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PAPER

Substrate oxidation during exercise: impact of time interval from the last meal in obese women

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OBJECTIVE: To investigate whether time interval between meal and exercise alters the balance of substrate oxidation during an exercise bout.
HYPOTHESIS: Exercise performed 3-h after meal induces a higher rate of lipid oxidation than when performed only 1-h after meal.
RESEARCH METHODS AND PROCEDURES: Eight overweight and obese postmenopausal women (age: 57.4 ± 2.4 y; BMI: 31.8 ± 2.1 kg m^{-2}; %FAT: 42.7 ± 1.2%, mean $\pm$ s.e.m.) performed two sessions of exercise training at an intensity corresponding to their ' crossover' point of substrate oxidation (COP_{ox}). One session was held 1 h after a standardized meal and the other, 3 h after an identical meal on another day. Substrate oxidation was evaluated by indirect calorimetry. Hormonal responses were investigated during exercise.
RESULTS: Respiratory exchange ratio values were lower in the 3-h condition, showing higher lipid oxidation during exercise (average difference $+ 38.9 \pm 2.7$ mg min^{-1}; $P<0.001$), while mean energy expenditure did not differ. Basal heart rate was reduced in the 3 h compared with the 1-h condition (78 ± 5 *vs* 87 ± 5 bpm; $P<0.05$). Glycemia, lactatemia and insulinemia were reduced when exercise was performed 3 h after meal ($P<0.05$).
DISCUSSION: When exercise is performed 3 h after meal at an intensity corresponding to the COP_{ox}, metabolic and hormonal responses are similar to those targeted during the submaximal exercise test performed at fast that we previously proposed to individualize exercise training in the obese.
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Keywords: indirect calorimetry; lipid oxidation; energy expenditure

Introduction

Regular physical activity, together with diet and behavioral modification, has a beneficial effect in the prevention and treatment of obesity. Exercise is not only one of the factors that determines long-term weight maintenance in weight reduction programs,[1] but it also has an effect on substrate utilization, with low intensity training increasing fat oxidation at exercise in obese subjects.[2–4] This finding is important because sedentary overweight patients have been shown to exhibit a significantly altered balance in substrate oxidation and impaired fat oxidation during exercise in comparison with control subjects.[5–7] The training program in terms of mode, intensity and frequency should therefore be carefully chosen and based on individual metabolic characteristics. We have demonstrated that the characterization of substrate balance during exercise can be used to prescribe individualized training.[6,8] We further investigated the effects of this type of prescription on obese insulin-resistant patients and observed post-training metabolic and ergometric improvements.[9,10] However, the submaximal exercise test used to investigate the substrate balance is performed early in the morning in fasting conditions, whereas exercise training is generally performed in the afternoon in a postprandial period. The problem is that the bioavailability of substrates in postprandial periods varies with the time since eating. Poirier *et al*[11] observed the impact of different time intervals separating the last meal from exercise on the carbohydrate (CHO) response during exercise in diabetic patients. They demonstrated that glycemia was not diminished by 1 h of exercise when the exercise was

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performed in fasting state, whereas it decreased 20–40% in the postprandial period, with greater decreases associated with longer postprandial intervals. In addition, it was recently reported that the effect of training on lipid oxidation during moderate exercise depends on the time interval from the last meal.[12] We hypothesized that the optimal conditions for exercise prescriptions based on substrate balance during exercise are better preserved when exercise is performed far from the last meal. To test this hypothesis, we compared two sessions of exercise training in overweight women: one performed 1 h after a meal and the other performed 3 h after an identical meal on another day. These two sessions were both compared to the standardized exercise calorimetry performed at fast.

Research methods and procedures

Subjects

Eight healthy overweight (body mass index (BMI) $>$ 25 kg m^{-2})) or obese (BMI $\geq$ 30 kg m^{-2}) middle-aged women (age: 57. 4 $\pm$ 2.4 y) volunteered to participate in the study. For inclusion in this study, the women should be older than 50 y and postmenopausal since at least 2 y. The subjects' anthropometric and metabolic characteristics are shown in Table 1. Subjects were excluded if they had ischemic heart disease or other medical conditions for which the prescribed exercise might be contraindicated. Other exclusion criteria were any medical or nutritional conditions, or use of any medications, known to affect substrate utilization. Before the two training sessions, the subjects had not spent more than 2 h/week in sports activities and none had physically demanding jobs. They were requested to maintain their dietary habits during the study. After a detailed explanation of the study, each subject provided written consent. The experimental protocol was approved by the Committee on Research for the Medical Sciences.

