

The effect of acute exercise session on thyroid hormone economy in rats

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Abstract

The hypothalamic–pituitary–thyroid axis is affected by acute exercise, but the mechanisms underlying thyroid function changes after exercise remain to be defined. The aim of this study was to elucidate the effects of a session of acute exercise on the treadmill at 75% of maximum oxygen consumption on thyroid function of rats. Male Wistar rats were divided into five groups: control (without exercise), and killed immediately after (0 min) or 30, 60, and 120 min after the end of the exercise session. A significant increase in serum tri-iodothyronine (T₃) occurred immediately after the exercise, with a gradual decrease thereafter, so that 120 min after the end of the exercise, serum T₃ was significantly lower than that in controls. Total thyroxine (T₄) increased progressively reaching values significantly higher than that in the control group at 120 min. T₃/T₄ ratio was

significantly decreased 60 and 120 min after the exercise, indicating impaired T₄-to-T₃ conversion. Liver type 1 deiodinase activity (D1) significantly decreased at 60 and 120 min, while pituitary D1 increased progressively from 30 to 120 min after the exercise, and thyroid D1 was increased only immediately after the end of the exercise. Brown adipose tissue (BAT) type 2 deiodinase activity (D2) was significantly lower at 30 min, but pituitary D2 remained unchanged. No change in serum thyrotropin was detected, while serum corticosterone was significantly higher 30 min after the exercise. Our results demonstrate that decreased liver D1 and BAT D2 might be involved in the decreased T₄-to-T₃ conversion detected after an exercise session on the treadmill.

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Introduction

Thyroid hormones act on multiple metabolic processes, influencing the concentration and activity of numerous enzymes, the metabolism of substrates, vitamins and minerals, and the response of target tissues to several hormones (Larsen *et al.* 1992). These hormones have critical roles in cell differentiation, growth, and regulation of oxygen consumption and thermogenesis (Yen 2001). Significant changes in energy metabolism occur during the exercise and are maintained for some hours thereafter, revealing challenges for energetic homeostasis. Exercise corresponds to a physical stress followed by some endocrine modifications that occur in order to counterbalance its effects on thermogenesis and substrate metabolism (Mastorakos & Pavlatou 2005). The influence of exercise on thyroid function is controversial and seems to depend on the intensity and duration of the training protocol (Rone *et al.* 1992).

The main thyroid gland hormonal secretion is thyroxine (T₄), which is then deiodinated to generate tri-iodothyronine (T₃), the most active thyroid hormone (Maia *et al.* 1995, Yen 2001). Types I, II, and III iodothyronine deiodinases (D1, D2,

and D3 respectively) regulate T₃ production and clearance via removal of specific iodine atoms from the precursor molecule T₄ or T₃ itself. D1 and D2 catalyze the 5'-deiodination of T₄ and are considered activating enzymes due to subsequent T₃ production. The role of D3 is to inactivate T₄ and T₃ through their 5-deiodination (Visser 1994, Bianco *et al.* 2002, Bianco & Kim 2006). Thus, deiodinases can acutely regulate serum T₄ and T₃ levels and also their tissue availability through their activation or inactivation.

Acute and chronic exercises elicit different effects in rats: serum levels of thyroid hormones increase after acute exercise, while the same is not observed in the majority of studies with chronic exercise protocols (Mastorakos & Pavlatou 2005). Wirth *et al.* (1981) observed an increase in total T₃, total T₄, and T₃/rT₃ ratio in rats immediately after the exercise for 20 min in treadmill, when compared with sedentary rats. Another study, using strenuous acute swimming exercise showed increased serum TSH levels, decreased T₃ and T₄ together with a blunted thyroid response to TSH stimulation immediately after the exercise protocol and a decrease in brown adipose tissue (BAT) D2 activity (Sullo *et al.* 2003). In humans, an acute aerobic exercise performed at 70% of

