Dr. Kouichi Wakimoto, who directed this study, passed away in January 16, 2017. Our thoughts and prayers are with you.

Dr. M. Takahashi (CEO;Petroeuroasia Co., Ltd.)

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Coenzyme Q_{10} Intake Increases Maximal Exercise Glucose Metabolism in Young Healthy Subjects

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Abstract

The purpose of this study is to clarify the effect of coenzyme Q_{10} (CoQ_{10}) supplementation (300mg/day for 6 weeks) on the endurance exercise performance after receiving the habitual steady loading exercise (30min/day, 3times/week for 6 weeks) in healthy young female having no exercise custom. For the double-blind study, 20 healthy young female subjects (age ranging 18 to 23 yr, average 19.8±1.3 yr) were divided into two groups, CoQ_{10} group (n=10) and placebo group (n=10). Before and just after the intervention, step exercise tolerance test with bicycle ergometer was loaded to the subjects, and their blood lactic acid (LA), blood sugar (BS), heart rate (HR), and the expiration gas analyses including VO_2, VCO_2, respiratory exchange ratio (RER), minute ventilation (VE), carbohydrate oxidation and fat oxidation were measured and compared between those before and after the intervention. In the CoQ_{10} group, LA at the time of exhaustion were significantly decreased when compared with that of before the intervention (before; 9.20 ± 1.79 mmol/l vs. after; 7.86 ± 1.87 mmol/l, $p<0.05$). Furthermore, carbohydrate oxidation at the time of exhaustion showed higher level than that of before the intervention, though not statistically significant (before; 4481.8 ± 1145.4 mg/min vs. after; 4939.4 ± 1084.8 mg/min, $p<0.06$). From these results, it could be concluded that habitual exercise with CoQ_{10} supplementation improves glucose metabolism at the time of high intensity exercise.

Key Words: Coenzyme Q_{10}, glucose metabolism, High-intensity exercise, lactic acid, young female

I. Introduction

Coenzyme Q_{10} (CoQ_{10}) is widely found in nature. Its structure consists of a quinone structure with 10 isoprenyl subunits attached, and it is a fat-soluble substance with a vitamin-like effect. [7] In the human body, it is synthesized in the mevalonate pathway, a synthetic pathway for cholesterol, and is mostly distributed in the heart, kidney, liver, etc.[1] CoQ_{10} performs 2 major functions: as Ubiquinol-10, the reduced state of CoQ_{10} in the body, it reduces peroxides such as lipid peroxide and works as an anti-oxidant, and it is also involved in the generation of ATP as a coenzyme in the mitochondrial electron transport chain.[7]

Since 2001, CoQ_{10} has been categorized as a food and has become easily obtainable in the form of a dietary supplement, for example. Before that, from the first half of the 1970s it was used as a pharmaceutical, mainly as a medicine to improve the myocardial metabolism in the treatment of heart disease patients. Based on this background, many studies are related to the intake of CoQ_{10} by heart disease patients[2,6,9,12]. In addition, as CoQ_{10} possesses an energy activation effect, many studies have now also been carried out to investigate a variety of effects of CoQ_{10} supplementation in improving exercise capacity in healthy persons [3,10,11,15]. Furthermore, research using CoQ_{10} combination supplementation is also being carried out.[8,13] On the other hand, Laaksonen et al.[10] carried out a double-blind cross-over placebo-controlled study targeting adult males (aged 22-38 years) and older males (aged 60-74 years) who participated in marathons or short triathlons (1.5 km swim, 40 km bicycle ride, 10km run), in which the subjects took 120 mg/day of a CoQ_{10} supplement or a placebo for

6 weeks, and a stress test was carried out using a bicycle ergometer. They reported that over each intake period, no difference was observed in the variation of the maximal VO_2, and in separate endurance tests, too, there was no significant difference in the time to al-out effort in each intake period. So while there are reports pointing to the effectiveness of CoQ_{10} supplementation with increased workload and duration or increased energy efficiency in endurance performance and steady-load exercise, currently no consensus has not been reached in research using CoQ_{10} supplementation to improve endurance exercise performance, with some reports observing no effectiveness. In addition, a lot of research has been carried out targeting heart disease patients[2,9], chronic obstructive pulmonary disease patients[4], persons training daily[3,10,13,15], middle-aged males likely to have low concentrations of CoQ_{10} in the blood[9], and older persons[15], but among young people identified as taking insufficient exercise, we have not found any contemporary research cases targeting young women in general who are healthy but have no exercise routine.

