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ORIGINAL ARTICLE

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L-Carnitine and the recovery from exhaustive endurance exercise: a randomised, double-blind, placebo-controlled trial

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Abstract We hypothesised that L-carnitine could accelerate recovery from exhaustive exercise since increased blood L-carnitine concentrations elicit a vasodilation in isolated animal vessels as well as in patients with peripheral vascular or coronary artery disease during exercise. Twelve subjects received either 2 g L-carnitine or a placebo in a study which was double-blind and crossover in design. Two hours after administration, the subjects performed a constant-load exercise test (CET_1) cycling at their individual anaerobic threshold to exhaustion. Three hours later this test was repeated (CET_2). After 4–14 days, each subject performed the same cycling tests after having taken the other substance. Exercise times of the 12 subjects were identical with L-carnitine (CET_1: 21.3 ± 5.7 min; CET_2: 21.4 ± 5.3 min) and placebo (CET_1: 21.9 ± 6.2 min; CET_2: 20.4 ± 4.8 min). Also, heart rate, oxygen consumption, respiratory exchange ratio, and blood lactate concentration were identical. In conclusion, 2 g of L-carnitine taken 2 h before a first of two constant-load exercise tests had no influence on the second tests performed 3 h after the first test compared with placebo.

Keywords Constant-load exercise · Vasodilative effect · Endurance performance

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Introduction

It is still a matter of debate whether the administration of L-carnitine improves performance of intensive endurance exercise (Brass 2000). Most scientific studies rather question a positive effect of L-carnitine on a single exercise bout. The lack of an effect of L-carnitine on exercise performance is not surprising taking into consideration that oral L-carnitine administration increases blood L-carnitine concentration (e.g., Rizza et al. 1992) but does not affect the L-carnitine content of skeletal muscles (Wächter et al. 2002).

Besides an influence on a single exercise bout, L-carnitine administration might improve recovery from exercise (Karlic and Lohninger 2004; Volek et al. 2002). Better recovery from exhaustive exercise should improve the outcome of the next exercise bout performed on the same or on the following day. Besides its enhancing fat-burning effect, an increased blood L-carnitine concentration can elicit a vasodilation as shown by the following facts: the endothelium of isolated rat heart vessels normally loses its ability to regulate blood flow under hypoxic and ischemic conditions with the result that cellular damage occurs (Dauber et al. 1990; Hülsmann and Dubelaar 1992; Tsao and Lefer 1990). When L-carnitine is added, ability of the endothelial cells to regulate blood flow in ischaemia is prolonged and the occurrence of cellular damage is postponed (Hülsmann and Dubelaar 1992). In another study, L-carnitine enhanced the effects of vasodilators in isolated bovine arteries (Bettini et al. 1990). A vasoactive effect of L-carnitine is also evident in clinical studies: In patients with peripheral vascular disease, L-carnitine administration enhances the hyperemic response after ischaemia (Brevetti et al. 1989) and increases the walking distance (Brevetti et al. 1988; Signorelli et al. 2001). In patients with coronary artery disease, L-carnitine intake increases the coronary blood flow during exercise (Fujiwara et al. 1991) and prolongs exercise duration before ischaemic ECG changes occur (Bartels et al. 1996; Cherchi et al. 1985; Lagioia et al. 1992). These effects are evident

during exercise but absent at rest (Brevetti et al. 1989; Fujiwara et al. 1991). In addition, Giamberardino et al. (1996) found that L-carnitine exerts a protective effect against pain and damage from eccentric effort. Taken together, L-carnitine seems to improve the endothelial cells' ability to maintain an adequate blood flow during hypoxia or exercise.