maximum heart rate induced significant increases in total T₃ and T₄, free T₃ and T₄, and thyrotrophin (TSH); at 90% of maximum heart rate, the levels of total T₄, free T₄, and TSH were also increased, but serum T₃ and free T₃ decreased significantly (Ciloglu *et al.* 2005). Increased serum thyroid hormones immediately after the exercise might reflect catecholamine stimulation of hormonal secretion since a concerted action of the adrenergic system and the thyroid axis might correspond to an important physiological response to increased metabolic demands. On the other hand, high thermogenesis that takes place during the exercise could trigger mechanisms involved in the decrease in serum thyroid hormone levels, in order to prevent significant increases in body temperature.

These previous studies show contradictory results possibly due to the different protocols of exercise intensity used, but could also reflect differences due to the time after the exercise when the animals or humans have been evaluated. Thus, a time-course study might better define the changes that occur in the pituitary–thyroid hormone axis in exercised animals. Hence, the aim of the present study was to elucidate the effects of a session of acute exercise on thyroid function just after the exercise protocol and during the recuperation period (30, 60, and 120 min). Since thyroid gland economy was affected by the exercise protocol used, we intended to further analyze proteins involved in thyroid hormone biosynthesis, as well as peripheral and central iodothyronine deiodinases, in order to try to elucidate the mechanisms involved in the changes that occur after the exercise.

Materials and Methods

Experimental groups

Adult male Wistar rats weighing 200–250 g were maintained in an animal room with controlled lighting (12 h light:12 h darkness cycle) and temperature (23/24 °C). The Institutional Committee for Evaluation of Animal Use in Research (CAUAP) approved the study, according to the International Guiding Principles for Biomedical Research Involving Animals (Geneva, Switzerland). The animals were submitted to an exercise protocol that consisted of 20 min treadmill running at 75% of maximum oxygen consumption velocity (VVO₂) and a constant slope of 10°. To determine VVO₂, the animals were adapted to run 2–3 days at 17 cm/s during 5 min. After the adaptation period, each rat was submitted to a maximum exercise test. We modified a ramp test for maximal treadmill running to measure the aerobic capacity of the animals (Henderson *et al.* 2002), as described previously (Werneck-de-castro *et al.* 2006). Trial began at a starting velocity of 17 cm/s and a constant slope of 10°. Treadmill velocity was then increased by 2 cm/s every 2 min and the rats ran until exhaustion (when the animals stayed in the steel grids despite increasing stimuli shocks). Maximum velocity was considered if animals completed at least 75% of the stage. Mean room

temperature was maintained at 22 °C and a stainless steel grid at the end of the treadmill provided an electrical stimulus to keep the rats running. All tests and exercise protocol were carried out with a motor-driven treadmill chamber (Panlab – LSI Leticia model, Sao Paulo, Brazil) and VO₂ was measured by an oxygen analyzer (Sable Systems FC-1B O₂, Las Vegas, NV, USA) at a constant flow rate of 500 ml/min. VO₂ consumption was obtained by the following formula: $VO_{2max} = ((\%O_2 \text{ max} - \%O_2 \text{ basal}/100) \times 500 \text{ ml/min})/\text{weight (kg)}$ (Werneck-de-castro *et al.* 2006).

After the experimental period, the animals were killed by decapitation and the blood was collected for hormone concentration analyses. Serum was obtained after centrifugation of the blood at 1500 g for 15 min and stored at –20 °C. Rat tissues were dissected out, weighed, and stored in liquid nitrogen until processing for enzymatic measurements.

RIA for total T₃ and T₄, TSH, and corticosterone

The measurement of serum TSH levels was carried out using a specific RIA for rat TSH obtained from the National Institute of Diabetes, Digestive and Kidney Diseases (NIDDK, Bethesda, MD, USA), and expressed in terms of reference preparation 2.