Table 1 Subjects characteristics

Variable	
Age (y)	57.38 $\pm$ 2.37
Weight (kg)	83.81 $\pm$ 5.76
Height (cm)	162.50 $\pm$ 1.72
Body mass index (kg m^{-2})	31.79 $\pm$ 2.15
Body fat (%)	42.68 $\pm$ 1.19
Fat mass (kg)	36.22 $\pm$ 3.33
Fat-free mass (kg)	47.76 $\pm$ 2.48
Waist girth (cm)	96.63 $\pm$ 4.38
Hip girth (cm)	114.19 $\pm$ 4.16
Waist-to-hip ratio	0.85 $\pm$ 0.02
VO_{2max} (ml kg^{-1} min^{-1})	16.51 $\pm$ 1.33
VO_{2max} (ml kg FFM^{-1} min^{-1})	28.61 $\pm$ 1.9
VO_{2max} (ml kg FM^{-1} min^{-1})	39.25 $\pm$ 4.1
Maximum workload (W)	103.38 $\pm$ 5.27
COP_{ox} (W)	31.25 $\pm$ 5.03
COP_{ox} (FC)	95.1 $\pm$ 4.47

VO_{2max}: maximal O_2 uptake; FFM: fat-free mass; FM: fat-mass; COPox: 'Crossover' point of substrate oxidation. Values are expressed as mean $\pm$ s.e.m.

Protocol

The subjects came to the laboratory on four separate days for (1) the clinical examination, anthropometric measurements and the incremental maximal exercise test for the determination of the maximal oxygen uptake (VO_{2max}, test 1); (2) the standardized submaximal exercise test (test 2) for the determination of the intensity of the next exercise test; and (3) and (4) two 30-min steady-state exercise tests at the same absolute individualized workload, one 1 h after a standardized meal (test 3) and one 3 h after an identical meal (test 4). Tests 3 and 4 were performed in random order. The tests were separated by at least 2 days and never more than 4 days.

Clinical examination and anthropometric measurements

A screening trial was used to establish the anthropometric and metabolic characteristics of the patients. Upon arrival at the laboratory, height and weight were measured. Body composition and fat mass were assessed by bioelectrical impedance (Human IM-Scan from Dietosystem, Milan, Italy). BMI was calculated as weight in kilograms divided by height in meters squared (kg m^{-2}). Waist and hip circumferences were taken with the subjects in a standing position and the waist–hip ratio (WHR) was calculated as waist circumference divided by hip circumference.

Materials for exercise testing

The patients performed each test on the same electromagnetically braked cycle ergometer (Ergoline 500, Bosch, Berlin, Germany). Heart rate was monitored continuously throughout the exercise test (CPX Medical Graphics, St Paul, MN, USA). Gas volumes, that is., ventilation (VE), O_2 consumption (VO_2) and carbon dioxide production (VCO_2) in inspired and expired air, were measured with a computer-based breath-to-breath exercise analysis system (CPX Medical Graphics, St Paul, MN, USA), using a mouthpiece and nose clip system. A 3-l syringe was used to calibrate the pneumotachograph volume using flow rates similar to subject ventilation. The gas analyzers were calibrated before each test with standard gases of known concentration with a certified commercial gas preparation. Reproducibility of gas analysis has been studied in 10 subjects tested twice. The coefficients of variation measured at steady state during 6-min steps at a fixed intensity for the RER ranged between 2.8% (low values) and 4.75% (high values).[6]

Aerobic capacity (test 1)

Each subject's VO_{2max} was measured during an 8–12-min incremental exercise test. The theoretical maximal aerobic power (W_{maxTh}), which is the power corresponding to the theoretical VO_{2max}, was calculated.[13] This equation takes anthropometric characteristics and sex into account. The initial power output was 20% of W_{maxTh} for 3 min and was increased by 10% every minute until maximal exercise was

reached, which was evaluated in terms of maximal heart rate, respiratory exchange ratio (RER) (>1.15) and VO_2 stability. Pedal frequency was maintained between 60 and 70 rpm throughout the test. The highest VO_2 value was considered as VO_{2max} and the highest power output reached was considered as the maximal workload (W_{max}).

Indirect calorimetry (test 2)

At least two days after test 1, the subjects arrived at the laboratory at 08 30 following an overnight fast (ie 12 h) for a second test. The test consisted of a 3-min warm-up at 20% of W_{max}, followed by four 6-min steady-state workloads at 30, 40, 50 and 60% of W_{max}, using the protocol described previously.[6] VE, RER, VO_2 and VCO_2 were measured continuously, as described below (see Calculations). No dietary restriction was imposed during the days before exercise testing.

Diet and exercise (tests 3 and 4)

For the two following tests, the subjects were placed under the same conditions as for traditional training: they had to perform a 30-min exercise in the afternoon following a meal. The subjects were allowed to have a breakfast of their choice on the test days but could not eat after 10 00. They arrived at the laboratory at 12 noon and ate a standardized meal of meat and potatoes, a plain yoghurt and stewed apples. The energy value of the meal was 550 kcal with 57% CHO (65 g), 26% protein (30 g) and 17% fat (19 g). The subjects all had the same meal and they were instructed to ingest the meal within 15 min. After eating, they remained at rest, in a sitting position or lying on a bed, for 1 h for one of the tests (1-h) and for 3 h for the other (3-h). The tests were performed in random order. The subjects were instructed to come for the second test under the same conditions as the first one in terms of meal and physical activity to exclude bias by these factors. After the rest period, they were instructed to pedal for 30 min at an intensity corresponding to their 'crossover' point of substrate oxidation (COP_{ox}). Gas volumes were collected 10 min before the test and throughout testing. After stopping the exercise bout, the subjects returned to reclining position for 15 min. During this recovery, heart rate was continuously monitored and gas exchanges were collected.

