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J Appl Physiol 102:1767-1772, 2007. First published Jan 18, 2007; doi:10.1152/jappphysiol.00704.2006

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Fat metabolism and acute resistance exercise in trained men

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Submitted 22 June 2006; accepted in final form 15 January 2007

Ormsbee MJ, Thyfault JP, Johnson EA, Kraus RM, Choi MD, Hickner RC. Fat metabolism and acute resistance exercise in trained men. *J Appl Physiol* 102: 1767–1772, 2007. First published January 18, 2007; doi:10.1152/jappphysiol.00704.2006.—The purpose of this study was to investigate the effect of acute resistance exercise (RE) on lipolysis within adipose tissue and subsequent substrate oxidation to better understand how RE may contribute to improvements in body composition. Lipolysis and blood flow were measured in abdominal subcutaneous adipose tissue via microdialysis before, during, and for 5 h following whole body RE as well as on a nonexercise control day (C) in eight young (24 ± 0.7 yr), active (>3 RE session/wk for at least 2 yr) male participants. Fat oxidation was measured immediately before and after RE via indirect calorimetry for 45 min. Dialysate glycerol concentration (an index of lipolysis) was higher during RE: 200.4 ± 38.6 vs. C: 112.4 ± 13.1 $\mu\text{mol/l}$, 78% difference; $P = 0.02$) and immediately following RE (RE: 184 ± 41 vs. C: 105 ± 14.6 $\mu\text{mol/l}$, 75% difference; $P = 0.03$) compared with the same time period on the C day. Energy expenditure was elevated in the 45 min after RE compared with the same time period on the C day (RE: 104.4 ± 6.0 vs. C: 94.5 ± 4.0 kcal/h, 10.5% difference; $P = 0.03$). Respiratory exchange ratio was lower (RE: 0.71 ± 0.004 vs. C: $0.85 \pm .03$, 16.5% difference; $P = 0.004$) and fat oxidation was higher (RE: 10.2 ± 0.8 vs. C: 5.0 ± 1.0 g/h, 105% difference; $P = 0.004$) following RE compared with the same time period on the C day. Therefore, the mechanism behind RE contributing to improved body composition is in part due to enhanced abdominal subcutaneous adipose tissue lipolysis and improved whole body fat oxidation and energy expenditure in response to RE.

adipose tissue; fat oxidation; lipolysis; microdialysis; resistance exercise; resting metabolic rate

RESISTANCE EXERCISE (RE) is recommended by both the American College of Sports Medicine and the American Heart Association as an integral part of an exercise program (24, 25). There is substantial evidence showing that aerobic exercise and RE can improve body composition by increasing lean body mass and/or decreasing fat mass (2, 26, 35). However, to our knowledge, no research has been performed to examine the acute effects of RE on adipose tissue fat metabolism, which may describe how the improvement in body composition is accomplished with RE. Despite a lack of data regarding adipose tissue metabolism, others have found that intramuscular triglycerides stores were reduced following RE and hypothesized that the triglyceride stores were used for fuel during the exercise bout (3, 16). Subsequently, resting respiratory ex-

change ratio (RER) has been shown to be reduced immediately (4) and at 15 h (6, 20, 21) following a RE bout compared with a nonexercise control (C) day, indicating increased postexercise fat oxidation.

Additional studies have investigated the acute effects of RE on substrate oxidation as measured by indirect calorimetry and have found equivocal results. Melanson et al. (19) observed a slight (5%) increase in 24-h fat oxidation following a RE bout, but this increase in fat utilization failed to reach statistical significance. It has been suggested that the enhanced fat oxidation observed as an acute response to RE is due to glucose sparing for the purpose of glycogen replenishment, thus resulting in fatty acids being the primary substrate for energy provision after RE (22). Similarly, de Glisezinski et al. (2) demonstrated that 60 min into endurance exercise, the highest rate of lipolysis matched a significant increase in fat oxidation. Thus availability and rate of fatty acid delivery may partially mediate whole body fat oxidation (8).