Serum total T₃ and T₄ concentrations were measured using commercial kits (T₃, DLS-3100 Active; T₄, DLS-3200 Active; TX, USA), based on the presence of specific antibodies adhered to the internal surface of propylene tubes. Rat hormone-free serum was used in the standard curves for total T₃ and T₄ and TSH. All the procedures were carried out following the recommendations of the kit.

The levels of serum corticosterone were measured by specific RIA for rats and mice (MP Biomedicals, LLC, Solon, OH, USA).

Thyroperoxidase (TPO) iodide oxidation activity

For extraction of TPO, each rat thyroid gland was homogenized in 50 mM Tris–HCl buffer (pH 7.2) and centrifuged at 200 000 g, 4 °C for 35 min. The pellet was suspended in digitonin (1%, w/v; Sigma) and stored for 24 h at 4 °C. After this incubation period, centrifugation was repeated in the same conditions, and the supernatant containing solubilized TPO was stored at –20 °C (Moura *et al.* 1989, Carvalho *et al.* 1994).

TPO iodide oxidation assay (Nakashima & Taurog 1978, Pommier 1978, Moura *et al.* 1989, Carvalho *et al.* 1994) was performed as follows: 1.0 ml of 50 mM sodium phosphate buffer (pH 7.4) containing 24 mM KI and 11 mM glucose was placed in a 2 ml cuvette; the volume of the solubilized TPO added was 10 to 100 µl, and the final volume was adjusted to 2.0 ml with 50 mM sodium phosphate buffer (pH 7.4). The assay was started by the addition of 10 µl of 0.1% (w/v) glucose oxidase (Boehringer Grade I). The increase in absorbance at 353 nm ($\Delta A_{353 \text{ nm}}/\text{min}$, triiodide formation)

was followed for 2 min on a Hitachi spectrophotometer (U-3000). The $\Delta A_{353 \text{ nm}}/\text{min}$ was determined from the linear portion of the reaction curve and corrected for a blank determined in the absence of TPO. One unit of iodide oxidation activity is defined as $\Delta A_{353 \text{ nm}}/\text{min} = 1.0$. The activity was related to protein concentration in the enzyme preparation. Protein concentration was measured by the method of Bradford (1976).

D1 assay

One pituitary gland, one thyroid gland, or 25 mg of liver were homogenized in 0.1 M sodium phosphate buffer containing 1 mM EDTA, 0.25 M sucrose, and 10 mM dithiothreitol (pH 6.9). Homogenates (150 μg of protein for pituitary samples and 30 μg of protein for liver and thyroid) were incubated in triplicate for 1 h at 37 °C with 1 μM [^{125}I] rT₃ (Perkin–Elmer Life and Analytical Sciences, Boston, MA, USA), and 10 mM dithiothreitol (USB/Invitrogen) in 100 mM potassium phosphate buffer containing 1 mM EDTA (pH 6.9) in a reaction volume of 300 μl , as described previously (Berry *et al.* 1991, Fortunato *et al.* 2006). Blank incubations were carried out in the absence of protein. The reaction was stopped at 4 °C in an ice bath with the addition of 100 μl fetal bovine serum (Cultilab, Campinas, Brazil) and 200 μl trichloroacetic acid (50%, v/v) followed by vigorous agitation. The samples were centrifuged at 8 000 g for 3 min and the supernatant was collected for the measurement of ^{125}I liberated during the deiodination reaction. A specific D1 inhibitor (1 mM propylthiouracil (PTU)) was added to completely block deiodinase activity; thus, in our assay conditions, only D1 activity was measured.

D1 activity was related to the protein concentration in the homogenates. Protein concentration was measured by the method of Bradford (1976), after incubation of homogenates with NaOH (2.5 M).

