Chronic Effect of Light Resistance Exercise after Ingestion of a High-Protein Snack on Increase of Skeletal Muscle Mass and Strength in Young Adults

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Summary We have previously reported on the possibility that light resistance exercise performed with a high plasma amino acid concentration resulting from the ingestion of a high-protein snack (HPS; 15 g protein, 18 g sugar) 3 h after a basal meal promotes the utilization of amino acids in peripheral tissues such as muscle in both rats and humans. In the present study, we further examined the effectiveness of a daily routine involving ingestion of HPS 3 h after a basal meal and subsequent light resistance exercise (dumbbell exercise) in increasing the mass and strength of human muscle. Ten young adult males were subject to the following 3 conditions for 5 wk each, with sufficient recovery period between each condition: (1) Snack-Exercise (SE), (2) Snack-Sedentary (SS), and (3) No snack-Exercise (NE). The SE group showed a significant increase in lean body mass and total cross-sectional area (CSA) of the right forearm muscles along with a significant decrease in body fat mass. The SS group showed no change in body composition. Furthermore, the SE group showed significant increase in grip strength and isometric knee extensor muscle strength, while the SS group showed no increase in muscle strength. The NE group showed significant increase in grip strength. In conclusion, daily routine ingestion of HPS 3 h after a basal meal and subsequent light resistance exercise is effective in increasing the mass and strength of human muscle.

Key Words high-protein snack, light resistance exercise, muscle mass, muscle strength, muscle blood volume

In their study on muscle loss in glucocorticoid-injected rats, Matsuo and Suzuki reported the effectiveness of a combination of ingestion of a high-protein snack (HPS) 3 h after a basal meal and light resistance exercise as a preventive measure against sarcopenia (1, 2). These studies showed that there was no increase in amino acid concentration in blood after ingestion of a basal meal when restricted to 2 meals per day, but a significant increase was initiated by the ingestion of HPS 3 h after a basal meal. The combination of HPS ingestion and light resistance exercise (voluntary climbing on a wire mesh tower 25 cm φ and 2 m in height) over 8 wk was shown to be effective in suppressing the loss of muscle protein. HPS ingestion alone did not suppress muscle protein loss. Therefore, we concluded that the tower-climbing exercise is a necessary condition for facilitating the nutritional effect of HPS on muscle protein synthesis.

Further, to determine whether the above effect could be observed in humans, we investigated changes in plasma branched-chain amino acid (BCAA) concentrations to determine whether light resistance exercise (dumbbell exercise) performed with high plasma BCAA concentrations resulting from ingestion of HPS 3 h after a basal meal is effective in the promotion of amino acid utilization by peripheral tissues (3). HPS ingested 3 h after a basal meal increased the plasma BCAA concentrations. The subsequent dumbbell exercise caused fluctuations in blood flow volume and promoted the utilization of BCAA in peripheral tissues. Continuation of this exercise regime as a daily routine showed the possibility of resultant increase in muscle mass and strength.

The present study investigated whether continuation of a daily routine dumbbell exercise after ingestion of HPS 3 h following a basal meal is effective in increasing muscle mass and strength.

SUBJECTS AND METHODS

Experimental protocol. In this daily routine study, ten young adult males (Table 1) were subjected to the following 3 different conditions for 5 wk each, with sufficient recovery intervals (Fig. 1). It was confirmed that the training effect had been reset before each stage of the experiment. The 3 conditions were as follows:

1. Snack-Exercise (SE): During the 5-wk study period, the subjects ingested HPS 3 h after breakfast every day and performed dumbbell exercise for 30–60 min, 5 times a week.

2. Snack-Sedentary (SS): During the 5-wk study...
period, the subjects ingested HPS 3 h after breakfast every day and thereafter performed no dumbbell exercises.

3. No snack-Exercise (NE): During the 5-wk study period, the subjects performed dumbbell exercise similar to the SE group and ingested one-half of HPS with both breakfast and lunch.

Body composition and muscle strength measurements were taken before and after the study period. During a 36-h period before the day the measurements were taken, all subjects were prohibited from eating and drinking or exercising excessively, drinking alcoholic beverages, and smoking. Eating or drinking, except for water, was prohibited for a 12-h period before the start of the experiment. The subjects recorded what they ate on the day before measurements were taken, and it was confirmed that there was no difference in total calorie intake or protein intake among the 3 study conditions. Body composition measurements of the subjects were obtained using InBody 720, a body composition measurement device that employs an eight-lead electrode impedance method.

