jp/eiken/english/research/pdf/dris2010_eng.pdf.
13. Rizzoli R, Reginster JY, Arnal JF, Bautmans I, Beaudart C, Bischoff-Ferrari H et al. Quality of life in sarcopenia and

frailty. Calcif Tissue Int. 2013;93:101-20. doi: 10.1007/s00223-013-9758-y.

14. Rubenstein LZ, Harker JO, Salvà A, Guigoz Y, Vellas B. Screening for undernutrition in geriatric practice: developing the Short-Form Mini Nutritional Assessment (MNA-SF). J Geront A Biol Sci Med Sci. 2001;56:366-72. doi: 10.1093/gerona/56.6.m366.
15. Newman AB, Kupelian V, Visser M, Simonsick EM, Goodpaster BH, Kritchevsky SB et al. Strength, but not muscle mass, is associated with mortality in the health, aging and body composition study cohort. J Gerontol A Biol Sci Med Sci. 2006;61:72-7. doi: 10.1093/gerona/61.1.72.
16. Bukhari SS, Phillips BE, Wilkinson DJ, Limb MC, Rankin D, Mitchell WK et al. Intake of low-dose leucine-rich essential amino acids stimulates muscle anabolism equivalently to bolus whey protein in older women at rest and after exercise. Am J Physiol Endocrinol Metab. 2015; 308:E1056-65. doi: 10.1152/ajpendo.00481.2014.
17. Yoshimura Y, Bise T, Shimazu S, Tanoue M, Tomioka Y, Araki M et al. Effects of a leucine-enriched amino acid supplement on muscle mass, muscle strength, and physical function in post-stroke patients with sarcopenia: A randomized controlled trial. Nutrition. 2019;58:1-6. doi: 10.1016/j.nut.2018.05.028
18. Haramizu S, Ota N, Hase T, Murase T. Catechins attenuate eccentric exercise-induced inflammation and loss of force production in muscle in senescence-accelerated mice. J Appl Physiol. 2011;111:1654-63. doi: 10.1152/japplphysiol.01434.2010.
19. Ota N, Soga S, Haramizu S, Yokoi Y, Hase T, Murase T. Tea catechins prevent contractile dysfunction in unloaded murine soleus muscle: a pilot study. Nutrition. 2011;27:955-9. doi: 10.1016/j.nut.2010.10.008.
20. Alway SE, Bennett BT, Wilson JC, Edens NK, Pereira SL. Epigallocatechin-3-gallate improves plantaris muscle recovery after disuse in aged rats. Exp Gerontol. 2014; 50:82-94. doi: 10.1016/j.exger.2013.11.011.
21. Wang H, Lai YJ, Chan YL, Li TL, Wu CJ. Epigallocatechin-3-gallate effectively attenuates skeletal muscle atrophy caused by cancer cachexia. Cancer Lett. 2011;305:40-9. doi: 10.1016/j.canlet.2011.02.023.
22. Ling CH, de Craen AJ, Slagboom PE, Gunn DA, Stokkel MP, Westendorp RG et al. Accuracy of direct segmental multi-frequency bioimpedance analysis in the assessment of total body and segmental body composition in middle-aged adult population. Clin Nutr. 2011;30:610-5. doi: 10.1016/j.clnu.2011.04.001.

A. Body-weight resisted exercises

1. Rising and sitting from a chair (lower body movement)

2. Leg extensions (lower body movement)

B. Resistance elastic band exercises

1. Seated chest press (upper body movement)

2. Seated row (upper body movement)

3. Knee extensions (lower body movement)

4. Squats (lower body movement)

5. Knee-ups (lower body movement)

C. The exercise intervention program
Elastic bands of five different resistance levels were used, with the level of resistance individually adjusted using a 1 maximum repetition (1 RM) test for the upper and lower limbs, prior to the intervention. Exercises were performed under the supervision of an exercise instructor initially and then completed by participants at home
1. For weeks 1 to 6, participants performed 2 sets of 20 repetitions of each of the body-weight resisted exercises and 2 sets of 10 repetitions of the resistance band exercises, at a resistance load of 50% of the 1 RM
2. For weeks 7 to 12, participants performed 3 sets of 10 repetitions of each of the body-weight resisted exercises and 2 sets of 15 repetitions of the resistance band exercises, at a load of 60% of the 1 RM.
3. For weeks 13 to 18, participants performed 2 sets of 15 repetitions of each of the body weight resisted exercises and 2 sets of 12 repetitions each of the resistance band exercises, at a load of 70% of the 1 RM.
4. For weeks 19 to 24, participants performed 3 sets of 15 repetitions of each of the body-weight resisted exercises and 3 sets of 12 repetitions each of the resistance band exercises, at a load of 70% of the 1 RM.