The aim of this study, with young females with no exercise routine as subjects, is to clarify whether or not there is an improvement in endurance exercise capacity through intake over a long period of 40SP, which has excellent dispersibility in water and absorbability in the body, while the subjects are subject to a routine, steady exercise load. In other words, a working hypothesis was set that for healthy, young females with no exercise routine who likely retain CoQ_{10} in the body, through intake of CoQ_{10} supplements in addition to a routine, steady, exercise load, after the study intervention, increased energy and oxygen uptake efficiency during the exercise stress test and steady load exercise, and increased maximal exercise load during the exercise stress test would be observed. The endurance exercise capacity was evaluated based on the blood lactic acid level (LA), the blood sugar level (BS), the heart rate (HR), the exhaled gas analysis measured value, the free fatty acids in the blood and the blood insulin measured values during the exercise stress test before and after the study intervention. Also, the body composition of subjects was measured and compared before and after the intervention.

Table 1. Blood properties of the subjects before the intervention

Articles	values	Articles	values
Total protein (g/dl)	7.39 ± 0.29	sfe (μg/dl)	104.4 ± 36.7
Total bilirubin (mg/dl)	0.83 ± 0.34	UIBC (μg/dl)	294.0 ± 65.1
Direct bilirubin (mg/dl)	0.29 ± 0.14	TIBC (μg/dl)	398.3 ± 55.8
ALP (IU/l)	178.5 ± 49.6	Serume amylase (IU/l)	68.6 ± 21.2
AST (IU/l)	16.4 ± 3.1	Arteriosclerosis index	1.9 ± 0.6
ALT (IU/l)	12.7 ± 4.7	Free-Cho (mg/dl)	43.2 ± 4.8
LDH (IU/l)	171.1 ± 25.8	Ester-Cho (mg/dl)	132.1 ± 20.3
γ-GT (IU/l)	13.9 ± 6.9	Ester ratio	0.75 ± 0.01
Ch-E (IU/l)	4791.1 ± 1119.7	Free fatty acid (mEq/l)	0.64 ± 0.29
CPK (IU/l)	89.3 ± 22.4	Phospholipid (mg/dl)	194.7 ± 28.2
Total cholesterol (mg/dl)	175.3 ± 24.7	Aldolase (U/l)	0.81 ± 0.29
Triglyceride (mg/dl)	55.4 ± 15.8	Lipase (IU/l)	23.5 ± 8.5
High-density lipoprotein cholesterolc (mg/dl)	63.0 ± 9.9	IgG (mg/dl)	1308.4 ± 246.2
Low-density lipoprotein cholesterol (mg/dl)	100.5 ± 23.6	IgA (mg/dl)	217.9 ± 82.0
BUN (mg/dl)	11.92 ± 2.81	IgM (mg/dl)	174.3 ± 59.3
Cr (mg/dl)	0.83 ± 0.06	C3 (mg/dl)	109.9 ± 14.7
UA (mg/dl)	4.30 ± 0.56	C4 (mg/dl)	20.8 ± 5.7
K (mEq/l)	4.53 ± 0.36	CH50 (mg/dl)	34.4 ± 3.8
Mg (mg/dl)	2.19 ± 0.13	Protein fraction	
Na (mEq/l)	141.10 ± 1.10	Albumin (%)	65.8 ± 2.6
Cl (mEq/l)	101.30 ± 1.40	α1 (%)	2.0 ± 0.4
Ca (mg/dl)	9.40 ± 0.30	α2 (%)	6.4 ± 0.9
Inorganic phosphorus (mg/dl)	3.70 ± 0.43	β (%)	9.4 ± 1.0
WBC (10^3/μl)	5.96 ± 1.59	γ (%)	16.4 ± 2.7
RBC (10^4/μl)	432.50 ± 33.23	A/G ratio	1.9 ± 0.2
Hb (g/dl)	12.65 ± 0.96	Cholesterol fraction	
Ht (%)	36.71 ± 2.64	LDL (%)	54.9 ± 6.7
MCV (fl)	85.5 ± 4.6	VLDL (%)	4.3 ± 1.9
MCH (pg)	29.45 ± 1.81	HDL (%)	40.8 ± 7.6
MCHC (%)	34.5 ± 0.9		
PLT (10^4/μl)	23.65 ± 4.13		