During the study period, the eating habits of subjects were not controlled; however, subjects were instructed not to make large variations in them. The eating habits of the subjects were determined by surveying what they ate during the 1st and 5th week of the study period. Surveys were performed by having them record the time when they ate (breakfast, lunch, and dinner) and what they ate (food name and amount eaten). Using Healthy Maker Version 432 (Mushroom Soft Co., Okayama, Japan), a nutritional value calculation program, levels of calorie, protein, fat, and sugar intake were calculated.

Measurement of body composition. We measured body weight, lean body mass, and body fat mass using InBody 720, a body composition measurement device that employs an eight-lead electrode impedance method.

Measurement of muscle cross-sectional area. We used a static magnetic field 1.5-Tesla superconductive MR device and a body coil for muscle tissue MR imaging.

Table 1. The characteristics of the subjects.

<table>
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<tr>
<th>Age (y)</th>
<th>24.5±1.2</th>
</tr>
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<tr>
<td>Height (cm)</td>
<td>172.5±2.0</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>64.4±2.1</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>21.6±0.6</td>
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</tbody>
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Values are means±SE (n=10).

Table 2. Program of dumbbell exercise.

| 1 | Shoulder press |
| 2 | Reverse bent-dumbbell row |
| 3 | Squat |
| 4 | Upper body twist |
| 5 | Pectoral squeeze |
| 6 | Side lateral raise |
| 7 | Upright row |
| 8 | One-arm curl |
| 9 | One-arm row |
| 10 | One-arm kickback |
| 11 | Double-arm front lateral |
| 12 | Double-arm extension |

**High-protein snack.** HPS was made of dried egg whites (15.0 g) (Kewpie Corporation, Tokyo, Japan), sugar (18.0 g), and water (120 mL), which provided 13.0 g protein and an energy content of 120 kcal. The protein level was the almost same as in our previous study (3, 4).

**Exercise.** The subjects performed the dumbbell exercise invented by Suzuki as a light resistance exercise (5, 6), using a pair of fabric dumbbells packed with 300 g of brown rice, for 30–60 min after ingestion of the snack. Dumbbell exercises were performed as follows: the subjects stood on the floor with feet shoulder-width apart, stretched their back, bent their upper body forward, bent their knees, and maintained the half-crouching position as a basic stance. Subsequently, they grasped the dumbbells firmly, twisted their wrists inward, and kept them flexed. The exercise program comprised of 12 different exercises (Table 2), with each movement repeated 15 times with an interval of about 7 s between each exercise. Subjects moved the dumbbells slowly (2–3 s for eccentric and concentric actions) and continuously.

**Dietary survey.** During the study period, the eating habits of subjects were not controlled; however, subjects were instructed not to make large variations in them. The eating habits of the subjects were determined by surveying what they ate during the 1st and 5th week of the study period. Surveys were performed by having them record the time when they ate (breakfast, lunch, and dinner) and what they ate (food name and amount eaten). Using Healthy Maker Version 432 (Mushroom Soft Co., Okayama, Japan), a nutritional value calculation program, levels of calorie, protein, fat, and sugar intake were calculated.

Fig. 1. Experimental protocol. (A) Overview of the experiment. (B) Time course after the ingestion of meals and high protein snacks.
We took both thigh and forearm CSA images using turbo spin echo. CS imaging parameters for the thigh were repetition time (TR) = 560 ms, echo time (TE) = 9 ms, and slice thickness = 10 mm. Imaging was performed from the greater trochanter to the knee joint, and we obtained T1-weighted images for 50% of the thigh. CSA was identified from imaging of the vastus lateralis muscle. Forearm CS imaging parameters were TR = 520 ms, TE = 11.3 ms, and slice thickness = 4 mm. Imaging was performed from the humeroradial joint to the radial styloid process and obtained T1-weighted images from the humeroradial joint to an area 5 cm distal to it. We identified the forearm flexor muscles from the obtained images and performed a total CSA imaging. During imaging, limbs were fully extended and subjects were positioned so as not to affect the CSA.

CSA measurements were performed using OsiriX Imaging Software (Version 3.2.2; Meditech Co., Tokyo, Japan). Each image was subjected to CSA measurements 3 times, and the mean values were recorded as the measured values.