Therefore, the purpose of this study was to investigate the effect of acute RE on the rate of lipolysis within adipose tissue and whole body substrate oxidation in healthy, resistance-trained men. We hypothesized the following: 1) that strenuous whole body RE would increase lipolysis, as measured with microdialysis, in abdominal subcutaneous adipose tissue (SCAT); and 2) that whole body fat oxidation, as measured by indirect calorimetry, would be increased immediately following RE. Adipose tissue was studied because this is the major source of fatty acids that are oxidized by skeletal muscle over prolonged periods of inactivity and activity. Microdialysis was utilized as a relatively noninvasive method of directly monitoring the release of glycerol from a SCAT depot.

MATERIALS AND METHODS

Participants. A preparticipation health history and physical activity questionnaire were used to screen all volunteers for inclusion in this study. Eight young (21–27 yr), physically active (>3 days RE/wk for >2 yr) men who were free from any existing acute or chronic illness or from any known cardiovascular, metabolic, or pulmonary disease, did not take any medications or supplements, and were nonsmokers were recruited for this study. A resistance-trained group was studied because the lipolytic and fat oxidation response to RE and subsequent refeeding is most relevant to this population. All participants were informed both orally and in writing of the purpose, risks, and benefits of the research and gave their written informed consent to participate before beginning the investigation. This study was approved by the

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Table 1. Participant demographic and body composition data

Variable	Mean \pm SE
<i>n</i>	8
Age, yr	24 \pm 0.7
Weight, kg	90 \pm 4.1
Height, cm	183.1 \pm 2.3
Body fat, %	9.0 \pm 2.1
Fat mass, kg	7.4 \pm 1.8
Fat-free mass, kg	75.3 \pm 3.3

Values are means \pm SE; *n*, no. of subjects.

East Carolina University Medical Center Institutional Review Board. Participant characteristics are presented in Table 1.

Study design. Participants reported to the Human Performance Laboratory at East Carolina University on three separate occasions. The first visit was used to gather baseline information, including height, weight, body composition (7-site skinfold), and 10-repetitions maximum (10 RM) lifts. In a randomly assigned crossover design participants completed either a RE or a C treatment on the second and third visits. Before the second and third visits, each participant abstained from any vigorous activity and from alcohol or caffeine intake for 48 h. The experimental time line for visits 2 and 3 are shown in Fig. 1. All participants remained resting in the supine position during the entirety of both experimental days except for during the RE session on the RE day. The protocol was identical on the C day; however, instead of performing RE, participants remained sedentary in a supine position in the Human Performance Laboratory. The prolonged period of study was performed to monitor the prolonged effects of RE and a subsequent refeeding. Subsequent studies will be needed to investigate possible differential antilipolytic effects of different refeeding strategies post-RE and to monitor these effects over longer periods of time. A minimum of 7 days separated experimental trials.

Body composition and 10-RM strength testing. Participants were weighed on an electronic scale with weight recorded to the nearest 0.1 kg, and height was measured with a standard stadiometer. Seven-site (chest, midaxillary, triceps, subscapular, abdominal, suprailium, and thigh) skinfold measurements were recorded, and percentage of body fat was calculated using the Siri equation (29). The participant's 10 RMs for the exercises used in the treatment sessions (mean \pm SE: chest press, 75.3 \pm 4.7 kg; lateral pull down, 60.7 \pm 3.0 kg; leg press, 157.8 \pm 6.4 kg; shoulder press, 52.6 \pm 2.5 kg; leg extension, 77.1 \pm 3.3 kg; leg curl, 67.2 \pm 4.5 kg) were determined on resistance training equipment (Cybex, Medway, MA) using previously described procedures (16, 31). All 10-RM testing and RE sessions were supervised by a certified strength and conditioning specialist.