Calculations

Substrate oxidation balance and derived parameters. Indirect calorimetric measurements were performed to obtain RER values and to determine whole-body substrate oxidation. During test 2, VO_2 and VCO_2 were determined as the mean of the values during the fifth and sixth minutes of each step, according to previous studies.[6,14] The RER was calculated by dividing VCO_2 by VO_2 at different times. In tests 3 and 4, the VO_2, VCO_2 and RER values were averaged from the 15-min rest period (REST), every 5-min period during the entire 30 min of exercise (0–5, 5–10, 10–15, 20–25, 25–30 min) and the 15-min recovery period (RECOV). As described in a previous study,6 we determined the COP_{ox} as a parameter representative of the balance between fat and CHO oxidation. The COP_{ox} is defined as the power at which energy from CHO-derived fuels predominates over energy from lipids.[6,15] This COP_{ox} was used to target the exercise intensity of tests 3 and 4 and was expressed either in absolute value (watts) or in corresponding heart rate (bpm).

Substrate oxidation and energy expenditure. The percentages of CHO and lipid oxidation were calculated using the following equation:[16]

$$\%\,\text{lipid} = [(1 - \text{RER})/0.29] \times 100$$
$$\%\,\text{CHO} = [(\text{RER} - 0.71)/0.29] \times 100$$

The RER values were determined as previously explained. The rates of substrate oxidation of CHO and lipid were calculated from gas exchange measurements by using non-protein RER values, according to the following equations:[17]

$$\text{lipid}\,(\text{mg min}^{-1}) = 1.6946VO_2 - 1.7012VCO_2$$
$$\text{CHO}\,(\text{mg min}^{-1}) = 4.585VCO_2 - 3.2255VO_2$$

with gas volume expressed in milliliters per minute. These equations are based on the assumption that protein breakdown contributes little to energy metabolism during exercise.[18] Energy expenditure was calculated from mean VO_2 given in l min^{-1} at different times, multiplied by 4.82, which is the average caloric equivalent to O_2 (4.82 kcal are burned to consume 1 l O_2), and then multiplied by 60 to give kcal h^{-1}. We then multiplied this result by 4.189 to convert kilocalories to kilojoules. Reproducibility of these measurements during this protocol has been studied in 10 subjects tested twice. Coefficients of variation were: for the lipid oxidation rates 18% (low intensity) and 28% (high intensity); for the CHO oxidation rates 17% (low intensity) and 15% (high intensity); for the power at the COP_{ox} 11.6%; power at the COP_{ox} 11.6%; for heart rate at the COP_{ox} 3.9 % 6 (partially published).

Blood samples

At 20 min before the beginning of exercise, a cannula was inserted in the forearm vein for blood sampling at various times. Subjects sat on the cycle ergometer 10 min before exercise. Two blood samples were taken just before exercise: the first corresponding to T0 and the second, 1 min after, to T0′. The mean of these two results gave the resting value (corresponding to REST). Blood samples were again taken 15 and 30 min after the beginning of exercise (corresponding to T15 and T30) and 15 min after cessation of exercise (corresponding to RECOV). The samples were immediately placed on ice for subsequent analysis.

Biochemical analysis

All samples were assayed for glucose, insulin, triglycerides, catecholamines and lactate. Plasma insulin was immediately

assayed by the Bi-Insulin IRMA kit (ERIA-Diagnostics Pasteur, France). Samples for the analysis of glucose, triglycerides and catecholamines were centrifuged for 10 min at $3000 \times g$, decanted, and frozen. Samples for the analysis of lactate concentration were deproteinated with 8% perchloric acid, vortex mixed, centrifuged for 10 min at $1500 \times g$, decanted, and frozen at -20°C for later analysis. Plasma glucose, triglyceride (Sigma Diagnostics, France) and lactate (Boehringer, Germany) concentrations were determined by specific enzymatic methods adapted to the spectrophotometer (Beckman DU 640, France). Plasma catecholamine concentrations, adrenaline (ADR) and noradrenaline (NOR), were determined using reverse-phase high-performance liquid chromatography procedures (Waters 460 Electrochemical Detector, France).

Statistical analysis

Data are presented as means $\pm$s.e. m. All statistical analyses were performed using a commercial software package (SigmaStat, version 1.0, Jandel Corporation, San Rafael, CA, USA). To compare the 1- and 3-h conditions during exercise, we use repeated-measure ANOVAs on ranks. When appropriate, the Student–Newman–Keuls *post hoc* test was performed to delineate at which points statistical significance was reached. A paired *t*-test or a Wilcoxon signed rank test was performed to compare various parameters in the two conditions during rest and recovery. Normality of values was assessed with the Kolmogorov–Smirnov test. When data were normally distributed we used the parametric tests and when they were not, we used the Wilcoxon test. A $P<0.05$ was considered to be statistically significant.