D2 assay

One pituitary gland or 25 mg BAT were homogenized in 0.1 M sodium phosphate buffer containing 1 mM EDTA, 0.25 M sucrose, and 10 mM dithiothreitol (pH 6.9). Homogenates (50 μg protein for pituitary and 150 μg for BAT samples) were incubated in triplicate, 2 h for pituitary and 3 h for BAT, at 37 °C with 1 nM [^{125}I]T₄ (Perkin–Elmer Life and Analytical Sciences), 1 mM PTU, and 20 mM dithiothreitol (USB) in 100 mM potassium phosphate buffer containing 1 mM EDTA (pH 6.9) in a reaction volume of 300 μl , as described previously (Berry *et al.* 1991, Fortunato *et al.* 2006). Blank incubations were carried out in the absence of protein. The reaction was stopped at 4 °C in an ice bath with the addition of 100 μl fetal bovine serum (Cultilab) and 200 μl trichloroacetic acid (50%, v/v) followed by vigorous agitation. The samples were centrifuged at 8 000 g for 3 min and the supernatant was collected for the measurement of ^{125}I liberated during the deiodination reaction. D2 activity was related to the protein concentration in the homogenates.

Protein concentration was measured by the method of Bradford (1976), after incubation of homogenates with NaOH (2.5 M).

Short-term radioiodide uptake: sodium–iodide symporter (NIS) activity

We have previously demonstrated that the measurement of radioiodide uptake 15 min after ^{125}I -NaI administration (short-term iodide uptake) reflects iodide transport through the NIS without the influence of *in vivo* thyroid iodine organification activity (Ferreira *et al.* 2005). Thus, in order to evaluate the *in vivo* NIS function using thyroid radioiodine uptake measurements without the influence of the TPO iodine organification reaction, the animals received Na- ^{125}I (250 000 c.p.m., i.p., Amersham) 15 min before decapitation. The thyroids were removed and weighed. The radioactivity of the thyroid glands was measured using a γ -counter (LKB, Mount Waverley, Brazil) and expressed as percentage of total ^{125}I injected per mg of thyroid.

Statistical analyses

The results are expressed as mean \pm S.E.M. Data from total T₃, total T₄, corticosterone, T₃/T₄ ratio, and deiodinase activities were analyzed by one-way ANOVA test followed by Dunnett's multiple comparison tests. The results of serum TSH, NIS, and TPO were analyzed by Kruskal–Wallis test followed by Dunnett's multiple comparison tests. Statistical analyses were done using the software GraphPad Prism (version 4, GraphPad Software, Inc., San Diego, CA, USA). $P \leq 0.05$ was considered statistically significant.

Results

Serum total T₃, T₄, TSH, and corticosterone concentrations

Immediately after the exercise, a significant increase in serum total T₃ was detected ($P < 0.05$ versus control); however, at 30 min after the exercise, serum T₃ returned to the basal levels and continued to decrease thereafter, reaching values that were statistically lower than controls at 120 min ($P < 0.05$) (Fig. 1A). Serum T₄ was significantly higher at 120 min after the end of the exercise in comparison with the control and 30 min groups ($P < 0.01$) (Fig. 1B). The T₃/T₄ ratio was significantly lower at 60 min in comparison with the control group ($P < 0.05$) and further decreased at 120 min, differing from all the other groups (120 min versus C = $P < 0.001$; 0 = $P < 0.01$; 30 = $P < 0.001$; 60 min = $P < 0.05$) (Fig. 1C). These data indicate a decrease in the T₄-to-T₃ conversion during the period of adaptation to exercise. Serum TSH did not change significantly after this acute exercise protocol (Fig. 1D). Serum levels of corticosterone were significantly higher at 30 min after the exercise session when compared with the control ($P < 0.05$) and normalized thereafter (Fig. 2).