Microdialysis and RE. Participants entered the laboratory early in the morning (~0700) having fasted for 10–12 h. Each participant was weighed and then lay down for insertion of the microdialysis probe. A previously sterilized microdialysis probe was inserted into the partic-

ipant with techniques previously described (9). Briefly, a linear designed probe (BAS LM3 probe: 30 \times 0.2-mm dialysis membrane with 35-kDa pore size; Bioanalytical Systems, West Lafayette, IN) was inserted into the abdominal SCAT. Before probe insertion into the abdominal SCAT, the skin was swabbed with iodine, and the insertion and exit site were numbed with a topical ethyl chloride spray to reduce discomfort.

After insertion, the probe was attached to a portable microdialysis pump that continuously perfused (2.0 μ l/min) a solution (147 mM NaCl, 2.7 mM KCl, 1.2 mM CaCl₂, 0.85 mM MgCl₂; order no. P000151, CMA/Microdialysis, Acton, MA) containing ~10 mM ethanol through the probe. The pumped perfusate was collected at the exit end of the probe (dialysate) and stored at 4°C for analysis of ethanol (index of local blood flow) within 24 h and subsequently at -20°C for later analysis of interstitial glycerol (index of lipolysis). After a 45-min period for probe equilibration, a new collection vial was added for collection of a baseline sample over 45 min. Energy expenditure was also measured via indirect calorimetry (Parvomedics, True Max 2400, Sandy, UT) in participants during this 45-min period with the room darkened and noise kept to a minimum. Participants were required to remain awake, quiet, and as motionless as possible. Substrate oxidation was calculated using CO₂ produced/O₂ consumed and calculations developed by Frayn (5).

Following preexercise measures, a new microdialysis collection vial was put in place, and the participants were instructed to move to the exercise equipment and begin the exercise protocol. The protocol consisted of the following resistance exercises performed in the listed order: chest press, lateral pull down, leg press, shoulder press, leg extension, and leg curl. Each exercise was performed for 3 sets of 10 repetitions with a load equaling 85–100% of the individual's previously established 10 RM. Rest periods were kept to 90 s between all sets and exercises, and the RE session lasted for a total of 40–45 min. The workout was designed to be similar to those from other studies in which plasma catecholamine, anabolic hormones, insulin, and lactate concentrations were significantly affected (17, 18, 34). The experiment was identical on the control day; however, instead of a RE bout, participants were kept recumbent and sedentary.

Immediately following the RE or C period, the participants lay supine to change the dialysate collection vial and to collect respiratory gas for a total of 45 min. The abdominal SCAT probe remained inserted to measure lipolysis and blood flow over the remainder of the experiment, with dialysate collection vials changed every hour until removal of the probe 540 min (9 h) after the start of the experiment. Two hours after completion of exercise, the participants were fed a liquid meal (Glucerna; 220 kcal per 8 oz, 18% of total kcal protein, 35% of total kcal fat, and 47% of total kcal carbohydrate) that equaled 25% of the individual's daily resting energy expenditure (calculated from the preexercise indirect calorimetry measure). The drink was a controlled simulation of a meal and was given to follow a real-life situation where fasting for >16 h would be unlikely. The participants were then free to leave the laboratory and go through their normal daily activities; however, they were instructed not to eat another meal