Supplementary figure 1. The detailed resistance exercise regime.

Supplementary table 2A. Recommendation of total energy and macronutrients intake amount in this study

Total energy (kcal/day)	Total protein (kcal/day)	Total fat (kcal/day)	Total carbohydrate (kcal/day)
1450	50	37	225
1550	60	39	240
1650	65	43	250
1700	70	44	255
1750	75	46	260

Supplementary table 2B. Food group (g/day)

Total energy (kcal/day)	1450 (kcal/day)	1550 (kcal/day)	1650 (kcal/day)	1700 (kcal/day)	1750 (kcal/day)
Cereals (g/day)	270	285	300	300	300
Potatoes (g/day)	30	30	30	50	60
Fish and shellfish (g/day)	40	40	50	60	70
Meats (g/day)	40	45	55	60	70
Eggs (g/day)	40	40	40	40	40
Milk and dairy product (g/day)	150	180	180	180	180
Bean and soybean product (g/day)	50	60	70	70	80
Vegetables (g/day)	300	300	300	300	320
Fruits (g/day)	50	60	60	70	80
Fat and oil (g/day)	10	10	13	13	13
Sugar and confectioneries (g/day)	10	10	15	15	15

Supplementary table 2C. Nutritional management

C. Nutritional management
Daily activity surveys were also reviewed to ensure sufficient total energy intake for all participants. The nutritionist instructed participants on the protein and energy contained within each serving of food and drink, and the researcher confirmed the intake of the protein supplementation at each meal during the intervention period at participants' home. This facilitated guidance regarding desirable food selection and promoted autonomous dietary management. The participants used a food model to choose the appropriate amount of energy, nutrients, food products, and schedule for themselves, choose food compositions based on their objectives for their individual estimated energy requirement, and choose balanced meals divided into staple foods, main meals, and side dishes.
Participants in the all three experimental groups performed the warm-up and resistance exercise program 3 h after lunch

Supplementary table 3. Comparison of outcome measure pre- and post-intervention

	Ex group (n=26)		Ex+ AA group (n=25)		Ex+AA+TC group (n=27)		*p* value
	Pre-intervention	Post-intervention	Pre-intervention	Post-intervention	Pre-intervention	Post-intervention	group ×time interaction
SMI (kg/m^2)	6.34±0.77	6.38±0.74	6.26±0.55	6.35±0.52	6.18±0.78	6.29±0.79	0.355
Grip strength (kg)	25.0±4.5	25.8±4.4	25.0±4.2	25.5±4.3	25.2±3.6	25.6±3.7	0.431
Knee extension strength (kg)	20.8±4.4	21.5±4.3	23.7±6.9	24.4±6.7	21.1±4.4	21.9±4.7	0.912
Gait speed (m/sec)	1.30±0.17	1.33±0.15	1.30±0.12	1.34±0.13	1.45±0.16	1.48±0.16	0.737
One-legged stand balance test (sec)	62.9±37.8	64.8±37.6	86.0±39.2	88.4±35.9	65.6±34.6	69.6±32.9	0.636
Total energy intake (kcal/kg IBW/day)	33.0±7.0	32.8±5.0	33.5±6.8	33.9±5.9	34.1±5.5	33.6±3.9	0.877
Total protein intake (g/kg IBW/day)	1.20±0.29	1.16±0.29	1.20±0.42	1.18±0.33	1.19±0.36	1.24±0.24	0.807
Physical QOL (score)	45.9±9.1	50.0±5.7	44.4±9.6	49.5±5.2	45.6±6.9	49.2±4.1	0.757
Mental QOL (score)	54.7±9.2	51.3±5.3	52.0±7.7	49.3±5.7	52.6±8.8	49.8±6.0	0.895

SMI: skeletal muscle mass index; IBW: ideal body weight; QOL: quality of life.
Mean value±standard deviation.
Two-way ANOVA, group (the exercise only [Ex] group, the exercise and amino acid [Ex+AA] group, and the exercise and amino acid and tea catechin [Ex+AA+TC] group) × time (pre- and post- or during the intervention period) interaction.