Measurement of muscle strength. We measured both isokinetic and isometric knee extensor strength using a Biodex System 3 isokinetic dynamometer. The isokinetic measurement consisted of setting the active knee extension position at 0° knee flexion and having the subject use the maximum possible effort to move his leg to a position of 100° knee flexion. The maximum value among 5 repetitions performed at a speed of 60°/s was used as the measured value. The isometric measurement consisted of setting the active knee extension position at 0° knee flexion and having the subject use the maximum possible effort to move his leg to the position at 75° knee flexion. There was a 1-min interval after every 3 exercise repetitions in all muscle strength measurements, and the maximum value was recorded as the measured value.

Grip strength was measured using a digital grip strength meter, with the subject in the standing position. Measurement of the maximum grip strength of the subject’s right limb was taken in a fully extended and hanging-straight-down position. We took 3 measurements and used the maximum value as the measurement value.

Statistical analysis. All the data are expressed as means±SE. Analysis of variance was performed based on time (before and after the study period) and the 3 experimental conditions (SE, SS, and NE), and the Huynh-Feldt correction was applied to the degrees of freedom to reduce the risk of Type I errors when Mauchly’s sphericity could not be assumed. The least significant difference (LSD) was used to compare multiple values.

Statistical processing was performed by statistical analysis software (SPSS15.0J, SPSS, Japan), using a 5% level of significance in all cases.

RESULTS

Body composition (Table 3)

Body weight. There were no significant changes in body weight in any of the 3 study groups during the 5-wk study period.

Lean body mass. Out of the 3 groups, only the SE group exhibited a significant increase in lean body mass after the study period as compared with before the experiment.

Body fat mass. A significant decrease in body fat mass after the study period as compared with before the experiment was seen only in the SE group; no such change was observed in the SS group. The NE group showed a tendency for body fat mass to decrease after
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the experiment.

Muscle cross-sectional area (Fig. 2)

Total cross-sectional area of forearm flexors. A significant increase of 2.8% during the study period compared with before the experiment was observed in the total CSA of forearm flexors only in the SE group; no such significant increase was observed in the SS or NE groups.

Total cross-sectional area of vastus lateralis muscle. No significant change was seen in the vastus lateralis muscle among the 3 study groups during the study period.

Muscle strength (Fig. 3)

Isometric extensor strength of the right knee. A significant increase of 8.2% in isometric right knee extensor strength during the study period compared with before the experiment was seen only in the SE group; no significant increase was seen in the SS or NE groups.

Isokinetic extensor strength of the right knee. No significant increase was seen in the isokinetic right knee extensor strength in any of the 3 study groups during the study period.

Grip strength of the right hand. A significant increase in grip strength during the study period as compared with before the experiment was seen in the SE and NE groups; no significant increase was seen in grip strength in the SS group.

Dietary survey. There was no significant difference in the levels of calorie, protein, fat, or sugar intake among the 3 study groups during the 5-wk study period compared with before the experiment (Table 4).

DISCUSSION

This study investigated the effectiveness of ingestion of HPS 3 h after a basal meal followed by dumbbell exercise of 30–60 min, continued over a 5-wk period, in increasing muscle mass and strength in 10 young adult males.

In the SE group, the total CSA of right forearm flexor significantly increased, but no such change was seen in the SS and NE groups.

In the SE group, grip strength and isometric knee extensor strength significantly increased, but the SS group showed no increase in either parameter. Only grip strength increased significantly in the NE group.

The above results indicate that, when continued as a daily habit over a period of 5 wk, the combination of dumbbell exercise for 30–60 min following ingestion of HPS 3 h after a basal meal is effective in increasing muscle mass and strength.

The prevailing view is that using a weight at 65% or more of one repetition maximum (1 RM) (7) and continuation of exercise until exhaustion, is effective in increasing the mass and strength of skeletal muscle (8). However, it is difficult for the elderly to continue heavy-load exercise on a daily basis. Recent studies have
reported that even light resistance exercise such as low-speed muscle flexing and extending exercise (10), is effective in increasing muscle mass and strength by restricting blood flow (9): this study used a dumbbell exercise devised by Suzuki that can be practiced even by the elderly (3, 5, 6). Movements in this exercise are very slow, with the subject’s muscle blood flow being restricted by holding the light dumbbells (300 g) and addingucting the wrists, which promotes protein synthesis and excretion of growth hormones (11). Other reports found that pressure training (Kaatsu training), which also restricts blood flow to active muscles even when using a very light weight of 0.2 RM, is effective in promoting protein synthesis (9), and may therefore be similar physiologically to Suzuki’s dumbbell exercise.