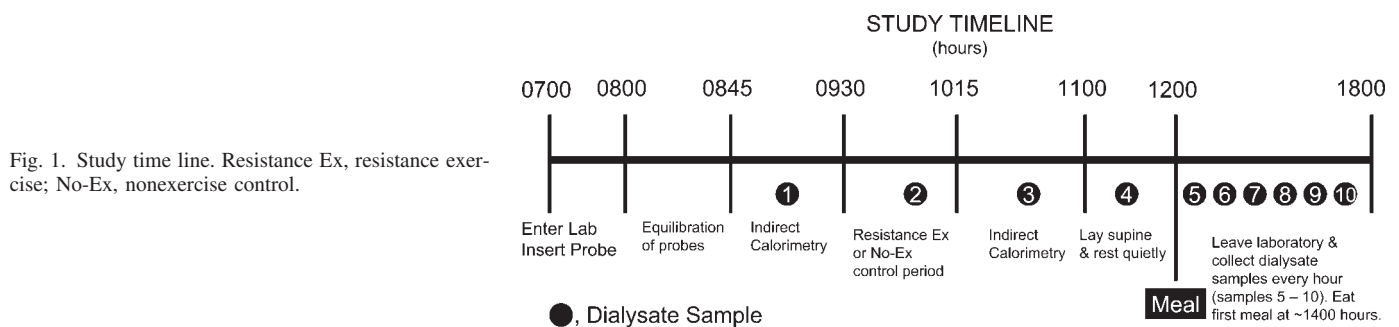


Fig. 1. Study time line. Resistance Ex, resistance exercise; No-Ex, nonexercise control.

or ingest any calories until an additional 2 h had passed (~4 h after exercise).

After leaving the laboratory, the participants recorded the time, type, and amount of dietary intake for the remainder of the experimental day. The participants were asked to store all collected microdialysis samples in a refrigerator or on ice.

Dietary control. Participants recorded their dietary intake for the 2 days before and the day of the initial testing session (randomly assigned as either RE or C). Each participant was instructed to replicate what they ate on the days before and during the first testing session for the corresponding days with respect to the second laboratory visit so that differences in dietary intake would have limited effect on lipolysis or substrate oxidation (Table 2). Dietary analysis was not performed for the second testing session because it was reported by the participants to be identical to the first testing session as instructed. Previous literature has shown that low levels of glycogen content can affect substrate oxidation; therefore, all subjects consumed a minimum of 200 g/day of carbohydrate for the 2 days before testing (4). Lipolytic response to feeding after RE was studied because it is common to consume some form of nourishment following a RE training bout. This could potentially alter the lipolytic and fat oxidation response following RE, which may have implications for body fat status.

Microdialysis sample analysis. All microdialysis samples were analyzed for glycerol according to the manufacturer's instructions (CMA 600 analyzer, CMA Microdialysis, Solna, Sweden). Microdialysis samples were also analyzed for ethanol concentration to determine blood flow in the region of adipose tissue surrounding the probe (10, 11) via previously described methods (12, 13).

Statistical analysis. Two-way [treatment (RE day vs. C day) \times time (time points during the microdialysis day)] repeated-measures ANOVA tests were used to determine differences in energy expenditure, RER, fat oxidation, lipolysis, and blood flow. Significance was located with Newman-Keuls post hoc analysis. The level of significance was set at $P < 0.05$. All values are reported as means \pm SE unless otherwise noted.

RESULTS

Body weight was not different between trials (C: 90.3 \pm 11.3 kg vs. RE: 89.7 \pm 11.5 kg; $P = 0.2$). Energy expenditure was not significantly different at baseline between the RE and C days (C: 91.8 \pm 4.9 vs. RE: 89.2 \pm 4.4 kcal/h) but was elevated after RE compared with the same time point on the C day (C: 94.5 \pm 4.0 vs. RE: 104.4 \pm 6.02 kcal/h, 10.5% difference; $P = 0.03$; Fig. 2). RER was lower at baseline on the C day compared with the RE day (3.7% difference; $P = 0.04$). There was a treatment \times time interaction ($P = 0.004$) for RER, in that there was a reduced RER in the 45 min after RE compared with before exercise on the RE day, but there was no

Table 2. Average dietary intake for 2 days before and the day of the first testing session (randomly determined to be either resistance exercise or a control period)

Total calories, kcal	2,564.6 \pm 212.9
Carbohydrate	
g	292.3 \pm 21.6
%	40.1 \pm 5.0
Protein	
g	158.0 \pm 15.4
%	23.1 \pm 1.6
Fat	
g	89.3 \pm 5.3
%	27.7 \pm 3.1

Values are means \pm SD.