Thus, we asked whether this vasodilative effect of L-carnitine might improve peripheral circulation in healthy subjects also. This effect could occur either towards the end of exhaustive constant-load endurance exercise, which is rather unlikely from what we discussed before, or during recovery from exhaustive exercise. A positive recovery effect of L-carnitine should improve a subsequent constant-load endurance exercise test. So far, only one study (Colombani et al. 1996) has investigated subsequent exercise with and without L-carnitine. Twenty-four hours after a marathon run no difference was found between the incremental test to exhaustion with or without L-carnitine. As a recovery time of 24 h is rather long and constant-load exercise is more appropriate than incremental exercise concerning possible vasodilatory effects, we investigated two exhaustive constant-load exercise tests in a randomised, double-blind study with and without the administration of L-carnitine on the same day. We found no positive recovery effect of L-carnitine in well-trained subjects.

Materials and methods

Subjects

Twelve healthy, well-trained men, age 25 ± 3 years (mean $\pm$ SD), body mass 71 ± 6 kg, height 178 ± 3 cm participated in the study. Procedures were in accordance with the Helsinki Declaration of 1975 and subjects were informed in detail about the protocols before they gave their written informed consent. Subjects were advised to continue their habitual training and to abstain from exhaustive training three days prior to testing. They noted every training in a diary, which was regularly controlled during the study.

Equipment

Cycling tests were performed on an electromagnetically braked cycle Ergometrics 900 (Ergoline, Bitz, Germany). Ventilation and gas exchange were measured with an OxyconGamma unit (Jaeger, Hoechberg, Germany) using a turbine for ventilation measurement, a paramagnetic analyser for O_2 determination, and an infrared absorption analyser for CO_2 measurement. Five-second averages of heart rate (HR) were recorded with a heart rate monitor (Polar, Kempele, Finland). Blood lactate concentration was determined from samples of ear lobe capillary blood using an enzymatic method (ESAT 6661, Eppendorf, Hamburg, Germany).

Protocols

First, the following preliminary test was performed: maximal power output (W_{max}), peak oxygen uptake $\left(\dot{V}_{O_2,peak}\right)$, and the ventilatory anaerobic threshold (AT_V) were determined with an incremental exercise test. The initial workload was 100 W. Every 2 min, the load was increased by 30 W until subjects were exhausted. Subjects were free to choose their personal favourite pedalling frequency within 60–100 min^{-1}. Once established, pedalling frequency had to be maintained throughout the cycling tests, i.e., during the incremental as well as during the constant-load exercise tests (see below). In all cycling tests, exhaustion was assumed either when subjects stopped cycling or when the pedalling frequency fell below 90% of the individually chosen frequency for more than 5 s despite a strong request of an investigator to increase the frequency.

After 4–7 days, subjects started with the main tests of the study consisting of two constant-load cycling endurance tests (CET, i.e., CET_1 and CET_2) on one day, and the same two CETs on another day 4–14 days later. CET_1 was performed in the morning, CET_2 followed after 3 h of rest. Two hours before each CET_1, subjects took an indistinguishable tablet (double-blinded) containing either 2 g L-carnitine or a placebo. The order of the L-carnitine or placebo administration was randomised. All CETs followed the same standardised protocol: the subjects started with 100 W for 5 min before the workload was set to the individual AT_V determined during the preliminary incremental exercise test. The subjects exercised with the individually determined workload until they were exhausted. Mean AT_V amounted to 294 ± 52 W ($84 \pm 5\%$ W_{max}) with a $\dot{V}_{O_2}$ of 58 ± 8 ml kg^{-1} min^{-1} $\left(91 \pm 7\% \ \dot{V}_{O_2,peak}\right)$. Subjects were allowed to monitor their pedalling frequency but were not given any additional information or encouragement. Heart rate and ventilatory parameters were measured continuously throughout the cycling test. Blood samples were taken every 2 min during the first 10 min of cycling, thereafter every 3 min, and at exhaustion in order to determine lactate concentration. Between CET_1 and CET_2 subjects drank Isostar (Wander, Berne, Switzerland), a sports drink with carbohydrates. The provided 0.9 g kg^{-1} h^{-1} carbohydrates led to a high glycogen resynthesis rate (vanHall et al. 1998). Other food intake was not allowed.

