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Carbohydrate supplementation increases intramyocellular lipid stores in elite runners

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A B S T R A C T

The objective was to determine the effects of carbohydrate (CHO) supplementation on exercise-induced hormone responses and post-training intramyocellular lipid stores (IMCL). Twenty-four elite male athletes (28.0 ± 1.2 years) were randomized to receive CHO (maltodextrin solution) or zero energy placebo solution (control group). The high-intensity running protocol consisted of 10 × 800 m at 100% of the best 3000-m speed (Vm3 km) and 2 × 1000 m maximal bouts in the morning and a submaximal 10-km continuous easy running in the afternoon of day 9. IMCL concentrations were assessed by ^{1}H-MRS before (–day 9) and after training (day 9) in soleus (SO) and tibialis anterior (TA) muscles. Blood hormones were also measured before, during, and post-exercise. The percent change (Δ%) in TA-IMCL was higher in the CHO group (47.9 ± 24.5 IMCL/Cr) than in the control group (–1.7 ± 13.1, respectively) ($P = .04$). Insulin concentrations were higher in the CHO group post-intermittent running compared to control ($P = .02$). Circulating levels of free fatty acids and GH were lower in the CHO group ($P > .01$). The decline in performance in the 2nd 1000-m bout was also attenuated in this group compared to control ($P < .001$ and $P = .0035$, respectively). The hormonal milieu (higher

Abbreviations: CHO, carbohydrate; IMCL, intramyocellular lipids; EMCL, extramyocellular lipids; ^{1}H-MRS, magnetic resonance spectroscopy; Cr, creatine; FFA, free fatty acids; GH, growth hormone; TA, tibialis anterior; SO, soleus; DXA, dual-energy X-ray absorptiometry; Vm3 km, mean 3 km velocity; VO_{2max}, maximal oxygen consumption.

Author contributions: Maysa Vieira de Sousa substantially contributed to the writing of the manuscript, experimental design, data acquisition and discussion, especially in the area of applied nutrition and metabolism. Herbert Gustavo Simões conducted a general review of the final manuscript and contributed to the statistical analysis. Claudio Campi contributed to the conception and design of the study and to the ^{1}H-MRS data acquisition. Maria Concepción García Otaduy contributed to the ^{1}H-MRS data acquisition and to the analysis and interpretation of metabolites using the LCModel software. Carlos Eduardo Negrão contributed to the analysis and interpretation of the maximal oxygen consumption data using a Sensor Vmax metabolic cart in the Cardiovascular Rehabilitation and Exercise Physiology Unit of InCor, HC FMUSP. Rosa Maria Rodrigues Pereira contributed to the acquisition, analysis and interpretation of the dual-energy X-ray absorptiometry data. Klavs Madsen substantially contributed to the drafting of the manuscript and statistical analysis. Maria Elizabeth Rossi Silva contributed to the conception and design of the study, drafting of the manuscript and discussion, particularly in the area of endocrine sciences.

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insulin and lower GH levels) in the CHO group, together with unchanged free fatty acid levels, probably contributed to the increased IMCL stores. This greater energy storage capacity may have improved post-exercise recovery and thus prevented performance deterioration.

1. Introduction

Distance runners and athletes such as football, soccer, tennis, basketball and field hockey players usually perform high-intensity intermittent exercise to develop their anaerobic endurance capacity [1]. These training sessions are frequently performed during an overload period and depend on carbohydrates (CHO) as the primary energy source. However, consecutive days of intensive and prolonged training sessions, if combined with insufficient intake of CHO, can reduce muscle glycogen stores and physical performance [2-5].

Skeletal muscle contains significant quantities of intramyocellular lipids (IMCL), which can act as a substrate during prolonged exercise and play a concomitant role in glycogen sparing [6,7]. However, there is no evidence supporting a possible relationship between CHO supplementation, athletic performance and IMCL content after a period of intense exercise training [8]. Studies investigating the role of IMCL in high-intensity training and running performance are scarce. Moreover, the use of IMCL as an energy substrate during exercise is controversial and most studies have produced conflicting results, probably due to the use of traditional muscle sample biopsy methods [9,10]. In this respect, De Bock et al [11] were unable to detect an exercise-induced IMCL decrease using muscle biopsies. In that study, between-assay and within-assay variability (~20%–25%) was high as a result of erroneous incorporation of adipose and extramyocellular lipid (EMCL) components in the biopsy sample.

Magnetic resonance spectroscopy (^{1}H-MRS) permits the identification of both IMCL and EMCL [12,13]. This method is noninvasive and provides more reproducible results than traditional biopsy methods [10,14]. To our knowledge, this technique has not been applied to determine the effects of CHO supplementation on IMCL content during intensive training in highly trained athletes. Therefore, the primary objective of the present study was to compare IMCL concentrations in tibialis anterior (TA) and soleus (SO) muscles of well-trained runners before and after a training protocol consisting of 8 days of a microcycle of overload training, followed by a high-intensity intermittent running protocol. An additional aim was to investigate the effect of these interventions on blood hormones including testosterone and cortisol. We hypothesized that CHO supplementation would be associated with a better hormonal response to high-intensity running and with higher post-training IMCL stores. Furthermore, these responses would permit faster recovery between training sessions, prevent performance deterioration, and preserve the anabolic status of the athletes.

2. Methods

2.1. Subjects and study design

Twenty-four competitive male endurance runners (28.0 ± 1.2 years) were recruited to participate in this study, which was approved by the Human Research Ethics Committee of the University Hospital, University of São Paulo Medical School (HC-FMUSP). These volunteers have been training for the last 8.6 ± 1.1 years and regularly participate in state, national and international competitions. After signing an informed consent form, the runners participated in pre-trial testing which consisted of the collection of the 1st blood sample (−9 day baseline), determination of IMCL stores by noninvasive ^{1}H-MRS, determination of body composition by dual energy X-ray absorptiometry (DXA), measurement of maximal oxygen consumption, and a 3-km performance test on the running track. These tests are described below. The volunteers were then randomly assigned to two groups matched for maximal oxygen consumption (VO_{2max}), body weight, and age (Table 1).

A double-blind intervention (CHO supplementation) trial using matched groups was conducted over a period of 8 days of intensive training, which started 4 days after the pre-trial testing. Fig. 1 provides an overview of the study design.

2.2. Pre-trial testing

The athletes underwent a 3-km running performance test for calculation of the mean velocity (Vm3km) and the velocity at which runners should exercise during the intermittent sessions as proposed by Simões et al [15]. The volunteers were also submitted, on a different day, to an incremental running test on a treadmill until exhaustion in order to determine VO_{2max}. This parameter was determined with a Sensor Vmax metabolic cart in the Cardiovascular Rehabilitation and Exercise Physiology Unit, InCor, HC-FMUSP. Table 1 shows the results of the pre-trial testing obtained for all subjects.

2.3. Dietary intervention and monitoring during intensive training

The athletes received a food diary to record the types and quantities of all foods consumed before and after the intensive training protocol (days 1–9). A handbook of information containing photographs of portion sizes and food types was given to each volunteer to help in keeping the food diary. In addition to the information found in the food diary and handbook, the volunteers received individual guidance on how to record food intake. The nutritional calculations were made using the Decision Support in Nutrition software, version 2.5 (UNIFESP).