Resistive training increases fat-free mass and maintains RMR despite weight loss in postmenopausal women

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Ryan, Alice S., Richard E. Pratley, Dariush Elahi, and Andrew P. Goldberg. Resistive training increases fat-free mass and maintains RMR despite weight loss in postmenopausal women. J. Appl. Physiol. 79(3): 818–823, 1995.—Percent body fat increases with age and is often accompanied by a loss in muscle mass, strength, and energy expenditure. The effects of 16 wk of resistive training (RT) alone or with weight loss (RTWL) on strength (isokinetic dynamometry), body composition (dual-energy X-ray absorptiometry), resting metabolic rate (RMR) (indirect calorimetry), and sympathetic nervous system activity (catecholamines) were examined in 15 postmenopausal women (50–69 yr). RT resulted in significant improvements in upper and lower body strength in both groups (P < 0.01). The nonobese women in the RT group (n = 8) did not change their body weight or fat mass with training. In the obese RTWL group (n = 7), body weight, fat mass, and percent body fat were significantly decreased (P < 0.001). Fat-free mass and RMR significantly increased with training in both groups combined (P < 0.05). There were no significant changes in resting arterialized plasma norepinephrine or epinephrine levels in either group with training. RT increases strength with and without weight loss. Furthermore, RT and RTWL increased fat-free mass and RMR and decrease percent fat in postmenopausal women. Thus, RT may be a valuable component of an integrated weight management program in postmenopausal women.

Aging; exercise; diet; body composition; sympathetic activity; resting metabolic rate

RESTING METABOLIC RATE (RMR) comprises 60–75% of total energy expenditure and decreases by ~1–2% per decade with aging (17). This decline in RMR with age is attributed in part to a loss of fat-free mass (FFM) (32). The loss of FFM with age is thought to be responsible for the decrease in strength that leads to an increase in frailty. This process is further exacerbated by a decline in physical activity and diseases, which further decrease muscle mass and bone mineral density in the elderly.

Because body fat increases with aging (9), adults frequently restrict caloric intake to reduce body weight (10). However, weight loss (WL) due to caloric restriction results in a decline in FFM and RMR (12, 16). In addition, sympathetic nervous system (SNS) activity also decreases with caloric restriction (4, 20, 37) and sympathetic hormones increase with an exercise intervention (23, 24). A decrease in FFM could aggravate the decline in strength in older women, whereas a decrease in RMR and SNS activity could predispose women to weight gain. A number of studies have shown that resistive training (RT) increases FFM in older men and women (3, 8, 13, 31). We have recently reported that an intensive RT program increased RMR, FFM, and resting norepinephrine (NE) levels in healthy older males (24).

The effects of RT with or without WL on RMR, strength, and SNS activity in older women are unknown. We hypothesized that RT would prevent or attenuate the reported decline in FFM and the associated reduction in RMR seen with WL in older women. To test this hypothesis, we enrolled nonobese and obese sedentary postmenopausal women of comparable age in either an RT or RT and WL (RTWL) program. These results demonstrate that RT can prevent the reported decline in FFM, RMR, and SNS activities that occur with WL.

METHODS

Subjects. Fifteen women who were ≥2 yr postmenopausal, not on any medication including hormone-replacement therapy, and between the ages of 50 and 69 yr were recruited to participate in the study. Only women who were weight stable and who had not participated in a regular exercise program for a minimum of 6 mo before the study were recruited. Based on initial body mass index (BMI), seven obese women (BMI >27 kg/m²) entered an RTWL program and the remaining eight women were assigned to an RT program (BMI <27 kg/m²). Subjects were screened by medical history questionnaire, physical examination, fasting blood profile, 2-h oral glucose tolerance test, and a graded exercise treadmill test to exclude those with disease. All subjects were nonsmokers and free of diabetes and cardiovascular disease. All methods and procedures were approved by the Institutional Review Board of the University of Maryland, and all subjects provided written informed consent.