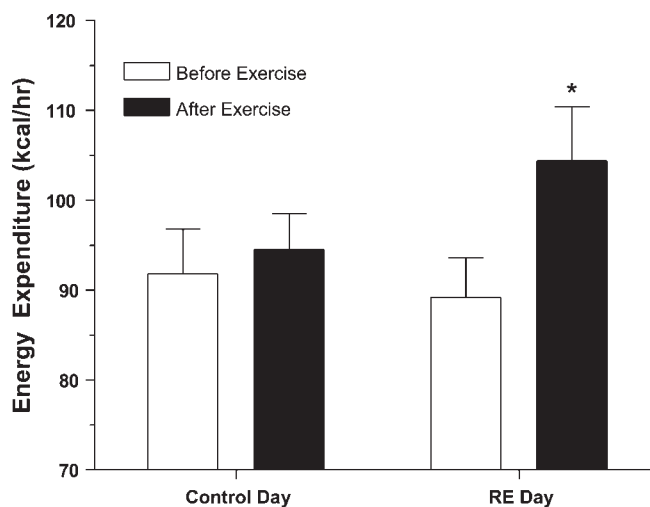


Fig. 2. Energy expenditure before and after resistance exercise (RE) or during corresponding control periods on a separate day in trained men. Values are means \pm SE. *Different from all other bars, $P = 0.03$.

change in RER on the C day over similar time points. Fat oxidation was lower at baseline on the RE day compared with the C day ($P = 0.04$). A treatment \times time interaction was present for fat oxidation ($P = 0.005$), in that there was an increased fat oxidation in the 45 min after RE compared with before exercise on the RE day, but there was no change in fat oxidation on the C day over similar time points. Fat oxidation increased (105% difference; $P = 0.004$) compared with the C day, indicating greater reliance on fat as a fuel (Fig. 3).

Dialysate glycerol concentration was not different between treatments at baseline (C: 108.9 \pm 12.5 vs. RE: 139.5 \pm 31.1 μ mol/l). There was a treatment \times time interaction ($P = 0.034$) for dialysate glycerol, in that there was a higher dialysate glycerol during and in the 45 min after RE compared with before exercise on the RE day, but there was no change in dialysate glycerol on the C day over similar time points. Dialysate glycerol levels were elevated during RE (78%; $P = 0.02$) and immediately following RE (75%; $P = 0.03$) compared with the corresponding measurements on the C day (Fig. 4).

Outflow-to-inflow ratio for ethanol (a measurement of abdominal SCAT blood flow) was not different during the RE bout compared with corresponding no-exercise time periods during the C (C: 0.47 \pm .08 vs. RE: 0.48 \pm 0.07), and it was not different at any time point during the RE compared with C treatment days (Fig. 5).

DISCUSSION

Metabolic effects of acute RE. The primary objectives of this investigation were to investigate the effect of acute RE on lipolysis within abdominal SCAT and whole body substrate oxidation in healthy, resistance-trained men to better understand how RE contributes to improvements in body composition. Using microdialysis, we were able to determine dialysate glycerol concentrations in abdominal SCAT adipose tissue before, during, and for 5 h after RE in healthy, physically active, young men. The primary findings from this investigation indicate that energy expenditure and fat oxidation were elevated immediately following RE, whereas lipolysis was elevated during and immediately following RE.