Calculations and statistical analysis

Before the order of L-carnitine and placebo administration was disclosed, inspection of raw data by analysis of variance (ANOVA) with repeated measures revealed that cycling times, HR, $\dot{V}_{O_2}$, R, lactate concentration, and subjective impression of performance were statistically not different between days 1 and 2. Therefore, we do not present these results.

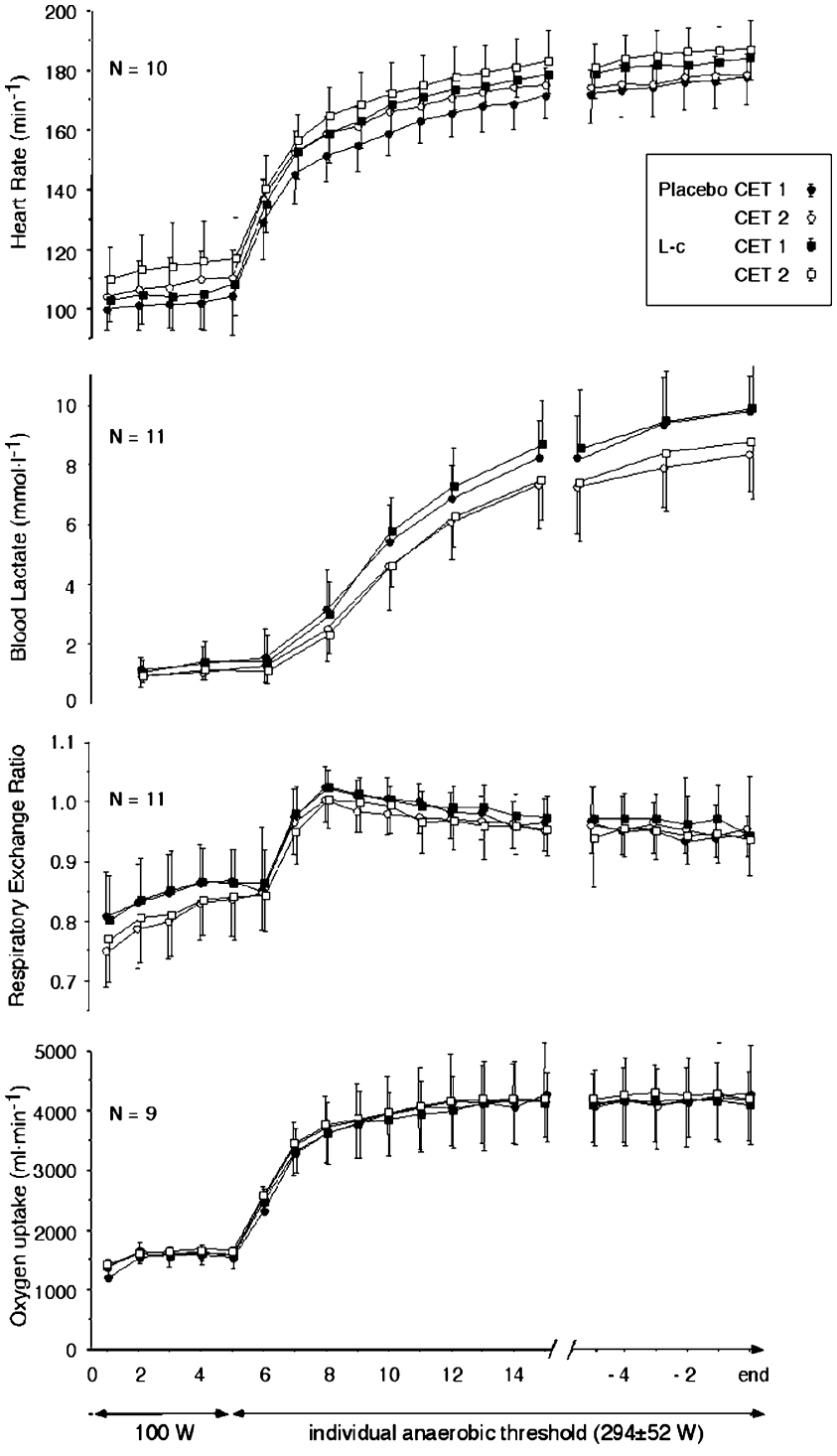

Fig.1 Heart rate, blood lactate concentration, respiratory exchange ratio, and oxygen uptake are plotted during cycling at 100 W (0–5 min after start) and at the anaerobic threshold (5–15 min after the start as well as the last 6 min before the end of cycling) in a constant-load exercise test (CET). No statistically significant differences at equal exercise times were found