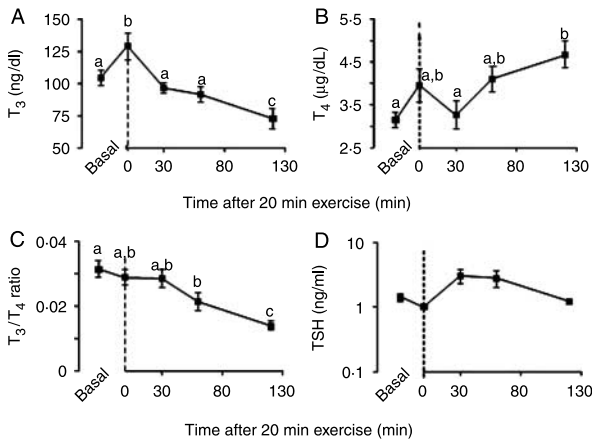


Figure 1 The effect of an acute exercise on (A) serum total T₃, (B) total T₄, (C) T₃/T₄ ratio, and (D) TSH in different times after the protocol. The number of animals for each group was control=12, 0=11, 30=11, 60=11, and 120=12. Data are shown as mean ± s.e.m.; different letters indicate statistically significant differences.

TPO activity

TPO is a key enzyme in the biosynthesis of thyroid hormones, and an alteration on its activity could account for changes in T₄ and T₃ biosynthesis. Corroborating with previous findings that discard acute changes in TPO activity, the protocol of an intense acute exercise did not modify the activity of this enzyme (C=3.53 ± 0.71, n=9; 0 min=3.55 ± 0.30, n=8; 30 min=3.56 ± 0.17, n=8; 60 min=4.30 ± 0.38, n=10; 120 min=3.65 ± 0.38 U/mg protein, n=9).

Short-term radioiodide uptake: NIS function

Although the NIS function might be acutely modulated by several factors, no changes in the short-term radioiodide uptake were seen among the groups (C=0.036 ± 0.002, n=11; 0 min=0.036 ± 0.003, n=12; 30 min=0.036 ± 0.005, n=8; 60 min=0.041 ± 0.009, n=9; 120 min=0.043 ± 0.006% I¹²⁵

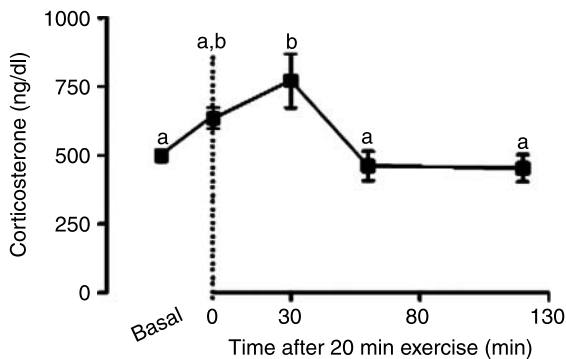


Figure 2 The effect of an acute exercise on serum corticosterone in different times after the protocol. The number of animals for each group was control=12, 0=11, 30=11, 60=11, and 120=12. Data are shown as mean ± s.e.m.; different letters indicate statistically significant differences.

per mg thyroid, n=11). Since thyroid iodide uptake did not change significantly, our data indicate no functional changes in thyroid hormone biosynthesis pathways after the acute exercise protocol. T₃ increase detected immediately after the exercise might be secondary to thyroid secretion stimulation by catecholamine and/or to increased peripheral production of T₃.

D1 enzymatic activity

Thyroid D1 activity was significantly increased at the end of the exercise when compared with the control group (Fig. 3C), but normalized thereafter, which could explain,