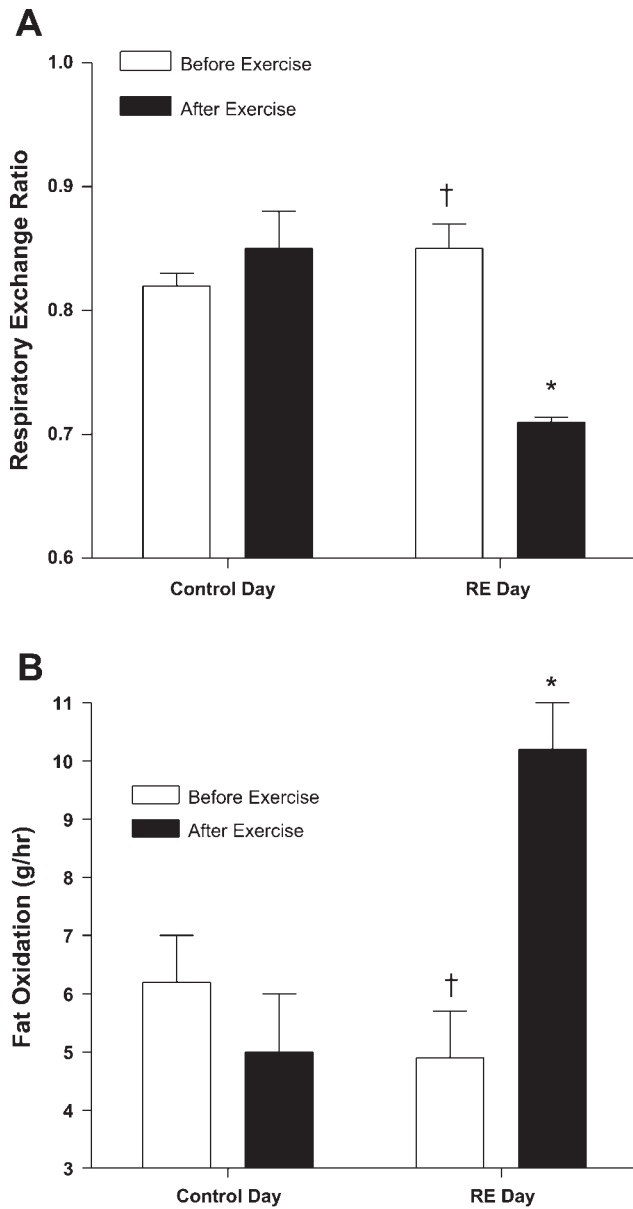


Fig. 3. A: respiratory exchange ratio before and after RE or during corresponding control periods on a separate day in trained men. Values are means \pm SE. *Significantly different from RE day before-exercise bar, $P = 0.0003$. †Significantly different from control day before-exercise bar ($P = 0.04$). B: fat oxidation before and after RE or during corresponding control periods on a separate day in trained men. Values are means \pm SE. *Significantly different from RE day before-exercise bar, $P = 0.005$. †Significantly different from control day before-exercise bar, $P = 0.04$.

As anticipated, and in agreement with others (20, 28), energy expenditure in this study was elevated postexercise for a period of 40 min and was significantly higher (10.5%) compared with energy expenditure during the corresponding time on the no-exercise C day. While energy expenditure was only measured before and immediately after RE in the present study, others have demonstrated an increase in energy expenditure for up to 2, 15, and 38 h after RE (1, 20, 28) using a similar RE protocol; thus our subjects likely had elevated energy expenditure for an extended time period.

Dialysate glycerol from microdialysis probes placed in SCAT was elevated during (78%) and immediately after (75%)