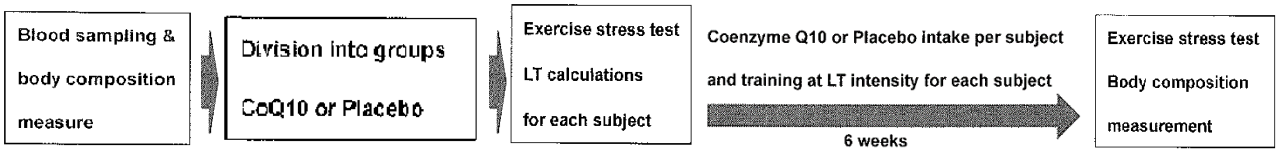

Fig.1. Flow chart We measured body composition before the intervention and divided the subjects into groups. Then, each subject was subjected to an exercise test, took CoQ10 supplements or the placebo, started LT intensity training, and again performed an exercise test after the 6-week intervention. LT (lactate threshold) = the threshold at which lactic acid works

II. Methods

1. Subject

The subjects were 20 healthy young women (Age: 19.8 ± 1.3 years, Height: 159.5 ± 5.4 cm, Weight: 55.1 ± 5.2 kg, Body fat percentage: 30.3 ± 3.3%, Body Mass Index: 21.7 ± 1.8) who were interviewed and confirmed to be non-smokers, to have no exercise habits, and to have not eaten any other dietary supplements. No abnormalities were found in any of the biochemical parameters of the blood before the intervention (Table1). At the start of the study, the subjects were informed verbally and in writing of the study objectives, methods, health hazards, risks, privacy compliance, and data management and disclosure. The study was conducted with the approval of the University Ethics Committee.

2. Experimental Design

As shown in the flow chart in Fig. 1, the test was conducted during an arbitrary 6-week period between August and October 2006 using the double-blind method. Body composition (height, weight, and body fat percentage) of each subject was measured before the intervention. Based on the results, the subjects were divided into two groups of 10 subjects each, a CoQ_{10} group and a placebo group, so that there was no difference in heights, weights, and body fat percentages (Table 2). Then, to determine the training load intensity, the exercise stress test was conducted using a bicycle ergometer to determine the lactate threshold 1 (LT1) of each subject. After each measurement, the subjects started the intervention by taking supplements and using a bicycle ergometer (LT1 equivalent load once for 30 minutes, 3 times a week).

After the 6-week intervention, the body composition measurement and exercise stress test were conducted as before the intervention, and changes in each measurement item were examined before and after the intervention.

Table 2. Changes in body composition and LT before and after intervention

	CoQ_{10} (n=10)		Placebo (n=10)	
	Before	After	Before	After
Age (years)	19.5 ± 1.1		20.1 ± 1.5	
Height (cm)	159.3 ± 3.8		158.2 ± 6.5	
Body weight (kg)	55.4 ± 6.1	55.0 ± 6.0	55.9 ± 6.0	55.6 ± 6.2
% Body fat (%)	30.5 ± 4.1	30.7 ± 3.5	30.4 ± 3.9	31.2 ± 4.4
LT (watts)	34.1 ± 11.1	32.2 ± 5.0	30.6 ± 3.0	35.5 ± 9.4

LT(Lactate threshold) (mean±S.D.)

3. Body Composition

Height was measured using a stadiometer, weight and body fat percentage were measured using an impedance-type body composition analyzer (TANITA Corporation's BC-118E), and BMI was calculated from the height and weight.