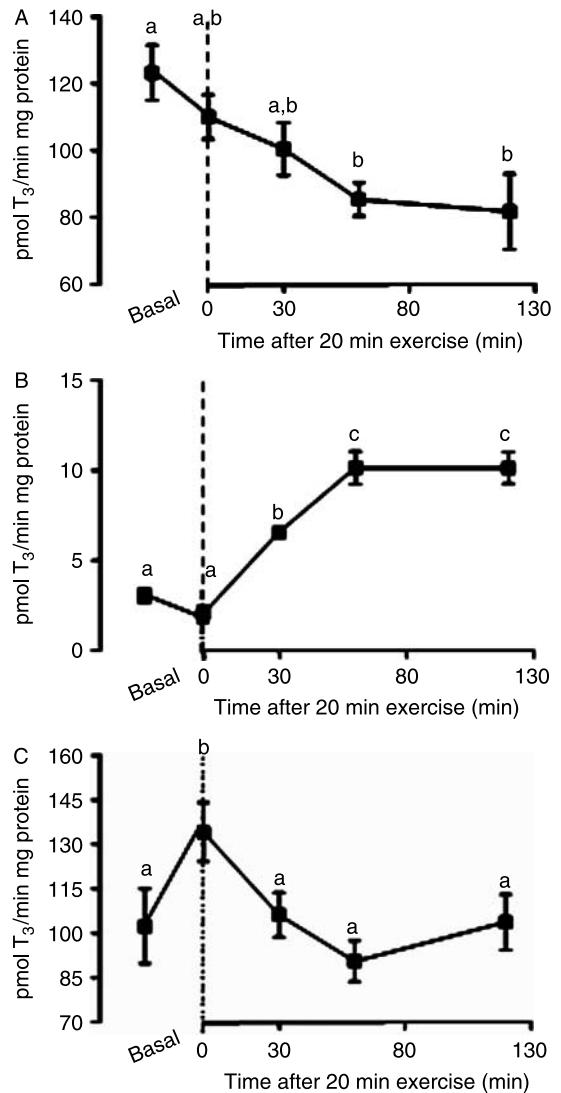


Figure 3 The effect of an acute exercise on iodothyronine deiodinase type 1 activity in (A) liver, (B) pituitary, and (C) thyroid in different times after the protocol. The number of animals for each group was control=10, 0=11, 30=10, 60=11, and 120=11. Data are shown as mean ± s.e.m.; different letters indicate statistically significant differences.

at least in part, the rapid increase in serum T_3 observed. Immediately after the end of the exercise session, hepatic D1 activity was normal and then progressively decreased, reaching significantly lower values in comparison with the control group, at 60 and 120 min ($P < 0.01$) (Fig. 3A), a mechanism probably involved in the progressive serum T_3 decrease after the end of the exercise. Conversely, pituitary D1 activity significantly increased at 30, 60, and 120 min in comparison with the control ($P < 0.01$) and 0 min groups ($P < 0.001$); at 60 and 120 min, pituitary D1 was also significantly increased when compared with 30 min (Fig. 3B).

D2 enzymatic activity

BAT D2 activity decreased significantly 30 min after the end of the exercise session, when compared with control ($P < 0.01$), 0 ($P < 0.05$) and 120 min group ($P < 0.001$). BAT D2 activity was only restored to the control levels 120 min after the end of the exercise ($P < 0.01$) (Fig. 4A). Pituitary D2 activity did not change significantly (Fig. 4B). The decrease in BAT D2 activity could also contribute to the decreased serum T_3 after the exercise.

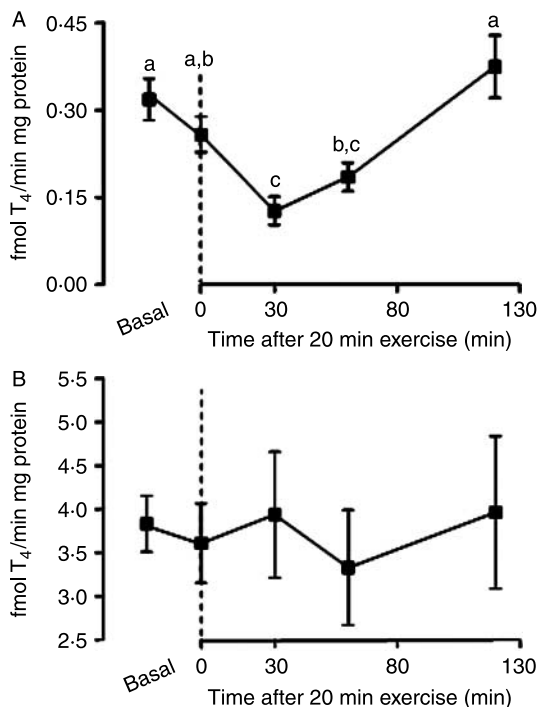


Figure 4 The effect of an acute exercise on iodothyronine deiodinase type 2 activity on (A) brown adipose tissue and (B) pituitary in different times after the protocol. The number of animals for each group for BAT was control = 10, 0 = 10, 30 = 9, 60 = 11, 120 = 9, and for pituitary was $n = 6$ for all groups. Data are shown as mean \pm S.E.M.; different letters indicate statistically significant differences.