Results

General results

The mean W_{max} achieved was 103.4 $\pm$5.3 W and the corresponding mean VO_{2max} was 16.5 ± 1.3 ml kg^{-1} min^{-1}. Mean COP_{ox} was $31.2 \pm$W with a corresponding heart rate at $95.1 \pm .5$ beat min^{-1} (bpm, Table 1). At this level during the exercise calorimetry at fast the average lipid oxidation rate was 123 ± 4.7 mg min^{-1}. Then 30-min exercise sessions were performed at that individualized intensity, which corresponded to an average power output of 31.2 ± 5 W (range: 15–55 W) and to 29.2 ± 5.9% of predetermined W_{max}.

Substrate oxidation

Basal RER was not significantly different in the 3- *vs* 1-h conditions ($P>0.05$). During exercise, RER was lower in the 3-h compared with the 1-h condition, although the difference was significant only at 0–5 min and during recovery ($P<0.05$; Figure 1). As a consequence, the rate of lipid oxidation was greater in the 3-h condition but the difference was only significant at 0–5 min ($P<0.05$; Figure 2). Figure 3 shows the respective contribution (expressed as percentages of total energy expenditure) of lipid oxidation and CHO oxidation between the two postprandial situations: 1- and 3-h. This presentation helps to visualize the differences presented on the other figures. The total energy expenditure and lipid oxidation during the whole 30-min sessions are shown in Figure 4. There was a significant difference in lipid oxidation during exercise, with a higher value in the 3-h condition (100 ± 5.7 *vs* 61 ± 5 mg min^{-1}; $P<0.001$), while mean energy expenditure did not differ between conditions.

Heart rate

Basal heart rate was reduced in the 3-h condition ($P<0.01$). It rose during exercise in both conditions but remained significantly lower in the 3-h condition than in the 1-h condition (Figure 5). It then returned to basal levels during recovery, with the 3-h recovery heart rate lower than in the

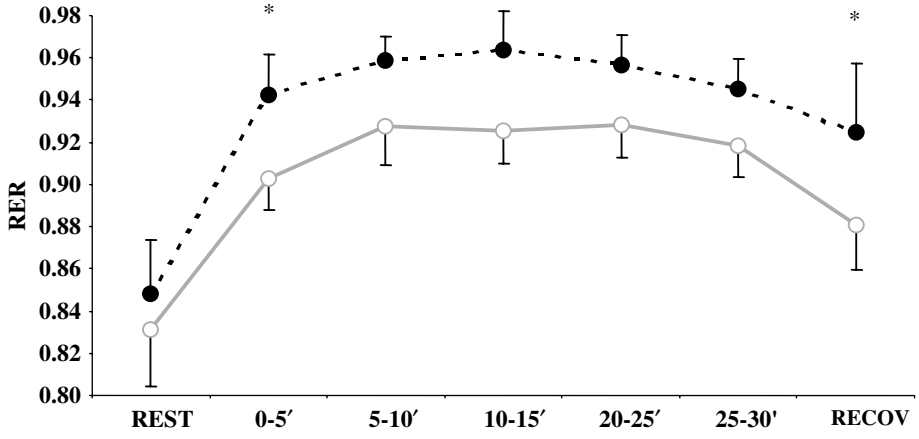

Figure 1 Respiratory exchange ratio (RER) during rest (REST), exercise and recovery (RECOV) . 3-h: exercise after 3 h of rest (open symbols); 1-h: exercise after 1 h of rest (closed symbols). Values are expressed as mean $\pm$s.e.m. *$P<0.05$ 3- *vs* 1-h values (ANOVA on ranks to compare the 1- and 3-h conditions during exercise and paired *t*-test or Wilcoxon signed rank test to compare during rest and recovery).

