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Effects of taurine administration in rat skeletal muscles on exercise

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Abstract To investigate the effects of taurine administration on exercise, we studied taurine concentrations in rat skeletal muscles after endurance running and the duration of running time to exhaustion, with and without taurine administration. For study 1 we divided 40 male SD rats into two groups: endurance exercise group (n = 20) and sedentary control group (n = 20). Each was further divided into two groups; one received distilled water (n = 10) and the other taurine solution in water 0.5 g/kg/day orally (n = 10) for 2 weeks. The exercise group performed treadmill running (60 min) once only after their nursing period. For study 2, we divided 10 male SD rats into two groups; one (n = 5) received taurine 0.5 g/kg/day, and the other (n = 5) received no taurine for 2 weeks; the two groups then performed treadmill running to exhaustion. In study 1, taurine administration increased taurine concentrations in leg skeletal muscles, whereas the concentrations were significantly lower in the exercised groups without taurine administration. Taurine administration reduced the decrease in taurine concentration in skeletal muscles on exercise. In study 2, the duration of running time to exhaustion was significantly increased by taurine administration. We concluded that peroral administration of taurine maintains the taurine concentration in skeletal muscle on exercise and upregulates physical endurance.

Key words Rat · Taurine · Skeletal muscle · Administration · Exercise

Introduction

Taurine is one of the most common amino acids and is the most abundant free amino acid in various mammalian tissues.[8,19] It is well known that taurine is associated with bile acids in the liver of many animals.[16,23] A large amount of taurine is found in other organs as well, especially the heart and skeletal muscles.[19,25] Despite its high concentration, it has no defined function.[30]

Taurine is considered a natural amino acid that may act as a powerful membrane stabilizer.[3,6,11,12] Many papers have reported several effects of taurine associated with pathological states of increased cellular excitability such as epilepsy,[14,17] congestive heart failure,[15] and muscular dystrophy.[1,6] Therefore, administration of taurine may be an effective antimyotonic treatment.[7] Taurine may affect cellular hyperexcitability by increasing the membrane conductivity of potassium and chloride ions,[18] possibly by modulating the intracellular availability of calcium.[5,10]

Muscle cramps are a common symptom of chronic liver diseases (CLDs).[21,29] Recently, some papers have mentioned the effects of taurine on such cramps.[21,29] Matsuzaki et al.[21] reported that when taurine was given to CLD patients with muscle cramps the cramps disappeared or decreased. It was concluded that long-term administration of taurine was a safe, effective treatment for alleviating the muscle cramps associated with CLD.

It is widely accepted that painful muscle cramps occur even in healthy people during some exercises and with fatigue. This type of cramp is mainly considered to be the result of a large loss of ions (Na^+, Cl^-) and water from the body. As the effects of taurine on muscle cramps have been reported in regard to several pathological conditions, it is suggested that taurine plays a role in the muscle cramps that occur during and after exercise, although the role of taurine in relation to exercise and its effect during exercise remain unclear.[22] Furthermore, nothing has been reported on the effects of taurine administration in respect to taurine concentration in skeletal muscles during exercise. The purpose of this study was to investigate the effects of taurine administration on the taurine concentration in rat skeletal muscles during exercise and on physical endurance.

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Materials and methods

Animals and grouping

Study 1: Male Sprague-Dawley rats (Japan SLC, Shizuoka, Japan) weighing about 200 g ($n = 40$) were cared for from the age of 6 weeks. They were divided into two groups: endurance exercise ($n = 20$) and sedentary controls ($n = 20$). Each group was further divided into two more groups: One received distilled water ($n = 10$) and the other taurine solution in water 0.5 g/kg/day for another 2 weeks ($n = 10$). Thus, there were four groups: (1) no taurine administration and no exercise (control) (NC); (2) taurine administration and no exercise (control) (TC); (3) no taurine administration and exercise (NE); (4) taurine administration and exercise (TE).

Study 2: Ten male SD rats 6 weeks old were divided into two groups: One ($n = 5$) received taurine 0.5 g/kg/day orally for 2 weeks, and the other ($n = 5$) received no taurine for 2 weeks. The two groups were made to perform treadmill running to exhaustion [exhaustive exercise and taurine (ET) and exhaustive exercise and no taurine (EN)]. The animals were maintained at two to three per cage with free access to non-taurine-containing food (MF; Oriental Yeast, Tokyo, Japan) and constant room temperature (20°–22°C). They were exposed to a light cycle of 12 h/day (8:00 a.m. to 8:00 p.m.) throughout the course of the experiments. The body weight of each rat was measured every morning.

