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INFLUENCE OF BODY CARBOHYDRATE STORE MODIFICATION ON CATECHOLAMINE AND LACTATE RESPONSES TO GRADED EXERCISE IN SEDENTARY AND PHYSICALLY ACTIVE SUBJECTS

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Aim of this study was to elucidate the influence of carbohydrate store modification on exercise capacity and catecholamine thresholds. Nine sedentary students and 10 endurance athletes volunteered for the study consisting of four sessions in one-week intervals. During control session (C) subjects performed graded exercise till exhaustion with workload increasing by 50 Watts every 3 min after an overnight fast. Blood lactate and catecholamines were determined at rest, after each workload and at exhaustion. In the evening preceding each of the remaining three sessions subjects performed glycogen reducing exercise lasting 1.5 hrs at 70% HRmax. Till next morning they did not eat any meal but drank water. Two hours before exercise subjects were given either a high-carbohydrate (H-CHO) or a low-carbohydrate (L-CHO) meal of approx. 1000 kcal or remained fasted (F). Depletion of carbohydrate stores enhanced contribution of fat-derived energy substrates at submaximal workloads, but did not influence either maximal oxygen consumption, workload and lactate concentration or lactate threshold. Low carbohydrate availability resulted in elevated concentration of catecholamines only in untrained subjects. Ingestion of a meal either high or low in carbohydrates diminished those changes. Catecholamine thresholds were similar in all sessions and higher in athletes’ group.

Key words: glycogen, exercise, lactate threshold, catecholamines

INTRODUCTION

The ability of human body to store carbohydrates is limited, thus during the high-intensity or prolonged exercise the proper nutrition becomes crucial. The repeated depletion of glycogen stores during exercise and their subsequent
regeneration during recovery increase exercise capacity and are one of the main elements of training. Exercise capacity strongly depends on the overall diet and the meal consumed prior to exercise. In recent years investigators have focused again on the low carbohydrate diet which results in enhanced contribution of fat oxidation as an energy source (1, 2, 3) and reduced muscles’ dependence on glycogen. Thus, the low carbohydrate diet would improve the ability to perform long lasting endurance exercise (2, 4, 5, 6, 7, 8).

At exercise intensities close to maximal anaerobic processes predominate and utilization of free fatty acids (FFA) is abolished (9). This phenomenon was called “crossover concept” by Brooks and Mercier (10). In well trained athletes the crossover point of shift from fatty to carbohydrate energy substrates occurs at the higher workloads. During enhanced glycolysis the excess of pyruvate, which does not enter Krebs cycle is transformed into lactic acid and as a salt – lactate, gets out of the cells and leads to decrease of pH deteriorating the muscle function. That is why the point of boundary workload where anaerobic metabolism markedly increases – anaerobic or lactate threshold, is so important in exercise physiology. The workload corresponding to lactate threshold increases with training, however, Podolin et al. (11) reported decreased lactate concentration during graded exercise and elevated lactate and catecholamine thresholds in a glycogen depleted subjects.

Activity of sympathetic nervous system and secretion of hormones regulating the glucose concentration in blood, excluding insulin, increases with exercise intensity and duration. Similarly to blood lactate concentration, the relationship between increases of either catecholamines or growth hormone concentrations and workload is exponential and the threshold workload above which more rapid secretion occurs can be detected (12). Activation of sympathetic nervous system involves both central mechanism (from motor cortex) and peripheral (from muscles mechano- and chemoreceptors) reflexes (13). Sympathetic activity can be significantly enhanced by the circumstances of fight or competition in sport event. It was also shown, that response of sympathetic nervous system, especially during prolonged exercise, strictly correlates with glucostatic mechanisms (14). Increased body carbohydrate stores result in lower exercise-induced increase of catecholamines concentrations (14). Similar effects were observed in dogs with glucose infusion into the carotid artery (15). Nevertheless the relationship between the activity of sympathetic nervous system and body carbohydrate content is not limited just to the blood glucose concentration recorded by glucodetectors in central nervous system, but the signaling path from liver also supplies some crucial informations (16, 17).

Observed improvements in performance after the high fat diet (2, 4-8) are accompanied by studies which by means of different diets increased the usage of fatty energy substrates which did not affect exercise capacity (1, 18). The relationship between lactate and catecholamines responses to exercise is significant (19, 20) and there are mere few reports concerning complex investigations on the influence of carbohydrate store modifications on work capacity and catecholamine and lactate thresholds in subjects of different physical activities.
The aim of this study was to elucidate the influence of the carbohydrate stores modification on exercise capacity and catecholamine thresholds during graded exercise to exhaustion in sedentary and physically active subjects.