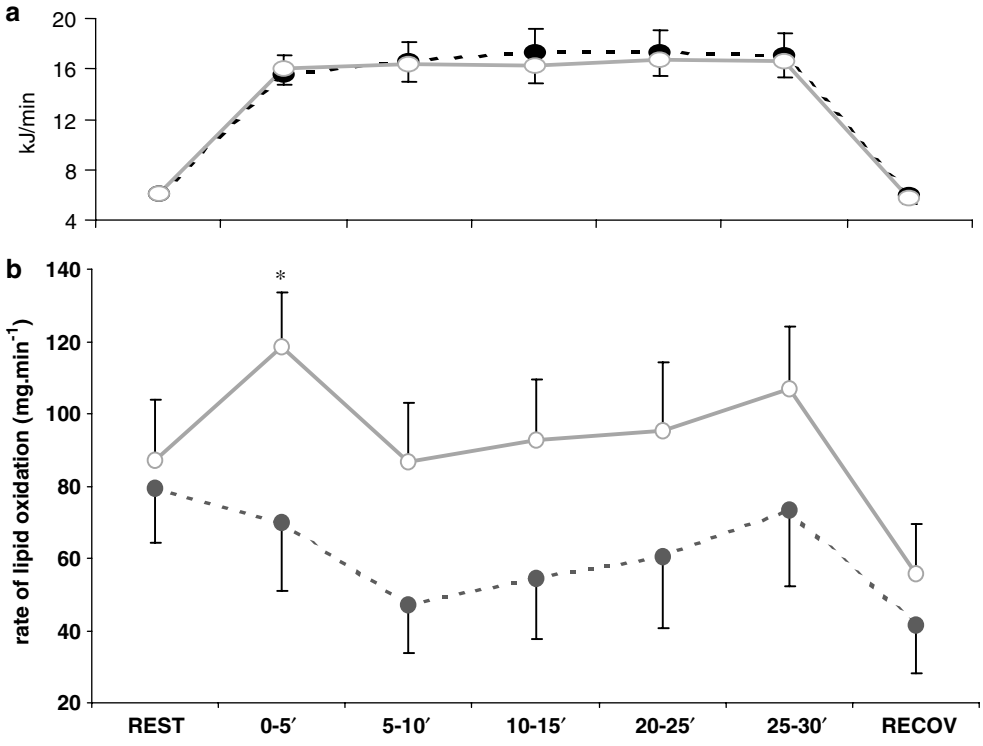

Figure 2 Energy expenditure (a) and rate of lipid oxidation (b) during rest (REST), exercise and recovery (RECOV). 3 h: exercise after 3 h of rest (open symbols); 1 r: exercise after 1 h of rest (closed symbols). Values are expressed as mean ± s.e.m. *$P<0.05$ 3- *vs* 1-h values (ANOVA on ranks to compare the 1- and 3-h conditions during exercise and paired *t*-test or Wilcoxon signed rank test to compare during rest and recovery).

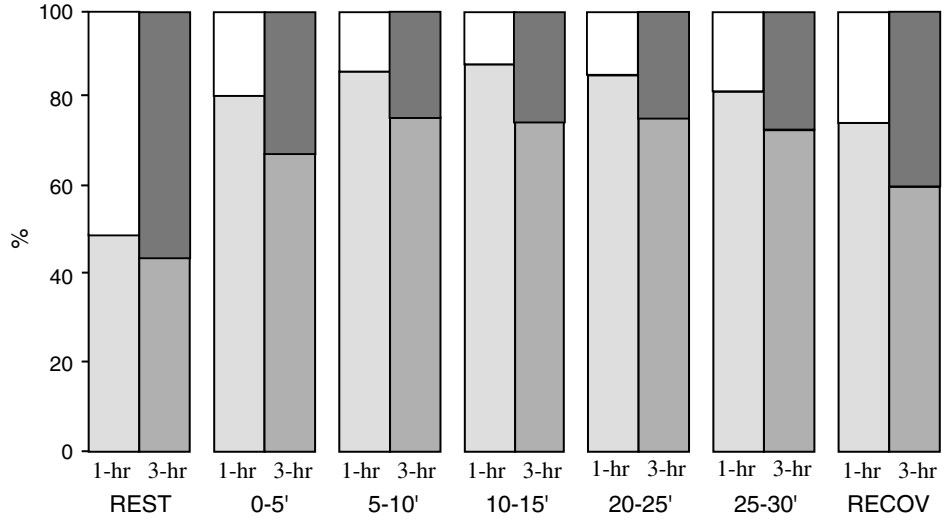

Figure 3 Comparison of the respective contribution (expressed as percentages of total energy expenditure) of lipid oxidation (empty bars) and CHO oxidation (dashed bars) between the two postprandial situations: 1- and 3-h during rest (REST), exercise and recovery (RECOV) .

1-h condition (Figure 5). Heart rate was increased during the 30-min exercise in both the 1- and the 3-h conditions in comparison with the heart rate corresponding to COP_{ox} (respectively, $+18\pm5$ bpm; $P<0.01$ and $+9\pm3$ bpm; $P<0.05$). In the 1-h condition, the values of the last period of exercise (25–30 min) were increased in comparison with the values of the first period (0–5 min) (respectively, 119 ± 8 *vs* 104 ± 4 bpm; $P<0.05$), whereas in the 3-h condition, the values did not differ (respectively, 107 ± 5 *vs* 102 ± 5 bpm; $P=0.06$; Figure 5).