After the disclosure of the substance order, the effects of L-carnitine were compared with the effects of placebo using ANOVA with repeated measures. Cycling times, HR, $\dot{V}_{O_2}$, R, and lactate concentration are presented as mean ± SD. Since the shortest CET lasted 15 min, HR, $\dot{V}_{O_2}$, R, and lactate concentration were compared during two separate periods: (1) 0–15 min after the beginning of cycling and (2) the last 6 min before the end of the cycling endurance tests. Because of missing values due to technical problems, the number of subjects included in each analysis varies (exact numbers are given in Fig. 1).

Results are presented as mean ± SD. Significance was accepted if $P < 0.05$.

Results

Preliminary testing

Subjects achieved a $\dot{V}_{O_2,peak}$ of 64 ± 9 ml kg^{-1} min^{-1}, a W_{max} of 346 ± 52 W, a HR_{max} of 185 ± 6 beats min^{-1}, and a maximal lactate concentration of 11.7 ± 3.6 mmol l^{-1} in the incremental exercise test.

CET results

Averaged cycling times of the CETs were similar: after L-carnitine administration, the 12 subjects exercised 21.3 ± 5.7 min in CET_1 and 21.4 ± 5.3 min in CET_2 ($P = 0.888$), respectively. After placebo administration, they exercised 21.9 ± 6.2 min in CET_1 and 20.4 ± 4.8 min in CET_2 ($P = 0.167$), respectively. Cycling time differences (CET_2 minus CET_1) were similar ($P = 0.152$) after L-carnitine ($+0.1 \pm 2.2$ min) and placebo (-1.5 ± 3.5 min). Lactate concentration of CET_1 showed a trend towards higher concentrations compared to lactate concentration of CET_2 irrespective of L-carnitine or placebo administration (Fig. 1; $P = 0.056$). HR ($P = 0.111$), $\dot{V}_{O_2}$ ($P = 0.986$), and R ($P = 0.194$) were similar.

Discussion

Two grams of L-carnitine improved neither CET_1 nor CET_2 compared to placebo in 12 well-trained male subjects. The similar CET_1 cycling times after L-carnitine and placebo administration confirmed that L-carnitine had no effect on a single performance as found in previous studies (Brass 2000). In addition, our new approach of repeating the intensive constant-load exercise bout within 3 h elicited no advantage of L-carnitine compared to placebo. $\dot{V}_{O_2}$, R, lactate concentration, and the subjective impression of performance were also not different between L-carnitine and placebo administration. Therefore, we speculate that 2 g of L-carnitine 2 h prior to CET_1 or about 5 h prior to CET_2 did not have a vasodilative effect important enough to improve exercise performance in either of these tests. Also, the lack of an improvement of CET_2 disproved an effect of L-carnitine during recovery in well-trained subjects.

One might wonder if a higher oral dose than 2 g of L-carnitine would alter the outcome of our study. This is not likely since the mucosal absorption of L-carnitine is saturated by a 2g dose (Harper et al. 1988). Furthermore, the 2g dose causes maximal blood L-carnitine for as long as 6 h (Lagioia et al. 1992). Therefore, it is unlikely that repetitive oral dosing at short intervals would lead to higher blood L-carnitine concentrations. In addition, we cannot exclude that a shorter interval between the two CETs in well-trained subjects or the same protocol in untrained subjects might give a different result.

In conclusion, 2 g of L-carnitine taken 2 h before a first of two constant-load exercise tests had no influence on the second tests performed 3 h after the first test compared with placebo.

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