**MATERIAL AND METHODS**

Nineteen healthy male subjects volunteered to participate in the study after giving their informed consent. They were divided into two groups according to the level of their physical activity (Table 1). Sedentary group (group S) consisted of 9 students who did not participate in any sport activities ($\text{VO}_2\text{max} 37.2 \pm 2.6 \text{ ml/kg/min}$) and active group (group A) of 10 nonprofessional athletes of endurance sport disciplines ($\text{VO}_2\text{max} 58.8 \pm 2.5 \text{ ml/kg/min}$). The study protocol was approved by the Ethics Committee at the Medical Research Centre, Polish Academy of Sciences in Warsaw.

The study consisted of four experimental sessions performed in at least one-week intervals. During the first session (control - C) the subjects performed graded, incremental cycle-ergometer exercise till volitional exhaustion in the morning, after an overnight fast. The workloads were increased by 50 watts every 3 min starting with 50 watts. The venous catheter was inserted to the antecubital vein 30 min before exercise and blood samples for lactate (LA) and catecholamines (epinephrine - E and norepinephrine - NE) were taken immediately before exercise, at the end of each completed workload, at the moment of exhaustion and after 30 min of recovery.

Catecholamines concentrations were determined using radioenzymatic test (Immunotech, Czech Republic), sensitivity of the method 0.10 and 0.12 nmol · L$^{-1}$ for E and NE, respectively, coefficient of variations 6.8 and 4.7%, respectively. Lactate was determined with spectrophotometric enzymatic method (modified Boehringer-Mannheim solution), coefficient of variation 3.6%. Oxygen uptake ($\text{VO}_2$), carbon dioxide production ($\text{VCO}_2$) and heart rate (HR) were continuously recorded using Vmax 29 (Sensormedics, USA) analyzer.

Further three sessions were performed in random order. In the evenings preceding each of these sessions subjects performed the exercise lasting 90 min at workload corresponding to 70% $\text{HRmax}$ obtained in the control session in order to reduce muscle glycogen content. Afterwards they were asked not to eat any meals but could drink water ad libitum. In the next morning subjects were given either a high-carbohydrate (H-CHO – 4% proteins, 1% fat, 95% carbohydrates) or a low-carbohydrate (L-CHO – 35% proteins, 64% fat, 1% carbohydrates) meal or remained fasted (F).

**Table 1. Characteristics of the subjects**

<table>
<thead>
<tr>
<th></th>
<th>Group S (n=9)</th>
<th>Group A (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age [yrs]</td>
<td>23.3 0.5</td>
<td>24.9 1.3</td>
</tr>
<tr>
<td>Body mass [kg]</td>
<td>80.6 3.5</td>
<td>72.6 1.5*</td>
</tr>
<tr>
<td>Height [m]</td>
<td>1.81 0.02</td>
<td>1.79 0.01</td>
</tr>
<tr>
<td>BMI [kg/m$^2$]</td>
<td>24.61 0.88</td>
<td>22.65 0.30*</td>
</tr>
<tr>
<td>$\text{VO}_2\text{max}$ [l/min]</td>
<td>3.00 ± 0.12</td>
<td>4.21 ± 0.13**</td>
</tr>
<tr>
<td>$\text{VO}_2\text{max}$ [ml/kg/min]</td>
<td>37.2 2.6</td>
<td>58.8 2.4**</td>
</tr>
</tbody>
</table>

The values are means ± SE, asterisks denote differences between groups * - $P<0.05$; ** - $P<0.001$. 

Both meals had energy value of approximately 1000 kcal (21). Two hours after the meal the graded exercise test was performed similarly as in control session.

Workloads corresponding to lactate and catecholamines thresholds were calculated according to the log-log transformation method introduced by Beaver et al. (22). All data are presented as means ± SE. Values’ normal distribution was examined with Kolmogorow-Smirnow test. Two values were compared appropriately with Student’s t test for dependent or independent measures. For more complex analyses two-way ANOVA for repeated measures was used. Accepted level of significance was $P<0.05$. All analyses were performed with Statistica 6.0 software.