4. Exercise Stress Test

In the exercise stress test, subjects were asked to complete a step load test using a bicycle ergometer (Combi Wellness Corporation's Aerobike 75XLH). Each subject finished meals by 2 hours before the start of the exercise test, visited the laboratory by 1 hour before the start of the exercise stress test, and rested in a sitting position or on a bed in the laboratory until the start of the test. While the subjects were resting, blood samples were collected from the median cubital vein to

measure free fatty acids and insulin in the blood before the start of the test. Blood samples were also collected from the fingertip, and LA at rest was measured using a simple blood lactate analyzer (Arkray, Inc.'s Lactate Pro). The test was started with the condition that LA at rest was below 1.2 mmol/l. If the start condition was not satisfied, the subject rested or repeated light exercise with a low-intensity load of 5W for 5 minutes using the bicycle ergometer, until the resting LA was below 1.2 mmol/l, and started the test after the start condition had been satisfied. The subjects first rested on the bicycle ergometer for 5 minutes, then warmed up at 10 W for 3 minutes, and then after 15 W for 4 minutes, gradually increased the load from 30 W in increments of 30 W every 4 minutes. From the point at which LA reached 4 mmol/l or higher at the end of a load stage, the load was switched to gradually increasing by 20W per minute, and the subjects were pushed to all-out effort. The subjects were asked to maintain the cycle ergometer at 50 to 60 rpm, and the all-out effort criterion was the point at which the subjects could no longer maintain 40 rpm. Blood samples were collected again after the test as before the test. LT1 was calculated from the LA measured using the lactic acid value management software MEQNET LT Manager (Arkray, Inc.).

The breath by breath method was used to measure exhaled gas (Minato Medical Science Co., Ltd.'s Aeromonitor AE300S) during the exercise stress test. VO2, VCO2, respiratory exchange ratio (RER), minute ventilation (VE), carbohydrate oxidation, and fat oxidation were averaged for every 9 breaths, and then averaged for every 30 seconds for each load stage. The blood glucose level was measured (Terumo Corporation's Medisafe Reader GR-101) at the same points as the blood lactate level before and after each load stage, and HR was measured with a heart rate monitor (Polar's s610i).

5. Supplement Intake Amount and Intake Method

40 SP was administered to the CoQ_{10} group, and placebo powder without CoQ_{10} (Table3), which was provided by the same company for this study, was administered to the placebo group by dissolving it in 500 ml of water. As a condition, each subject was asked to take one or more meals a day, but they were instructed to take the supplement during or after meals, avoiding taking it before meals, and although no dietary restrictions were imposed, most of the subjects were students of a dietician training school.

Table 3. Comparison of CoQ_{10} supplement and placebo ingredients

	CoQ_{10}	Placebo
Hydrogenated Maltose Starch Syrup Powder	5821.2	5667.2
Indigestible dextrin	5544.0	5390.0
Grapefruit powder	1540.0	1540.0
Citric acid	1078.0	1078.0
40SP	770.0	0
Dextrin	0	770.0
Grapefruit flavor	616.0	616.0
Gardenia yellow	0	308.0
Aspartame	30.8	30.8
Total (mg)	15400.0	15400.0

6. Training During the Intervention Experiment

Using the bicycle ergometer, the subjects performed a series of exercises three times a week consisting of a 5W, 3-minute warm-up, followed by 30 minutes of steady load exercise at each subject's LT1 intensity calculated from the exercise load test before the intervention, and then a 3-minute cool down. The subjects used a laboratory and a bicycle ergometer similar to those used in the exercise stress test, and they walked more than 8000 steps/day, and this was monitored and controlled by a lifestyle recorder (Kenz's Lifecorder EX).

7. Statistical Analysis

The repeated measures analysis of variance was used to compare each measurement value in the exercise test before and after the intervention, and the Paired t-test was used at each load stage if there was any interaction. Fisher's PLSD method was used to compare body composition, free fatty acid in the blood, and insulin before and after the intervention between the groups if there was any interaction. All the statistics were expressed as the standard deviation of mean value, and the significance level was judged by $p < 0.05$.

III. Results

In the exercise test after the intervention, one subject in the CoQ_{10} group was unable to obtain data due to an accident in which he was unable to take exhaled breath during the measurement of exhaled gas, and one subject in the Placebo group was unable to monitor his heart rate. Consequently, the respective analyses were carried out excluding these subjects' data.

1. Body Composition

There were no significant changes in body weight, body fat percentage or BMI between the CoQ_{10} group and the placebo group (Table2).