Exercise program

The exercise groups performed treadmill running (using a Nazme KN-73 treadmill device; Nazme, Tokyo, Japan) once only after their nursing period. In study 1, the slope of the treadmill was fixed at 0°, and the rats were loaded for continuous running for 60 min at 25 m/min. In study 2, the rats were exposed to the same procedure but were forced to run to exhaustion until they were no longer able to continue to run and were not able to right themselves when placed on their backs.[13] Throughout the course of this experiment, one researcher (who did not know the grouping of the rats) determined the duration of running time to exhaustion.

Taurine administration

Taurine 0.5 g/kg dissolved in distilled water (5% taurine solution in water) was administered orally with a catheter to the rats in volumes of about 20–30 ml once a day in the morning for the taurine groups. The no-taurine groups received distilled water in the same manner. For the rest of the day all rats had free access to taurine-free drinking water. This treatment lasted 14 days. All animals received humane care in accordance with the guidelines of the University of Tsukuba for the care of laboratory animals.

Tissue preparation and high-performance liquid chromatography analysis

Immediately after finishing the last program (or after finishing their exercise), all rats were killed under ether anesthesia. Blood samples were taken by needle aspiration from the hearts and prepared for measuring the plasma lactic acid and plasma taurine concentrations. The extensor digitorum longus (EDL), gastrocnemius (GC), and soleus (SOL) muscles were removed as quickly as possible, cleansed of adipose and connective tissue, and weighed. Portions of each muscle were fully homogenized in ice-cold 5% trichloroacetic acid for further examinations (Homogenizer PT 10/35, Generator PTA-10S, Brinkmann/KINEMATICA POLYTRON; Kinematica AG, Lucerne, Switzerland). All muscle samples were centrifuged at 6200 *g* for 30 min at 6°C. The supernatants were stored at −80°C until assay. Derivatization with *o*-phthalaldehyde was performed, and samples were processed for high-performance liquid chromatography (HPLC) taurine determination.[20,22]

Statistical analysis

All data are reported as the mean ± SD. Statistical analysis was performed in study 1 using a one-way analysis of variance (ANOVA) followed by Fisher's PLSD to determine differences between groups. Statistical significance was determined in study 2 by the unpaired Student's *t*-test for the means of taurine-administered and nontreated rats. Differences at $P < 0.05$ were considered significant.

Results

Study 1

Taurine treatment did not modify food consumption in any of the groups (no data shown). All rats were in good health, with no impairment of hindlimb movements or locomotor activity. No pathological signs were observed in any group of rats throughout the period of study. No mortality was observed in either taurine-treated or non-taurine-treated rats.

Body weight and muscle weight

Growth of rats in all groups was accompanied by an increase in their body weight until the end of this experiment (14 days). The body weights of each group (pre-

Table 1. Body weight and muscle weight

Group No.	Body weight (g)		Muscle weight (mg)		
	Pre	Post	EDL	GC	SOL
TC 10	231.60 ± 6.65	324.30 ± 17.92	171.60 ± 16.02	901.90 ± 46.74	135.70 ± 19.39
NC 10	228.70 ± 7.09	321.70 ± 20.39	175.00 ± 12.30	909.70 ± 42.16	134.60 ± 11.71
TE 10	224.90 ± 11.13	322.90 ± 24.32	182.00 ± 10.17	938.40 ± 94.61	137.10 ± 17.40
NE 10	227.60 ± 8.85	317.60 ± 23.05	182.00 ± 14.75	911.60 ± 45.95	136.70 ± 17.04

Data are means ± SD
There is no significant difference in body weight or muscle weight among the four groups
TC, taurine administration and no exercise (control) group; NC, no taurine administration and no exercise (control) group; TE, taurine administration and exercise group; NE, no taurine administration and exercise group
Pre, pretreatment; Post, posttreatment; EDL, extensor digitorum longus; GC, gastrocnemius; SOL, soleus muscle

Table 2. Plasma lactic acid and taurine concentrations

Group	Lactic acid (mg/dl)	Taurine (nmol/ml)
TC	22.15 ± 7.60	282.94 ± 116.44
NC	21.55 ± 1.36	265.66 ± 83.67
TE	32.98 ± 6.98	270.13 ± 119.89
NE	32.50 ± 15.98	230.28 ± 95.30

Data are means ± SD

treatment/posttreatment) were as follows: TC, 231.60 ± 6.65/324.30 ± 17.92; NC, 228.70 ± 7.09/321.70 ± 20.39; TE, 224.90 ± 11.13/322.90 ± 24.32; NE, 227.60 ± 8.85/317.60 ± 23.05 (Table 1). There was no significant difference in either body weight or muscle weight for any of the four groups (Table 1). There were no significant differences in the weights of EDL, GC, and SOL muscles between the taurine-treated groups and the corresponding nontreated groups.