RESULTS

As expected, maximal workload ($P<0.001$) and $VO_2\text{max}$ ($P<0.01$) were higher in A than in S group, however in neither group there were significant differences between tests in maximal workload, $VO_2$ and HR (Table 2).

Respiratory quotient (RQ) at rest and during submaximal exercise loads was significantly ($P<0.05$) decreased after glycogen depletion. After H-CHO meal RQ was significantly increased ($P<0.01$) and after L-CHO decreased ($P<0.05$) to the value similar to F session. There were no significant differences in resting and maximal RQ between groups (Fig. 1).

Blood lactate concentrations during submaximal workloads (50 - 200 W) were significantly lower in group A than in group S and significantly higher at the end of exercise (Fig. 2). Lactate thresholds were significantly higher in group A except of F session (Table 2 and Fig. 3).

During exercise in both groups the concentration of epinephrine increased (Fig. 4). In the second part of exercise in group S there were higher concentrations of epinephrine in F session (at 150W compared to C session).

<table>
<thead>
<tr>
<th>Test</th>
<th>Control</th>
<th>F</th>
<th>H-CHO</th>
<th>L-CHO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wmax [W]</td>
<td>233 ±12</td>
<td>250 ±7</td>
<td>233 ±14</td>
<td>228 ±15</td>
</tr>
<tr>
<td>HRmax [sk/min]</td>
<td>184±5</td>
<td>185±3</td>
<td>181±5</td>
<td>185±4</td>
</tr>
<tr>
<td>$VO_2\text{max}$ [l/min]</td>
<td>3.00 ±0.12</td>
<td>3.14 ±0.14</td>
<td>2.95 ±0.16</td>
<td>3.13 ±0.17</td>
</tr>
<tr>
<td>$VO_2\text{max}$ [ml/kg/min]</td>
<td>37.2 ±2.6</td>
<td>40.4 ±2.6</td>
<td>36.5 ±2.2</td>
<td>38.6 ±2.2</td>
</tr>
<tr>
<td>LAmax [mmol/l]</td>
<td>8.4 ±0.5</td>
<td>10.1 ±0.5</td>
<td>10.2 ±0.7</td>
<td>10.1 ±0.9</td>
</tr>
</tbody>
</table>

Table 2. Maximal work load (Wmax), heart rate (HRmax), oxygen uptake ($VO_2\text{max}$) and blood lactate concentration (LA max) attained during four tests in sedentary (group S) and physically active (group A) subjects.

Fig. 1. Respiratory quotient (RQ) at rest and during exercise in sedentary (S) and physically active (A) groups.
Fig. 2. Blood lactate (LA) concentration at rest and during exercise in sedentary (group S) and physically active (group A) subjects.
p<0.05 and to H-CHO and L-CHO sessions p<0.001; at 200W to H-CHO p<0.01; at the end of exercise to C, H-CHO and L-CHO sessions $P<0.05$). In group A there were no significant differences between sessions. Maximal concentrations of epinephrine were higher in group A in C and H-CHO sessions ($P<0.05$). Epinephrine thresholds were similar in all sessions and significantly higher in group A then S (Fig. 5).

Norepinephrine concentration also increased during exercise in both groups (Fig. 6). Like epinephrine, in the second part of exercise in group S higher concentrations of norepinephrine in F session were observed (at 150W compared to C session, H-CHO and L-CHO sessions $P<0.001$; at 200W to C and H-CHO sessions $P<0.01$; at the end of exercise to C session $P<0.06$ and to H-CHO and L-CHO sessions $P<0.05$). In group A there were no significant differences between sessions. Maximal concentrations of norepinephrine were higher in group A in C, H-CHO and L-CHO sessions ($P<0.05$). Norepinephrine thresholds were similar in all sessions and significantly higher in group A then S (Fig. 7).

DISCUSSION

The lack of influence of different pre-exercise meals modifying availability of energy substrates on exercise capacity, expressed as maximal workload and
Fig. 4. Blood epinephrine concentration at rest and during exercise in sedentary (group S) and physically active (group A) subjects.
oxygen consumption, observed in both experimental groups was previously described in several studies (1, 3, 6, 18, 23, 24). Hawley et al. (25) found no change in power output generated during one hour exercise of intensity of 80% VO\textsubscript{2}max although RQ was lower after a high fat meal followed by heparine infusion. In the present study RQ was higher during exercise in both groups after H-CHO meal than in other sessions. These results are consistent with findings of most authors (3, 23). Moreover, in physically active subjects RQ during exercise was higher in control session than in L-CHO and F sessions, what means that in endurance trained man with depleted glycogen stores there is a higher contribution of fat in energy metabolism than in sedentary ones. The RQ values exceeding 1.0, achieved by the subjects from both groups at their maximal intensity of exercise, indicate that they all reached the similar, presumably maximal, relative workloads resulting in hyperventilation.