Standardized diet. To minimize any effect that diet might have on the measured metabolic variables, 4 wk before the initiation of the study all subjects were instructed on the American Heart Association (AHA) Step I (1) diet by a registered dietitian. The composition of this diet was 50–55% carbohydrate, 15–20% protein, <30% fat, and <300 mg of cholesterol per day. They were asked to maintain this composition throughout the duration of the study (20 wk). Compliance was monitored by reviews of 7-day food records taken every 4 wk. All subjects were weight stable 2 wk before each testing period. After the initial 4 wk of AHA stabilization diet and initial testing period, the RTWL group underwent individualized dietary counseling and energy restriction (hypocaloric diets) to induce ~0.25–0.5 kg WL/wk during the training period. The women in the RT group were instructed to not lose weight. At the end of the 16-wk program, subjects were asked to continue training but maintain a constant weight on a diet similar in composition to the diet consumed before baseline testing. The total calories and percentage of calories from carbohydrate, protein, and fat were calculated by using Nutritionist III (19).

Body composition. All body composition measurements were performed after a 12-h overnight fast. A total body scan
was performed with dual-energy X-ray absorptiometry (model DPX-L, LUNAR Radiation, Madison, WI). All scans were analyzed by the same investigator using the LUNAR Version 1.3 DPX-L extended analysis program for body composition. Fat mass, lean tissue mass, and bone mineral content were determined. FFM was calculated as lean tissue plus bone mineral content. The precision of the DPX-L for the ratio of soft tissue attenuation and percent fat measurements were assessed by placing the aluminum spine phantom at the head of the scan table followed next by a plastic container filled with 9 cm of water and 6 cm of 100% vegetable oil to simulate 40% fat. This set up was scanned five times before the start of the study and five times after the training period to yield identical values for the ratio of soft tissue attenuation (coefficient of variation = 0.1%) and percent fat (coefficient of variation = 0.9%). The in vivo reproducibility was previously shown to be ~1% (31).

Maximal oxygen consumption \( (\dot{V}O_2\text{max}) \). \( \dot{V}O_2\text{max} \) was measured before and after training to confirm that subjects were untrained before the study and that they did not engage in regular aerobic exercise during the study. A continuous treadmill test protocol was used in which speed was kept constant but varied for each individual depending on her level of conditioning (3.4 mph). The grade was increased from 0 to 4% at 2 min and was then increased 2% every minute after 4 min until the subject was unable to continue. Expired air was continuously collected to determine the fractional concentrations of oxygen and carbon dioxide as previously determined in our laboratory (27). Validation that \( \dot{V}O_2\text{max} \) had been reached was established if two of the following criteria were met: 1) a plateau in oxygen consumption with an increased workload as evidenced by a difference in oxygen consumption of <2 ml kg\(^{-1} \) min\(^{-1} \); 2) a respiratory exchange ratio >1.10; and 3) a maximal heart rate within 10 beats/min of the age-predicted maximal value.

RMR. All testing was performed in the morning after a 12-h overnight fast. Subjects were transported to the Baltimore Veterans Affairs Medical Center on the morning of testing. They rested quietly in the supine position in a thermoneutral environment (23 ± 1°C) for ~30 min before determination of RMR. RMR was measured for 30 min by the open-circuit indirect calorimetry (model 2900, Sensormedics, Yorba Linda, CA) with calibrations performed before each test. Energy expenditure was calculated by the Weir equation (36) and expressed per 24 h. The coefficient of variation of RMR measured under these conditions in our laboratory is 1.1%, with an intrasubject correlation coefficient of 0.96 (6 older men).

SNS activity. After the first determination of RMR, an antecubital vein and a dorsal hand vein were cannulated with 20-gauge intravenous catheters, which were kept patent with slow (<60 ml/h) infusions of 0.9% NaCl. The hand was then placed in a warming box thermostatically controlled at 70°C to arterialize the blood. After an additional 30 min of quiet rest, a second determination of RMR was performed to test the effect of the placement of the catheters (if any) on RMR and to ensure that the subjects were resting during measurements of SNS activity. Duplicate blood samples 15 min apart were obtained for baseline catecholamine measurements in the RTWL group. In the RT group, a primed continuous infusion of \( ^{1}H\text{NE} \) (prime: 15 \( \mu \text{Ci}/\text{m}^{2} \); continuous infusion: 0.35 \( \mu \text{Ci} \cdot \text{m}^{2} \cdot \text{min}^{-1} \)) was administered through the antecubital vein for 60 min using a screw-type pump (Harvard Apparatus, South Natick, MA). Infusates contained 1 mg/ml ascorbic acid to prevent oxidation of NE. Arterialized blood samples (10 ml) were drawn at 50, 55, and 60 min after the start of the NE infusion for the measurement of plasma levels and for calculation of the rates of appearance (Ra) and clearance (Rc) of NE in the RT group as described by Esler et al. (7). The blood samples collected for the measurement of catecholamines were placed in prechilled heparinized tubes containing reduced glutathione and EDTA. The plasma was promptly separated and stored at ~70°C until assayed by the single-isotope radioenzymatic method (22). All samples for each patient were run in duplicate in a single assay. The intra-assay coefficients of variation for NE and epinephrine were 7 and 9%, respectively. Because of the inability to obtain arterial blood samples, catecholamines were not measured in two of the participants. RMR, catecholamine turnover rate, and catecholamine levels were measured at baseline before exercise and again on completion of the 16-wk interventions 22-24 h after the last training session.