Plasma lactic acid concentration

The plasma lactic acid concentrations of the exercised groups (TE, NE) were higher than those of the nonexercised groups (TC, NC) but not significantly so (Table 2). There also were no significant differences between the TE and NE (exercise) groups or the TC and NC (nonexercise) groups.

Plasma and skeletal muscle taurine concentration

There were no significant differences in the plasma taurine concentration of the four groups (Table 2). Taurine concentrations in all skeletal muscles of the taurine-treated groups (TC) were significantly higher than those of the untreated groups (NC) (Figs. 1–3), but the concentrations in the non-taurine-treated exercise groups (NE) were significantly decreased compared to those in the NC groups (Figs. 1–3). Taurine concentrations of the taurine-treated exercise groups (TE) were significantly higher than those of the NE groups in all muscles, despite their heavy exposure to running (Figs. 1–3).

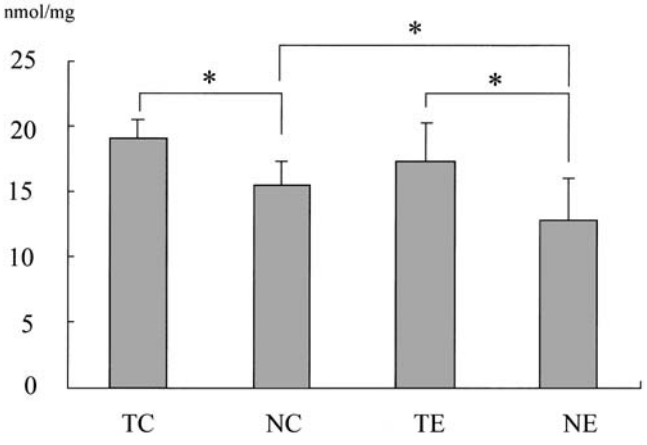

Fig. 1. Taurine concentration in skeletal muscle (extensor digitorum longus). Data are means ± SD. *There is a significant difference between groups (ANOVA, $P < 0.05$). *TC*, taurine administration and no exercise (control) group; *NC*, no taurine administration and no exercise (control) group; *TE*, taurine administration and exercise group; *NE*, no taurine administration and exercise group

Study 2

Running time to exhaustion

The duration of running time to exhaustion was 98.8 ± 17.5 min in the taurine-administered groups (ET) and 73.8 ± 8.2 min in the non-taurine-treated groups (EN). The difference between the taurine- and non-taurine-treated groups was significant.

Discussion

As shown in Figs. 1–3, taurine administration increased taurine concentrations in rat skeletal muscles. Many papers have shown that taurine administration increases the taurine concentration in plasma or internal organs,[6,9,16,23] but few have given the particulars of taurine concentration in skeletal muscles. Pierno et al.[24]

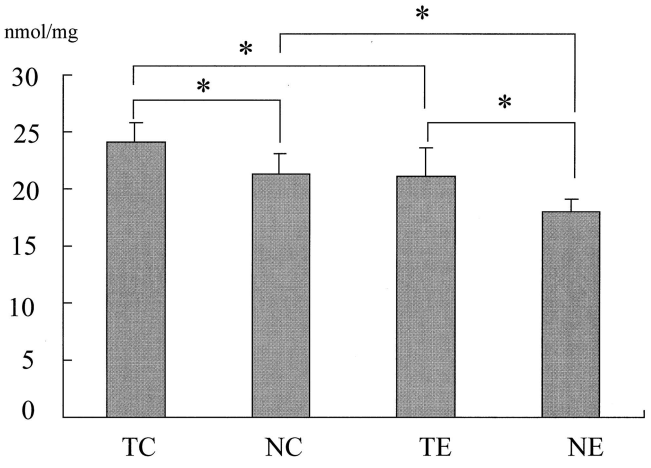

Fig. 2. Taurine concentration in skeletal muscle (gastrocnemius). Data are means ± SD. *There is a significant difference between the groups (ANOVA, $P < 0.05$)