In endurance trained subjects during submaximal workloads (50 – 200W) blood lactate concentrations were lower than in sedentary ones at corresponding exercise intensity. With lower lactate thresholds in sedentary subjects it reflects the earlier shift to anaerobic metabolism in this group and greater usage of carbohydrates as energy substrates than in endurance trained men.

Decreased carbohydrate stores resulted in neither lower blood lactate during exercise nor in shift of lactate threshold. Previous studies are equivocal in this matter. Some authors described lower lactate concentrations and shift of lactate
Fig. 6. Blood norepinephrine concentration at rest and during exercise in sedentary (group S) and physically active (group A) subjects.
thresholds towards higher workloads after glycogen depletion (11, 26 - 28). However, in other studies, similarly to the present one, no changes in lactate thresholds (29) or concentrations during strenuous exercise were described (30, 31). Probably during long lasting exercise glycogen is depleted mostly in the slow twitch muscle fibers. High intensity exercise performed in the following morning recruits majority of fast twitch fibers, what compensates decreased glycolysis in the fibers with depleted or reduced glycogen stores.

After ingestion of the high carbohydrate meal, although carbohydrates’ contribution in energy supply during exercise was increased, blood lactate concentration was similar as in the other tests. In the previous studies higher lactate concentrations were described after consuming a high carbohydrate meal (32). Lack of this effect in our study is not clear, it could be due to glycogen reducing procedure applied before the tests, which enhanced lactate uptake in liver for glycogenesis thus diminishing difference of its concentrations in blood.

During exercise maximal concentrations of norepinephrine and epinephrine in blood were higher in endurance trained subjects then in sedentary ones (in control and after high carbohydrate meal). This supports findings of Greiwe et al. (33), who showed that catecholamines concentration depends not only on relative workload (%VO₂max), which was the same in both groups, but on absolute workload (Wmax) as well. Course of changes of catecholamines concentrations
during exercise in both groups was shaped exponentially, as in the previously described studies (11, 12, 20, 34 - 37).

Workloads corresponding to catecholamines thresholds were in all tests higher in physically active subjects. It is consistent with previous findings, that in untrained men catecholamine thresholds occur at the relative workload 20 - 30% lower than in athletes (12, 38). Increased carbohydrate stores inhibited secretion of catecholamines during exercise of long duration (14) while decreased carbohydrate stores by low carbohydrate diet enhanced catecholamines secretion during short exercise of high intensity (39) and decreased norepinephrine threshold during incremental exercise (40). On the other hand Podolin et al. (11) reported that glycogen depletion on the day before the test resulted in elevated catecholamines thresholds, that is opposite to the finding of Langfort et al. (40). In our study there were no significant changes in catecholamines thresholds, but in the sedentary group only, there were elevated concentrations of epinephrine and strong tendency in norepinephrine in the test without a meal at the workloads exceeding 150W. It means that the sedentary subjects were stressed much more in the condition of the limited availability of the carbohydrate energy substrates. „Physiological effort” to maintain similar exercise intensity appeared to be much higher in this condition. Regular physical activity induced adaptive changes which diminish the load resulting from exertion in unfavorable conditions.

In summary, the present study showed that during graded exercise performed until volitional exhaustion decreasing body carbohydrate stores enhanced contribution of fat-derived energy substrates to exercise metabolism at submaximal workloads, but did not influence either maximal oxygen consumption (VO₂max), workload and lactate concentration or lactate threshold. Depletion of body carbohydrate stores resulted in mere changes in neurohormonal response to maximal exercise – elevated concentration of catecholamines occurs only in untrained subjects. Ingestion of a meal either high or low in carbohydrates diminished those changes. Lack of influence of body carbohydrate store modifications on plasma catecholamine concentrations at maximal exercise in endurance trained man indicates that this response depends mostly on absolute achieved workload. Modifications in body carbohydrate stores did not altered plasma catecholamine thresholds in either sedentary or trained subjects.

REFERENCES


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