Discussion

Exercise is a stressful situation that challenges body homeostasis, so that the organism has to reestablish a new dynamic equilibrium in order to minimize cell damage. One of the systems affected is the hypothalamic–pituitary–thyroid axis (Mastorakos & Pavlatou 2005). While increased metabolic demands occur during exercise, higher thermogenesis is counterbalanced by mechanisms that are activated in order to dissipate heat-like vasodilatation. Both metabolism of substrates and thermogenesis are tightly regulated by thyroid hormones, and we show herein some of the mechanisms involved in thyroid function alterations that occur immediately after the exercise and for some hours thereafter. The intensity, duration, and type of exercise may elicit different patterns of response, and thus the results obtained are contradictory. The utilization of experimental animals to clarify these questions is useful to discard variables that are commonly found in human subject studies, apart from the possibility of studying the mechanisms involved in the hormonal changes observed.

In our study, the rats were submitted to an exercise session at 75% of maximal oxygen consumption, during 20 min, and the thyroid function was assessed immediately after and 30, 60, and 120 min after the end of the exercise protocol. Serum total T_3 levels were significantly higher immediately after the end of the exercise, while serum total T_4 and TSH levels were not altered. These findings are in agreement with the results found by Límanová *et al.* (1983), in a study with untrained young subjects, and those by Wirth *et al.* (1981), who showed an association of increased T_3 with an augmented norepinephrine response (Wirth *et al.* 1981, Límanová *et al.* 1983). Increased serum T_3 immediately after the end of an acute exercise session is probably caused by the adrenergic stimulus that occurs during the exercise, since exercise protocols at 60% of maximum oxygen capacity or greater are accompanied by large increases in circulating catecholamine levels, and the ability of adrenergic stimulus to increase basal thyroid hormone secretion is well established (Ahren *et al.* 1986, Coggan *et al.* 2000). However, in other studies, the levels of T_3 , T_4 , and TSH at the end of the exercise were unaffected or decreased by the exercise protocol. While Sullo *et al.* (2003) found a decrease in serum total T_3 and T_4 concentrations and an increase in TSH in rats at the end of a strenuous swim exercise. Krotkiewski *et al.* (1984) in a study with obese women showed no changes in these hormone levels. The divergence among these works is probably due to the different exercise protocols executed, as we know that catecholamine secretion depends on the intensity and duration of exercise.

TPO and NIS are two important proteins involved in the biosynthesis of thyroid hormones; while TPO is the enzyme that catalyzes the formation of T_3 and T_4 , NIS is a symporter that transports two sodium ions along with one iodide into the follicular thyroid cell (Carvalho *et al.* 1994,

Eskandari *et al.* 1997). In our study, exercise had no effect on TPO and the NIS function. This is the first report evaluating the effect of acute exercise on these parameters. Rosołowska-Huszcz (1998) studied the effect of different intensities of 5-week exercise in rats and have shown a decrease in TPO activity at the higher intensities (Rosołowska-Huszcz 1998). The primary hormonal stimulator of TPO and NIS is TSH (Gerard *et al.* 1988, Uyttersprot *et al.* 1997, Ferreira *et al.* 2005). Serum TSH was not acutely modulated by the exercise protocol used herein, and the activities of TPO and NIS did not change, discarding a possible acute effect of catecholamines or other hormonal regulators on these parameters after intense acute exercise.