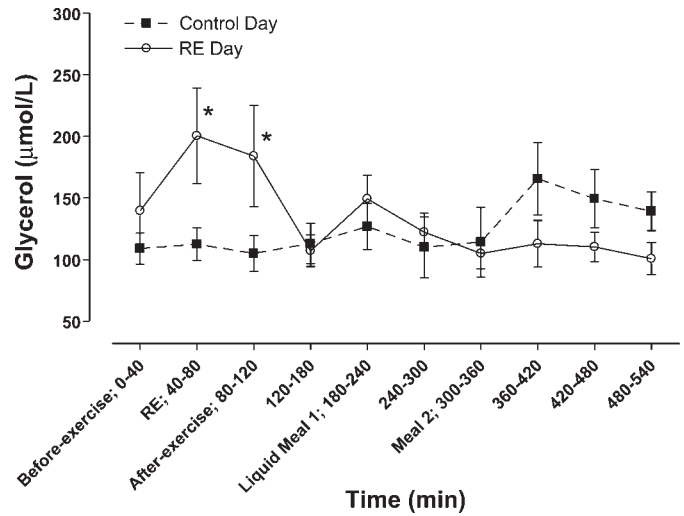


Fig. 4. Lipolytic rate, represented by dialysate glycerol concentrations from microdialysis probes placed in subcutaneous abdominal adipose tissue, before, during, and following RE or the corresponding time point on a control (no exercise) day in trained men. Values are means \pm SE. *Glycerol concentration on the RE day is significantly elevated above the same time point on the control day, $P < 0.05$.

RE compared with corresponding time points during the no-exercise C day. These data clearly show that RE stimulates increased rates of lipolysis. Interestingly, the recovery of glycerol may change during or after RE if there is an alteration of blood flow or diffusion properties within adipose tissue. In light of minor changes in adipose tissue blood flow during RE, it is unlikely that there were major changes in interstitial glycerol due to blood flow alterations. In addition, it is likely that the increased lipolysis provides fuel for the increased energy expenditure that is seen during and after a RE bout. Earlier work from Hurley et al. (14) and Tesch et al. (32) showed that plasma catecholamine concentrations are markedly increased during heavy RE compared with endurance

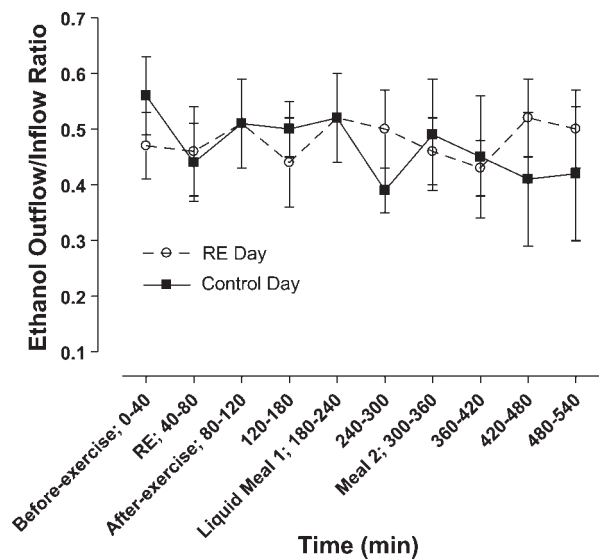


Fig. 5. Ethanol outflow-to-inflow ratio (indicator of adipose tissue blood flow) before, during, and following RE or the corresponding time point on a control (no exercise) day in trained men. Values are means \pm SE. No differences were observed between the RE day and the control day at any time point.

exercise performed at the same energy expenditure. An additional question is how long are catecholamines elevated after exercise, and could growth hormone, another potent activator of lipolysis, also be playing a role. Although not measured in our study, a previous study from Goto et al. (7) used a similar RE protocol and found that epinephrine and norepinephrine levels were significantly elevated immediately postexercise but that the levels were similar to preexercise levels by 15 and 30 min post-RE. However, they did find that growth hormone levels were significantly increased (80–90%) immediately, 15 min, and 30 min following the RE bout. Thus growth hormone levels could play a role in the elevated lipolysis that we witnessed after RE. Although no attempt was made in this study to determine what caused the increase metabolic rate or change in fat metabolism, a rise in catecholamines likely contributed to the increased lipolysis (2). It should also be noted that RE can also lower intramuscular lipids in skeletal muscle presumably by activating lipolysis. Like lipolysis in subcutaneous adipose tissue, catecholamines can activate lipolysis in the intramuscular lipid stores. Interestingly, little is known about the amount of substrate derived from intramuscular lipid stores with intensive exercise. Future studies measuring lipolysis in the interstitial space of skeletal muscle may provide answers.