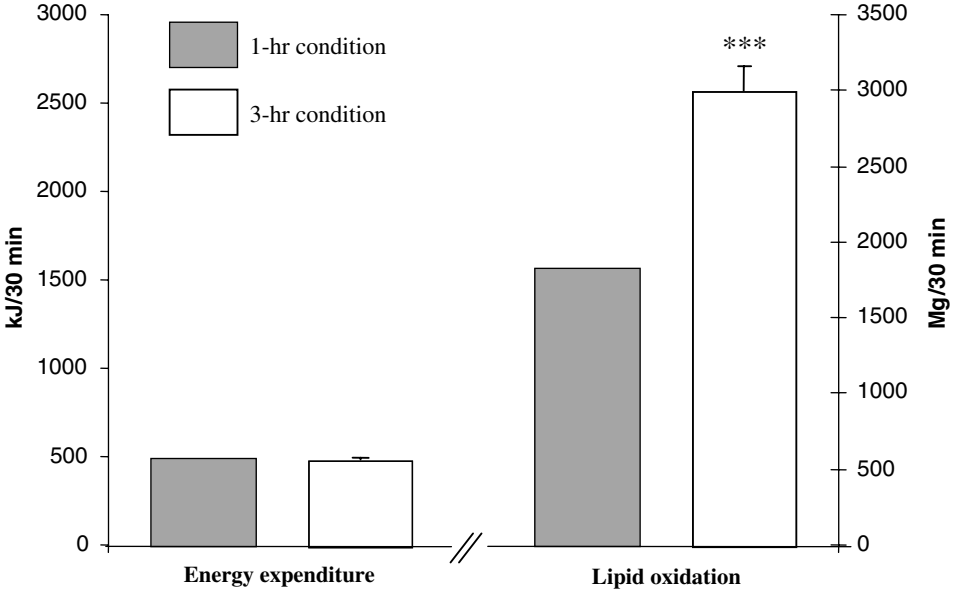

Figure 4 Energy expenditure and rate of lipid oxidation during the 30-min session of exercise. Values are expressed as mean ± s.e.m. ***$P<0.001$ 3- *vs* 1-h values (paired *t*-test).

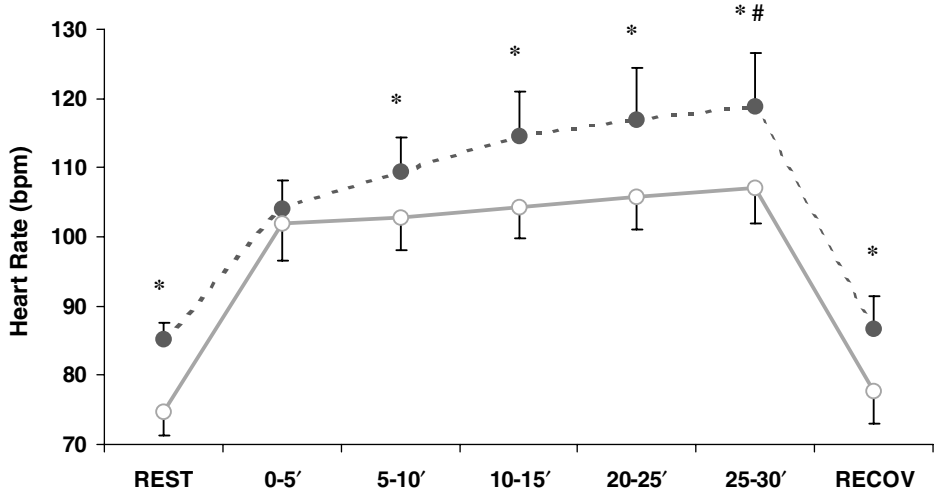

Figure 5 Heart rate during rest (REST), exercise and recovery (RECOV). 3 h: exercise after 3 h of rest (open symbols); 1-h: exercise after 1 h of rest (closed symbols). Values are expressed as mean ± s.e.m. *$P<0.05$ 3- *vs* 1-h values; # $P<0.05$ values during last period of exercise (25–30 min) compare with the first period of exercise (0–5 min) in 1-h condition (ANOVA on ranks to compare the 1- and 3-h conditions during exercise and paired *t*-test or Wilcoxon signed rank test to compare during rest and recovery).

Blood substrates and hormone concentrations

There were significant differences between conditions (3- *vs* 1-h) in terms of glucose, lactate and insulin responses (Figure 6a–c). The average glucose, lactate and insulin concentrations were significantly lower at rest, during exercise, and during recovery in the 3-h condition compared with the 1-h condition ($P<0.05$). Plasma triglyceride, glycerol, adrenaline and noradrenaline concentrations were not significantly changed between conditions.

Discussion

This study clearly demonstrates that lipid oxidation during submaximal exercise was higher and glucose, lactate and insulin concentrations were lower during an exercise bout performed 3 h after a meal at an intensity corresponding to the COP_{ox}, compared with 1 h after a meal for the same level of energy expenditure. Its mean value (100 mg min^{-1}) was quite similar to that obtained after the standardized exercise calorimetry performed at fast (123 mg min^{-1}). In addition,