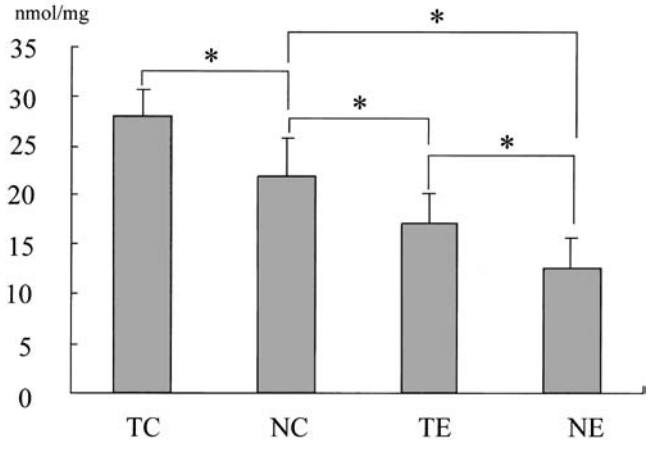

Fig. 3. Taurine concentration in skeletal muscle (soleus). Data are means ± SD. *There is a significant difference between the groups (ANOVA, $P < 0.05$)

showed that taurine administration increased the taurine concentration in aged rat skeletal muscles, but in this study the taurine concentrations in young rat skeletal muscles treated with oral taurine for 14 days were significantly higher than that in nontreated rats. The results of our research clarify that oral taurine administration increases the taurine concentration in normal rat skeletal muscles as well.

As shown in Figs. 1–3, taurine concentrations in rat skeletal muscles were significantly decreased in the exercised groups. Several articles have referred to the effects of taurine with exercise,[26–28] but few have reported on the taurine concentration in skeletal muscles with exercise. Only Matsuzaki et al.[22] have reported that the taurine concentration in rat skeletal muscles was decreased with exercise. The results in our study are in agreement with their report.

Cuisinier et al.[4] evaluated changes in urinary and plasma taurine concentrations with exercise in humans. In their study urinary taurine excretion increased immediately after running a marathon. There was excessive muscular damage that resulted in the release of taurine, which was then excreted in the urine. They concluded that the increase in taurine urinary excretion could be used as an indicator of muscle damage during exercise. They had been unable to identify the source of the taurine, but they guessed it might be released from the muscle. Results of our research may support their hypothesis.

As shown in Figs. 1–3, the administration of taurine reduced the decrease in taurine concentrations in rat skeletal muscles with exercise. As Cuisinier et al.[4] indicated, whether taurine supplementation would minimize such increases in urinary taurine excretion, reflecting muscle damage with exercise, is an interesting scientific question and merits investigation. Our paper makes no mention of changes in urinary taurine excretion because we did not evaluate it.

Examination of the experimental results clarified the following points: The administration of taurine reduced the decrease in taurine concentrations in rat skeletal muscles with exercise. In other words, the results of our research strongly support the hypothesis that the decrease in taurine concentration in skeletal muscles on exercise may be reduced by preexercise taurine administration.

Furthermore, as shown in study 2, the duration of running time to exhaustion was significantly increased by taurine administration. Several articles have referred to the effects of taurine on exercise,[26–28] and Baum and Weiss[2] reported the effects of taurine-containing drink on exhaustive bouts of endurance exercise in humans. Echocardiographic examinations were performed before and after exercise, and they reported increases in the stroke volume (SV) and fractional shortening (FS), resulting in an increase in cardiac contractility after exercise. In addition, compared to some other drinks, these increases were not observed in the caffeine-only group, but in they were in the group given a taurine plus caffeine-containing drink. They concluded that taurine alone or in combination with caffeine is responsible for the difference. They speculated that their results might explain why taurine improves maximal performance on exercise.

As in study 2, the duration of running time to exhaustion was significantly increased by taurine administration; so our examination convincingly supports their speculation. Furthermore, in study 1 the administration of taurine reduced the decrease in taurine concentrations in rat skeletal muscles on exercise. No one has reported the effects of taurine in respect to the taurine concentration in skeletal muscles on exercise, although

many papers have reported that taurine may act as a powerful membrane stabilizer[3,6,11,12] and may affect cellular hyperexcitability[5,10,18] in vitro. Furthermore, De Luca et al.[5] suggested that maintaining an appropriate level of intracellular taurine ensures muscle performance. Therefore, maintaining taurine concentrations in skeletal muscle might be one of the explanations for the improved maximal performance on exercise.

Conclusions

Taurine concentrations in rat leg skeletal muscles after endurance running and the duration of running time to exhaustion, with and without taurine administration, were studied. Taurine administration increased taurine concentrations in rat skeletal muscle. Taurine concentrations in skeletal muscle were significantly decreased in exercised groups without taurine administration. However, taurine administration reduced this decrease in skeletal muscles on exercise.

The duration of running time to exhaustion in taurine-administered groups was significantly increased (98.8 ± 17.5 min) compared to that for non-taurine-treated groups (73.8 ± 8.2 min), suggesting that peroral administration of taurine up-regulates physical endurance.

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