Krotkiewski *et al.* (1983) evaluated the changes in thyroid hormones at 30, 60, and 90 min after the end of the exercise in obese women and have shown a progressive decrease in serum TSH along with a progressive increase in serum total T_4 , with no significant changes in serum T_3 levels. In our study, the levels of serum T_3 progressively decreased after the end of the exercise, reaching values 30% lower than control levels 2 h after the end of the exercise, while serum T_4 increased progressively, indicating impaired T_4 -to- T_3 conversion after the end of the exercise.

The T_4 -to- T_3 conversion is catalyzed by iodothyronine deiodinase types 1 and 2 (D1 and D2 respectively). It is believed that about 80% of circulating T_3 is formed from the T_4 molecule. Type 1 iodothyronine deiodinase enzyme (D1) that is widely expressed in tissues such as liver, kidney, thyroid, and pituitary provides part of the plasma T_3 through the 5'-deiodination of the T_4 molecule (Bianco *et al.* 2002). In rats, the extra-thyroidal deiodination reaction is responsible for about 60% of the circulating T_3 , and both peripheral D1 and D2 seem to equally contribute to T_3 generation, while the remaining 40% come from thyroid secretion (Bianco *et al.* 2002). There are few studies about the regulation of deiodinases after acute exercise, but no time-course studies showing the activity of these enzymes after an acute exercise protocol have been reported so far.

As we show herein, the increased serum T_3 that occurs immediately after the exercise is accompanied by a significant increase in thyroid D1 activity, an enzyme that is involved in thyroid T_4 -to- T_3 conversion. Liver D1 activity progressively decreased after the end of the exercise protocol, and BAT D2 activity was significantly reduced at 30 min after the exercise. At 30 min after the end of the exercise, serum corticosterone levels reached its maximum concentration. It is known that plasma glucocorticoids can decrease liver D1 activity (Bianco *et al.* 2002). Both the decrease in BAT D2 at 30 min and decreased liver D1 might contribute to the lower serum T_3 levels during the recuperation period after the exercise.

A previous report has described decreased BAT D2 activity in rats acutely submitted to a strenuous swimming protocol (Sullo *et al.* 2003). In our study, BAT D2 activity decreased 30 min after the end of the exercise, but at 120 min its activity was restored. It is noteworthy that BAT D2 is up-regulated by catecholamines during cold exposure, but its regulation

in BAT seems to be far more complex (Obregon *et al.* 1987). Cold exposure significantly increases D2 activity by the adrenergic pathway, but ob/ob mice that have high serum corticosterone levels show defective induction of BAT D2 during cold acclimation (Kates & Himms-Hagen 1990). In our study, 30 min after the exercise protocol, we detected low BAT D2 activity and high serum corticosterone levels. Corticosterone levels normalized after 60 min, and BAT D2 activity also returned to the normal value, suggesting a negative regulation of D2 by corticosterone notwithstanding high catecholamine stimulus. Since BAT D2 plays an important role in the intracellular T_4 -to- T_3 conversion, the decrease in D2 during the exercise recuperation period is probably important for the control of BAT thermogenesis after the exercise.

Pituitary D1 activity increased 30 min after the exercise and remained high until 120 min. Since somatotrophs express high D1 activity and correspond to ~50% of the pituitary cell population, the induction of pituitary D1 might reflect the activation of this cell type during the exercise. However, further studies are needed in order to evaluate the importance of pituitary D1 activation on the stimulation of GH secretion that might occur after the exercise.

In conclusion, we show herein that serum thyroid hormone changes that follow an acute exercise protocol seem to be mainly due to the regulation of both thyroid and liver D1 and BAT D2. The understanding of iodothyronine deiodinases regulation by corticosterone and adrenaline, as well as by other mediators induced by exercise, is of great interest in order to clarify their physiological role after an acute exercise protocol.

Declaration of Interest

The authors declare that there is no conflict of interest that could be perceived as prejudicing the impartiality of the research reported.

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