2. Exercise Stress Test

1) Blood Lactate Acid, Blood Glucose and Heart Rate

There were no significant changes in BS and HR at each load stage during the pre- and post-intervention exercise testing in the CoQ_{10} and Placebo groups (the data is not shown.). There were no significant changes in LT, an indicator of endurance exercise capacity, in the CoQ_{10} group at 34.1 ± 11.1 W before the intervention and 32.3 ± 5.0 W after the intervention, nor in the placebo group at 30.1 ± 3.0 W before the intervention and 35.5 ± 9.4 W after the intervention (Table2). LA did not change significantly after the intervention from rest to 120 W in either the CoQ_{10} or placebo groups. However, LA decreased significantly from 9.20 ± 1.79 mmol/1 before the intervention to 7.86 ± 1.87 mmol/1 after the intervention only in the CoQ_{10} group during all-out effort ($p < 0.05$, Fig. 2). The LA integrated value showed a significant decrease from 11.97 ± 2.49 mmol/1 before the intervention to 11.11 ± 3.13 mmol/1 after the intervention only in the CoQ_{10} group, during the period from rest to 120 W ($p < 0.05$, Fig. 3). LA also decreased significantly from 21.17 ± 3.09 mmol/1 before the intervention to 18.97 ± 3.33 mmol/1 after the intervention in the period from rest to all-out effort ($p < 0.05$, Fig. 3).

2) Exhaled Gas Analysis

In the exhaled gas analysis before and after the intervention, no significant changes in VO2 and RER were observed in either the CoQ_{10} and Placebo groups (the data is not shown.), and in VCO2, a significant decrease ($p < 0.05$) was observed in the CoQ_{10} group from 409.9 ± 38.7 ml/min before the intervention to 388.1 ± 24.6 ml/min after the intervention at 15 W, but no significant changes were observed in the other load stages. VE did not change significantly from rest to 120 W, but increased from 56.4 ± 15.7 ml/min before the intervention to 64.4 ± 16.1 ml/min after the intervention ($p = 0.055$). Carbohydrate oxidation tended to increase ($p=0.054$, Figure 4.) during all-out effort for the CoQ_{10} group, at 4481.8 ± 1145.4 mg/min before the intervention and 4939.4 ±1084.8 mg/min after the intervention.

Fat oxidation tended to decrease in both CoQ_{10} and Placebo groups, but the difference was not significant (Figure 5.).

3. Free Fatty Acids and Insulin in the Blood

There were no significant changes in the absolute value or rate of change ((after intervention - before intervention)/before intervention x 100)) in the free fatty acids in the blood during the exercise stress test in the CoQ_{10} group or placebo group, but if compared respectively before and after the intervention, whilst in the placebo group, the amount of free fatty acid in the blood increased after the intervention at the exercise stress test finish, in the CoQ_{10} group, conversely, it showed a tendency to be suppressed (Figure 6.). There were no significant changes in the absolute value and rate of change ((after intervention - before intervention)/before intervention x 100)) of insulin in the blood from during the exercise stress test in either the CoQ_{10} group or placebo group, but if the respective rates of change are compared, in the CoQ_{10} group before the intervention, a reduction is seen during the exercise stress test start, and after the intervention, it increased during the exercise stress test start, while in the placebo group the same changes as the CoQ_{10} group were not observed (Figure 7.)

IV. Discussion

As shown in Fig. 2, LA in the CoQ_{10} group decreased significantly during all-out effort in the exercise stress test after the intervention compared with that before the intervention ($p < 0.05$). As shown in Fig. 4, carbohydrate oxidation tended to increase ($p = 0.054$), and as shown in Fig. 3, LA integral values at the time of the exercise stress test decreased after the intervention at 120 W from rest and at all-out effort from rest ($p < 0.05$).

In general, the decrease in LA during all-out is interpreted as a decrease in glucose utilization from a kinesiological point of view. However, in the exhaled gas analysis in this study, carbohydrate oxidation tended to be higher at this time (Fig. 4.), which generally means an increase in glucose utilization. On the other hand, the absolute value of free fatty acid in the blood before and after the exercise stress test tended to increase in the Placebo group (Fig. 6), whereas it tended to decrease in the CoQ_{10} group (Fig. 6). The change rate of blood insulin before and after the exercise test did not change in the Placebo group, but in the CoQ_{10} group before the intervention, it tended to decrease, but this changed to a tendency to increase (Fig. 7.) after the intervention.