There are many studies on the combined effects of ingestion of protein or amino acids and timing of exercise, with many researchers reporting that ingestion of protein or amino acids directly after exercise is effective in muscle protein synthesis (12–15). In addition, some studies on ingestion of proteins or amino acids prior to exercise have shown the ingestion to be effective in muscle protein synthesis (16–18). This study fixed the timing of HPS ingestion at 3 h after a basal meal (1–4) in the SE and SS groups, thereby aiding the daily ingestion of proteins by elderly people with reduced appetite. Since the demands of the small intestine and liver are quickly met by amino acids from the protein of the basal meal, amino acids from the HPS protein are rapidly disseminated to the peripheral tissues. The timing of the exercise was set at 30–60 min after the ingestion of HPS, which is when amino acid levels in the blood are high. To maintain consistency in the amount of snack ingested, the NE group’s HPS was divided into 2 equal parts, served at breakfast and lunch. For this reason, during the 5-wk study period the levels of exercise and food ingested were the same for both study groups that ingested HPS. In spite of this, the SE group showed an increase in forearm muscle total CSA during the study period, while the NE group showed none. The main reason for this is attributed to the timing of HPS ingestion, which promotes muscle protein synthesis. Considering that our previous study showed plasma BCAA concentrations rising by 40% after HPS ingestion compared with that prior to ingestion (3), and reaching a concentration that optimally stimulated protein synthesis in muscle (19), it is conceivable that the HPS used in this study was also fully active in promoting protein synthesis.

Regarding the relationship between the ratio of increase in muscle mass and strength resulting from muscle training, Jones and Rutherford reported an increase in muscle CSA of 4–5% and a maximum increase in muscle strength of 11–15% (20). Esmarck et al. reported an increase in muscle CSA of 7% and a maximum increase in isokinetic muscle strength of 15% (12). In our study too, in spite of the fact that the areas measured were different from those of previous studies, forearm muscle CSA increased by 2.8% and grip strength by 8.8%, indicating that the ratio of increase in muscle strength was greater than that in muscle CSA. We confirmed that grip strength is proportional to muscle CSA (21, 22), but the prevailing view is that increase in muscle strength in the beginning of training is mainly due to adaptations in the nervous system, and the ratio of increase in muscle mass and strength is not consistent (23–25).

Regarding knee extensor strength, isometric muscle strength significantly increased in the SE group over the study period but not in the other 2 study groups. None of the 3 study groups showed any significant increase in isokinetic knee extensor strength over the 5-wk study period. The prevailing view is that increase in muscle strength as a result of training is speed dependent (26, 27). For this reason the dumbbell exercise, which is performed in a half-sitting posture with the upper body bent forward and knees bent, had little effect on isokinetic muscle strength because it includes many types of isometric knee extensor exercises. Considering there was no increase in isometric muscle strength, we believe the possibility that the timing of HPS ingestion did influence isometric knee extensor strength.

The lower increase in muscle mass and strength compared with previous studies is likely due to the fact that our experiment lasted for 5 wk, whereas previous studies were performed over 12 wk (11, 19), although there are reports of increase in muscle CSA in experiments lasting around 5 wk (28, 29). Moreover, there is a report that Kaatsu training at 20% of 1 RM for 8 d increased the muscle mass and strength by 5% and 10%, respectively (30).

We focused on the intermittent changes in blood flow volume in muscle tissue resulting from dumbbell exercise as one of the key causes of increased muscle mass and strength in a short duration of 5 wk via the combination of a light-load resistance exercise, such as dumbbell exercise, and ingestion of HPS 3 h after a basal meal. Our previous study indicated a pattern of no increase in total hemoglobin in the forearm flexors or vastus lateralis muscle during the execution of dumbbell exercise but indicated a significant increase during the intervals between exercises (3). It is possible that due to these changes, amino acids assimilated from ingestion of the snack were transported to muscle tissue and that uptake by muscle cells was promoted: these amino acids may be effective in increasing muscle mass and strength. This is thought to occur due to efficient uptake by muscle tissue via intermittent blood volume fluctuation through light resistance training with a high blood amino acid concentration. Future research needs to focus on blood flow volume in muscle tissue to identify the fluctuation patterns that promote efficient uptake of nutrients into peripheral tissues such as skeletal muscles.

Elucidation of the mechanisms involved in this process should lead to prevention of sarcopenia, which could also be applied to the prevention of metabolic syndrome, and to a way of promoting better fitness in children as well as the building and strengthening of muscles in sporting disciplines.
REFERENCES