Although it has been reported that intramuscular lipids are utilized during RE, it is presumed that the immediate and glycolytic energy systems provide most of the energy during intensive RE (33), which leads to a significant lowering of glycogen stores in recruited muscle (3). It has been suggested that the increase in fat oxidation after a RE bout allows for available glucose to be utilized for glycogen restoration as the skeletal muscle switches to utilizing the elevated fatty acids as the primary energy source (22). Whole body fat oxidation, as indicated by a significant reduction in the RER, was indeed increased (105%; 5.3 g/h) following RE compared with preexercise and compared with the same time on the C day. Previous literature supports our data, because the RER has been shown to be reduced immediately (4) and at 15 h (6, 20, 21) following a RE bout compared with a nonexercise C day, indicating increased fat oxidation after RE. However, when averaged over a 24-h period, one group (19) has observed only a slight, nonsignificant increase (5%) in 24-h fat oxidation following a RE bout. The increased fat oxidation is therefore relatively small when considered in the context of total energy expenditure over a 24-h period.

There was no measurable change in subcutaneous abdominal adipose tissue blood flow in this study of RE. The authors are unaware of any data on adipose tissue blood flow during RE. The microdialysis ethanol technique has been used to detect a twofold increase in adipose tissue blood flow in response to aerobic exercise. This is a relatively small absolute increment in blood flow compared with the large rise in skeletal muscle blood flow during exercise. Adipose tissue blood flow may increase more over the active limb than in other adipose tissue depots (30), which may explain why there was no measurable increase in abdominal adipose tissue blood flow in the present investigation.

A few methodological limitations exist and need to be addressed. Participants were allowed to eat and go about their normal daily routine after the in-laboratory portion of the experimental day to more closely simulate in vivo conditions.

Participants were therefore ambulatory and collected microdialysis samples 5–10 without the supervision of the research team. Furthermore, participants ate ad libitum following the in-laboratory experimental sessions, because they were not provided foods by the research team other than the first liquid meal on each experimental day. The research team took precautions, however, to minimize compliance deviation between the RE and C experimental days by collecting all dietary logs, by instructing subjects to complete the same type of physical activity before both testing days, and by personal questioning. In addition, it is possible that resting energy expenditure may have been elevated due to anticipatory arousal or excitation from the insertion of the probes, despite not knowing whether they were going to exercise or not on the first experimental day and despite allowing for a 45-min resting period before indirect calorimetry measures. If there was an anticipatory or excitatory stimulation during the basal period, then the exercise and postexercise increases in oxygen consumption and the postexercise increase in fat oxidation may have been underestimated. Furthermore, measurement of interstitial and plasma catecholamine concentrations, as well as other regulators of lipolysis and fat oxidation, would help to more specifically determine the cause of increased lipolysis and fat oxidation and should be included with future research. In addition, a similar study using overweight or aged individuals who are initiating a RE program to improve strength and body composition would be relevant and warranted. Future studies are required in these areas. Additional studies using stable isotope tracers to monitor both whole body lipolysis and fat oxidation may also provide valuable information in future studies.

In conclusion, the novel findings from this investigation are that free fatty acid mobilization in abdominal SCAT was increased both during and for at least 40 min following 45 min of acute RE in young, healthy active men. In addition, fat oxidation was elevated following RE compared with the same time point on the C day. Recently, it was shown that dynamic strength training over a period of 3 mo was able to increase lipolysis in obese men by more efficiently stimulating β -adrenergic receptors (23). Therefore, chronic or acute RE may help to attenuate weight gain and improve body composition and we have demonstrated that this may, in part, occur through the mechanisms of increasing energy expenditure, abdominal subcutaneous lipolysis and whole body fat oxidation.

ACKNOWLEDGMENTS

The authors acknowledge the efforts of Hannah Carrithers, John Carrithers, James Drew, Chris Evans, and Patty Brophy for help with data collection in this study.

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