Glycolysis, one of the energy production systems, promotes the breakdown of glucose when exercise intensity increases, but the metabolic rate is not precisely controlled [5]. However, the TCA cycle is closely controlled because it is related to oxygen uptake. Therefore, even if metabolism in the glycolytic system increases, metabolism in the TCA cycle does not increase in accordance with that in the glycolytic system. Metabolism in the glycolytic system increases during high-load exercise, but in the TCA cycle, the metabolic rate is slower than that in the glycolytic system because oxygen is not supplied in time. Therefore, a difference between the glycolytic system, which has a faster metabolic rate, and the TCA cycle, which has a limit, results in the production of lactic acid. This can also be understood from the increase in the

amount of lactate acid in the blood in terms of acceleration toward all-out effort, as indicated in the placebo group and CoQ_{10} group's Before figures in Fig. 2. In this study, LA and other parameters in the exercise stress test were similar in the CoQ_{10} group and the Placebo group, but differences appeared in the all-out effort stress test. In order to consistently explain the four movements of LA decrease in the all-out effort stress test, increase in carbohydrate oxidation, increase in blood insulin and decrease in free fatty acid in the blood after the exercise stress test, it can only be considered that lactate production was suppressed while glucose utilization was promoted. In other words, the difference in metabolic speed of the glycolytic pathway and TCA cycle was not widened even at the maximum load. From this study, it is considered that there was no shortage in the body's CoQ_{10} in the healthy, young subjects. We propose the hypothesis that the effects of taking CoQ_{10} supplements only appear under extreme conditions, such as all-out effort, suggesting that smooth rotation of the electron transport chain under extreme conditions by taking CoQ_{10} supplements maintains sufficient rotation of the TCA cycle and does not widen or narrow the gap with glycolysis. Considering that muscle fatigue was associated with an increase in lactate levels, this could be interpreted as a clear reduction in muscle fatigue at high loads after CoQ_{10} intake. In fact, many of the subjects in the CoQ_{10} group reported faster recovery from fatigue and reduced muscle soreness after exercise.

Investigations into the effects on exercise capacity due to the ingestion of CoQ_{10} supplementations have mainly targeted heart disease patients [2,9], lung disease patients[4] and healthy subjects carrying out daily training[3,10,13,15]. Ylikoski at al. have reported the increase in ANT (anaerobic threshold) in a treadmill load test targeting national level, cross-country skiing athletes. In addition, Hofman-Bang et al.[6] reported an increase in maximum exercise capacity in patients with chronic congestive heart failure. Fujimoto et al. [4] reported an increase in serum CoQ_{10} in patients with chronic obstructive pulmonary disease and patients with idiopathic pulmonary fibrosis who tended to have low serum CoQ_{10} levels. These results suggest that CoQ_{10} supplementation may have a beneficial effect on muscle energy production in patients with hypoxemia at rest and chronic lung disease during exercise. In addition, in a study by Yasuma et al. [14] using animals, they studied the effects of CoQ_{10} on hypoxic ventilation response in unanesthetized dogs.. They reported that CoQ_{10} administration enhanced the ventilatory response to hypoxia, suggesting that CoQ_{10} administration is required to maintain respiratory muscle and lung metabolism during hypoxia. These results suggest that CoQ_{10} administration may be meaningful in the condition where CoQ_{10} is not sufficiently supplied. The results of this study suggest that CoQ_{10} administration is different from normal administration in young healthy subjects. However, under extreme conditions such as all-out effort, CoQ_{10} may be at least relatively deficient. It is considered that CoQ_{10} supplements have sufficient potential to be applied to sports nutrition in order to increase the efficiency of energy production under hypoxic conditions during all-out or high-load exercise in exercise stress tests in young healthy subjects.