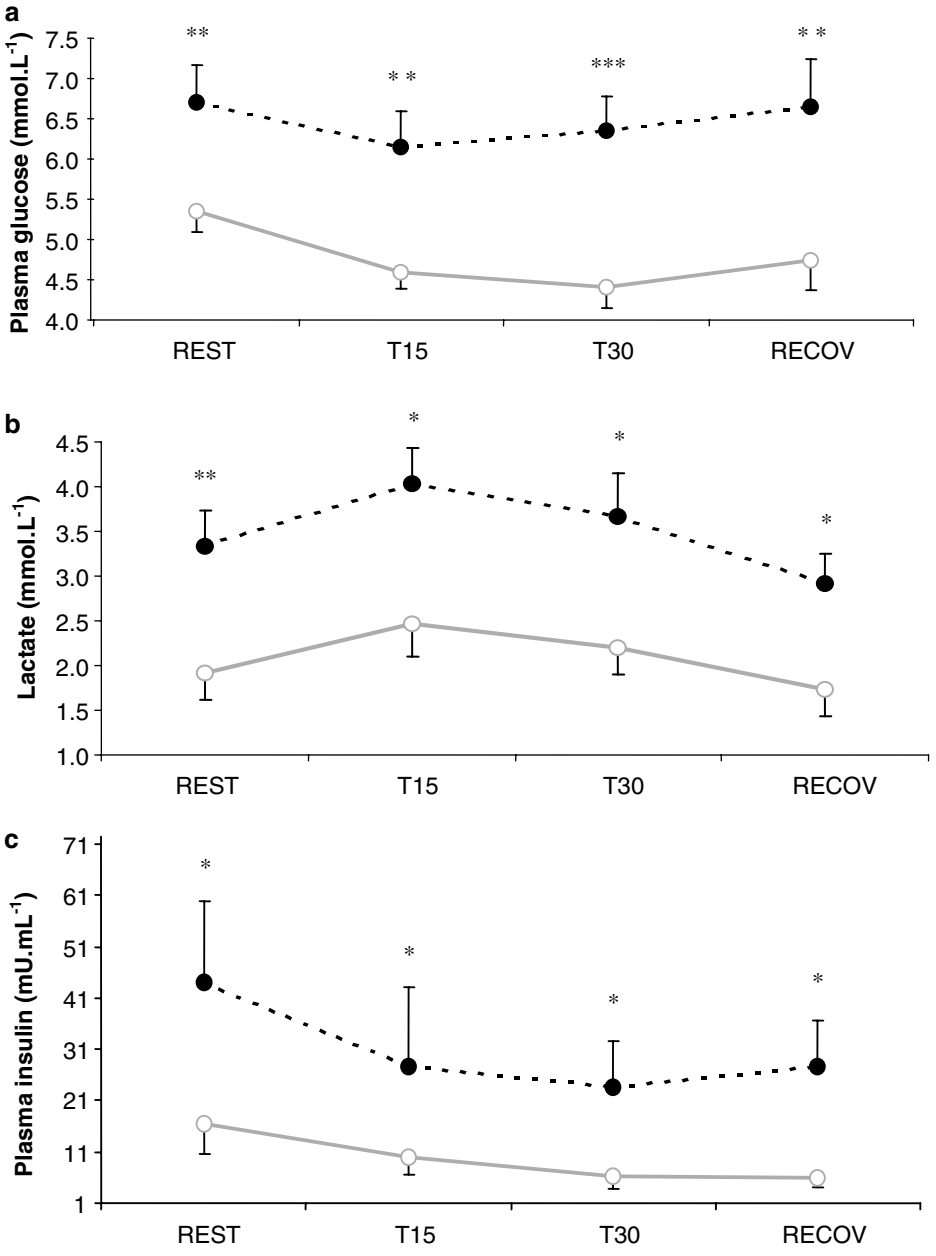

Figure 6 Plasma glucose (a), lactate (b) and insulin (c) concentrations during rest (REST), exercise (T15 and T30) and recovery (RECOV). 3-h: exercise after 3 h of rest (open symbols); 1-h: exercise after 1 h of rest (closed symbols). Values are expressed as mean ± s.e.m. *$P<0.05$; **$P<0.01$; ***$P<0.001$ 3- *vs* 1-h values (ANOVA on ranks to compare the 1- and 3-h conditions during exercise and paired *t*-test or Wilcoxon signed rank test to compare during rest and recovery).

the heart rate in the 3-h condition was more stable and was closer to that measured at the COP_{ox}, whereas a drift was seen in the 1-h condition.

Since middle-age is a period where women are prone to overweight, we focused on this period. For inclusion in this study, the women should be older than 50 y and postmenopausal since at least 2 y. These inclusion criteria have also the advantage of ruling out the effect of menstrual cycle on the balance of energetic substrates.

To assess this balance of substrates, we made the choice to calculate lipid and CHO oxidation rates rather than to only use the RER. Actually, since we were mostly interested by lipid oxidation, this measurement appeared preferable, keeping in mind that the relationship between lipid oxidation and RER is not linear, as shows the empirical equation given above (lipid ($mg\,min^{-1}$) = 1.6946 VO_2–1.7012 VCO_2). This equation can be simplified as lipid ($mg\,min^{-1}$) = 1.7 VO_2 (1- RER), that is, lipid oxidation increases proportional

to $V\mathrm{O}_2$ and decreases when RER increases. Due to this aspect of 'bell-shaped curve' is difficult to evaluate lipid oxidation from RER alone, as can be seen, for example in Figure 2. However, the accuracy of indirect calorimetry during exercise has been much discussed, mainly because bicarbonate kinetics and thus CO_2 production can be markedly altered above the lactate threshold. $V\mathrm{CO}_2$ may therefore overestimate tissue CO_2 production and concomitantly overestimate the rate of CHO oxidation.[19] In fact, it has been demonstrated that the contribution of bicarbonate-derived CO_2 to $V\mathrm{CO}_2$ is rather negligible and that $V\mathrm{CO}_2$ can be considered to be a reliable reflection of muscle tissue CO_2 production during exercise, including at high intensity, as long as RER is lower than 1.[20,21] Furthermore, as previously shown, this type of exercise testing can be used to characterize alterations in substrate utilization in the obese during exercise[6] and has clear beneficial effects.[8–10] In this study, the values of $W_{\max}$, expressed in absolute value, in terms of percentage of predetermined $W_{\max}$ and in terms of heart rate corresponding to $\mathrm{COP}_{\mathrm{ox}}$, were very close to those reported previously in overweight females.[6] The exercise session may appear relatively short (30 min) but this duration is well adapted to the deconditioned state of obese sedentary subjects. In addition, there is no significant change in substrate availability and oxidation between 30 min and 2 h at low exercise intensity (25% of $\mathrm{VO}_{2\max}$).[22]