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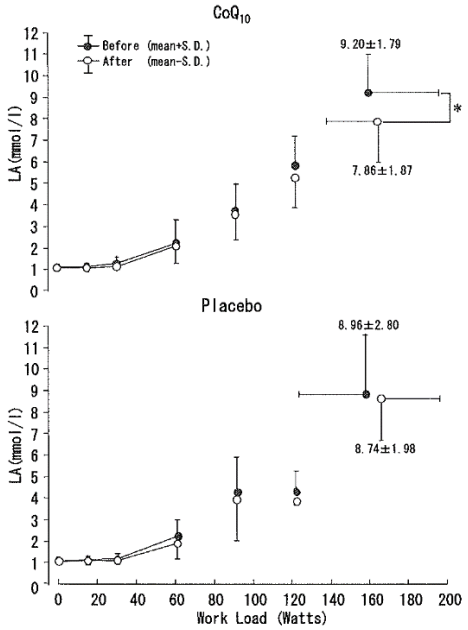
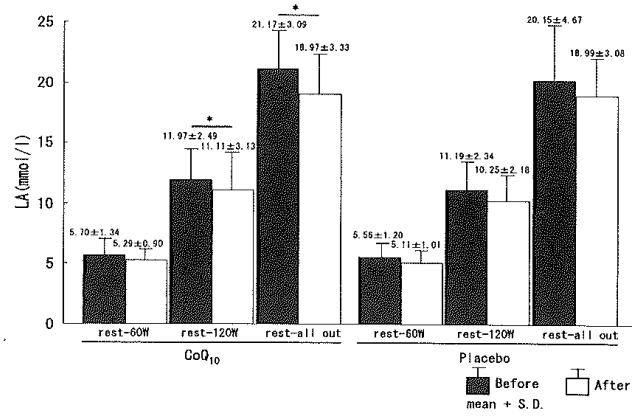
* This is an English translation of a document written in Japanese.

Fig.2. Effects of CoQ_{10} and the Placebo on Blood Lactate Levels during Exercise Stress Testing



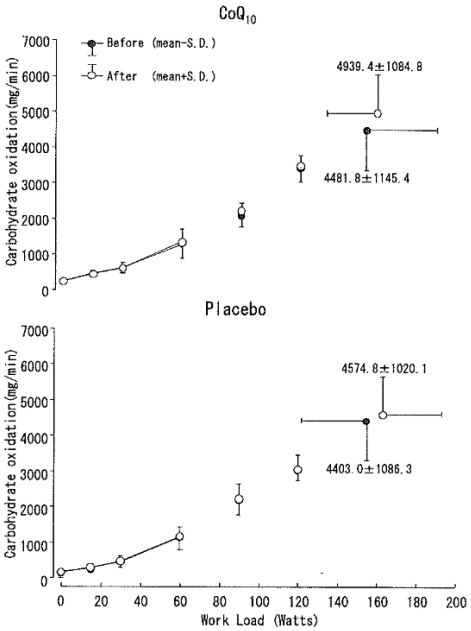
"Before" indicates before the intervention and "After" after the intervention. The X-axis represents the standard deviation of work load (Watts) during all-out effort. Since the final load stage is different for each subject, the number n is different for each load stage (CoQ10: 0-60W, all-out effort n=10, 90W n=9, 120W n=5, Placebo: 0-90W, all-out effort n=10, 120W n=3). LA (lactic acid) = blood lactate level. In the CoQ10 group, a significant decrease (* $p < 0.05$) was observed between the pre- and post-intervention phases in the all-out effort test between the same load stages.

Fig.3. Blood Lactate Level Integrated Values from Resting to Each Load Stage during Exercise Stress Testing



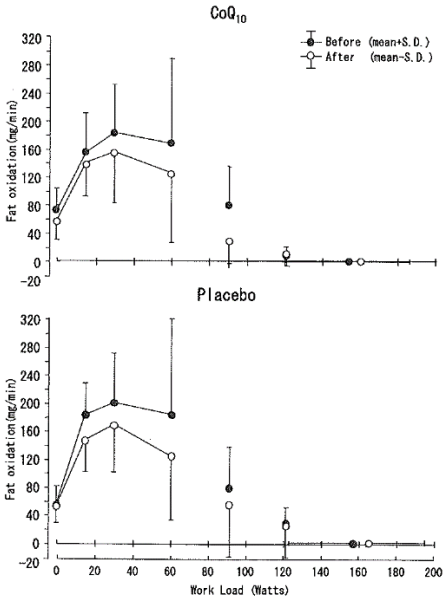
"Before" indicates before the intervention and "After" indicates after the intervention. The data are expressed as means + standard deviations. The integrated value of LA (blood lactate level) is shown for each of rest-60W (from resting to 60W), rest-120W (from resting to 120W), and rest-all-out (from resting to all-out). The values for rest-120W and rest-all-out were significantly lower (*$p < 0.05$) after intervention than before intervention.

Fig.4. Effects of CoQ_{10} and the Placebo on Carbohydrate Oxidation Levels during Exercise Stress Testing



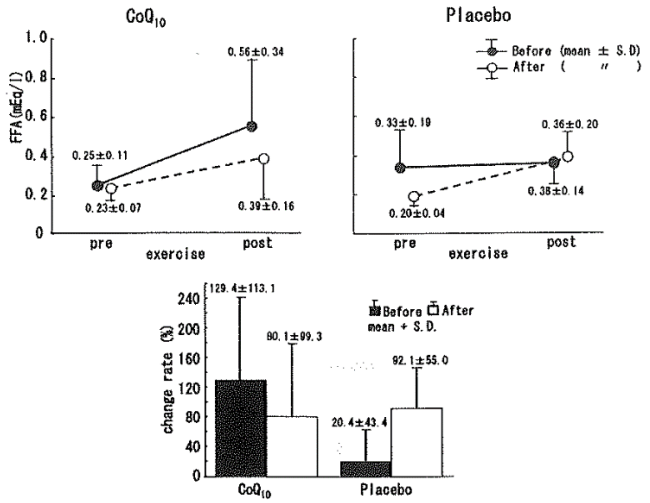
"Before" indicates before the intervention and "After" after the intervention. The X-axis represents the standard deviation of work load (Watts) during all-out effort. Since the final load stage is different for each subject, the number n is different for each load stage(CoQ_{10}；0-60W, all-out n=9, 90W n=8 120W n=5, Placebo；rest-60W, all-out n=10, 90W n=9, 120W n=4). Carbohydrate oxidation levels in the CoQ_{10} group during all-out increased ($p = 0.054$) during the same load stages after the intervention compared to before.

Fig.5. Effects of CoQ_{10} and the Placebo on Fat Oxidation Levels during Exercise Stress Testing



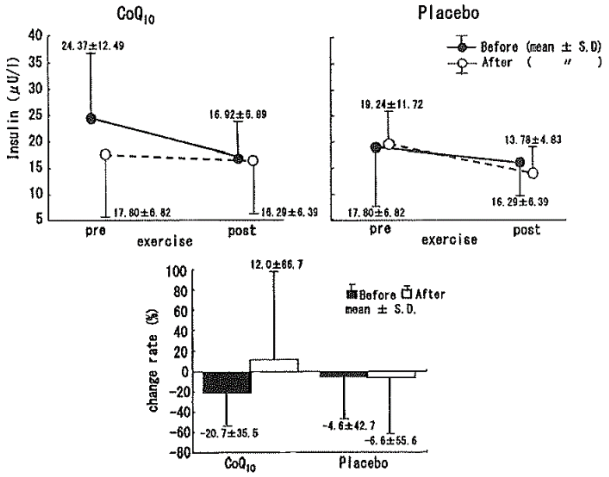
"Before" indicates before the intervention and "After" after the intervention. The X-axis represents the standard deviation of work load (Watts) during all-out effort. Since the final load stage is different for each subject, the number n is different for each load stage(CoQ_{10}；rest-60 W, all-out n=9, 90W n=8 120W n=5, Placebo；rest-60W, all-out n=10, 90W n=9, 120W n=4). There were no significant differences in fat oxidation levels in either the CoQ_{10} group or the Placebo group.

Fig.6. Changes in Fatty Acids in the Blood during Exercise Stress Testing



"Before" indicates before the intervention, "After" indicates after the intervention, "Pre" indicates before the start of the exercise stress test, and "Post" indicates the end of the exercise stress test. CoQ_{10}; n = 10, Placebo: n = 10. FFA (Free fatty acid) = free fatty acids in the blood. Change Rate: the rate of change from the start to the end of the exercise test. There was no significant change in the absolute value and the rate of change. However, when compared before and after each intervention, the Placebo group tended to increase, while the CoQ_{10} group tended to decrease.

Fig.7. Changes in Blood Insulin in the Exercise Test and the Rate of Change



"Before" indicates before the intervention, "After" indicates after the intervention, "Pre" indicates before the start of the exercise stress test, and "Post" indicates the end of the exercise stress test. CoQ_{10}; n=10, Placebo; n=10. FFA (free fatty acid) = free fatty acid in the blood. The CoQ_{10} group showed a decrease in the change rate at the end of the exercise stress test compared with the CoQ_{10} group before the intervention, and the Placebo group did not show the same changes as the CoQ_{10} group.