In order to assess the influence of a meal, we standardized it, as shown in the section 'Methods'. This meal was rather light, in order to mimic to some extent the habits of those women who most of the time drastically reduce or totally skip this meal. One can of course argue that a more important meal, or a meal including a higher percentage of CHO, could exert a more prolonged effect on the balance of substrates. Actually we selected a standardized meal, which had been previously studied in our department and compared to a hyperglucidic breakfast[23] so that its postprandial effects on insulin and blood glucose were already well known. It was known that at 3 h insulin and blood glucose had returned to values quite close from baseline, so that this interval of 3-h appeared to be a reasonable compromise between fasting and absorptive conditions. Although it remains obvious that other kinds of meal would perhaps modify a little such results, we think that one could reasonably estimate that a post meal interval equal or higher to 3-h is likely to improve the lipid-oxidizing effect of such a targeted submaximal training session.

It is now quite well documented that exercise training at low intensity (30–50% $V\mathrm{O}_{2\max}$) increases fat oxidation during exercise in lean and obese subjects,[2,3] but few studies have investigated the effect of dietary status on substrate utilization during exercise in the obese. Some reports have encouraged training in fasting conditions because overweight subjects seem to oxidize more fat during an exercise session performed after an overnight fast than after a meal[12] and glucose homeostasis appears to be maintained, whereas a decrease is observed when the same exercise is performed postprandially.[11,12] However, to our knowledge, no study has been carried out in obese subjects with all the training sessions performed in fasting condition. Thus, we chose to work on the assumption that training is often performed in daily life in the postprandial rather than the fasted state. Our hypothesis was that the optimal conditions determined during exercise testing performed in fasting condition would be reproduced when exercise was performed later in the postprandial period. This was confirmed because we clearly demonstrated that an exercise session 3 h after a meal induces a rate of lipid oxidation very similar to that measured during the standardized test.

In order to decrease fat mass and reduce the risk of developing type 2 diabetes mellitus and cardiovascular disease, the purpose of exercise training is to increase fat oxidation. This purpose is reached when exercise is performed at least 3 h after a meal because, as this study showed, fat oxidation was clearly higher 3 h after a meal compared to 1 h after. The difference in substrate oxidation between the 1- and 3-h conditions was not related to the catecholamine response because we observed no difference between the two conditions in terms of ADR and NOR. The lower lipid oxidation observed 1 h after a meal may be explained by three mechanisms: (1) greater CHO availability and utilization by skeletal muscle in the postprandial condition; (2) an inhibition of lipid oxidation by the postprandial hyperlactatemia;[24] and (3) higher insulin concentration in the 1-h condition, which may promote CHO utilization and reveal the antilipolytic effects of insulin.[7,25]

One could argue that this difference in lipid oxidation between 1- and 3-h is not very important, and that it should not be concluded from such studies that exercise should be avoided after the meals because it is not efficient on lipids. Obviously, in such patients as well as in the general population, regular exercise at any time is likely to be beneficial and should be encouraged. However, we think that targeting exercise in individuals at a level where they actually oxidize lipids is an improvement in exercise prescription, and we have repeatedly demonstrated that such a training improves after a few weeks the ability to oxidize lipids, which is initially often quite low in obese subjects.[8,9] By contrast, exercise training targeted at intensity levels where the muscle mostly oxidizes CHO improves principally the ability to oxidize CHO.[26] Moreover, this study focuses only on the balance of substrates during an exercise bout, and gives no information on the delayed increase in lipid oxidation that occurs for several hours during recovery, and that may play an important role in the energetic metabolism of subjects submitted to regular exercise training. For all these reasons, we think that our finding of a better lipid oxidation at 3-h is an useful finding for investigators aiming at improving exercise training protocols in obesity.

The other finding of our study was that heart rate was closer to that determined for exercise prescription when the exercise was performed in the 3-h condition compared with the 1-h condition. In the absence of differences in ADR and NOR between the two conditions, the higher level of the curve and the drift toward higher heart rate values when exercise was performed 1 h after a meal are difficult to understand. One possible explanation may be a greater distribution of the cardiac output toward the gut. In fact, it has been shown that, following a meal, the effects of food are additive to those induced by exercise and thus result in an increase in heart rate.[27] Whatever the explanation of the significant difference between the 1- and 3-h conditions, this is quite important from a practical point of view because heart rate is used to supervise the exercise training intensity.

Conclusion

Our results show the importance of the time interval between eating and exercise in postmenopausal women to modulate the balance of substrate utilization. We demonstrate that metabolic and hormonal responses during an exercise bout performed 3 h after a meal at an intensity corresponding to the COP_{ox} are closely similar to those targeted during the submaximal exercise test performed in fasting state that we previously proposed to better individualize exercise training in obese.

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