Strength tests. A dynamometer was used to assess upper and lower body torque (Kin-Com 125 E Plus, Chattex, Chattanooga, TN). Muscular strength was defined as the amount of torque exerted volitionally at various speeds. Knee extension of the right side was tested at 30 and 180°/s with the lever arm from the Kin-Com attached to the tibia and its axis of rotation aligned with the rotation axis of the knee joint. Support straps around the chest, pelvis, and thigh were used to stabilize the trunk, hip joint, and thigh. The hip joint was at ~90° during testing. Elbow extension and elbow flexion of the right side were tested at 45°/s while subjects were in a seated position and stabilized with straps around the hips, chest, and biceps. The rotational axis of the lever arm was aligned with the rotational axis of the elbow adjacent to the lateral epicondyle of the humerus. The arm was positioned at 45° of abduction. The wrists were locked in a neutral position throughout the full range of motion, and the test began with the elbow in full flexion. Before maximal testing, subjects were given four warm-up trials at a submaximal effort and one maximal effort for practice. Three maximal efforts were then performed and recorded for both extension and flexion. All subjects received verbal encouragement to exert maximal force. The highest value obtained for these three trials was recorded as the final peak torque score. The Kin-Com 125 E Plus was calibrated on each testing day by using standard weights placed on the lever arm. A built-in software correction was made for forces due to gravitational effects by weighing the limb at specific angles.

RT program. The RT program consisted of 3 exercise sessions/wk on nonconsecutive days for ~16 wk using 14 exercises on pneumatic variable-resistance machines (Keiser K-300, Keiser Sports Health, Fresno, CA), dumbbells, and floor exercises. Each training session was preceded by a 3-min warm-up of low-intensity cycling followed by 10 min of static stretching. Training began at a resistance of approximately five-repetition maximum resistance (RM) or 90% of 3 RM as previously described (27) for the first three to four repetitions. Starting with the fourth or fifth repetition, resistance was reduced on the Keiser equipment just enough to permit the subject to complete a total of 15 repetitions at a resistance requiring near maximal effort on every repetition without interruption of the normal cadence of each repetition. Starting and finishing resistances were recorded for each exercise. The resistance level was checked weekly and adjusted to accommodate strength gains for each individual. Upper and lower body exercises were alternated to minimize fatigue with a rest interval of 1-2 min between exercises, with no rest between repetitions. The exercises were performed in the following order: leg press, chest press, leg curl, latissimus pull down, leg extension, overhead press, leg adductor, leg abductor, upper back, triceps, lower back, upper abdominals, biceps curl (dumbbells), and lower abdominals (floor). After the entire circuit was completed, a second set of exercises were performed on the leg press, leg curl, and leg extension machines,
RESULTS revealed no changes in total caloric intake; kilocalories obtained after the intervention, in the RT group two sets of 7-day food records, one obtained before and groups, baseline caloric intakes (first either group, and there was no difference between the

but only one set was performed on the other exercises. The energy expended during each RT session was ~150 kcal. Blood pressures and heart rates were recorded before warm-up, after the overhead press, after the second circuit on the leg machines, and before departure. Subjects were weighed at every third exercise session. All sessions were monitored by a registered nurse and an exercise physiologist.

Statistical analyses. Differences between and within RT and RTWL groups for the dependent variables were calculated using a one-way or repeated-measures analysis of variance as appropriate. Mean values of the duplicate samples of plasma catecholamines were used in all analyses. Pearson correlation coefficients were calculated to test for associations among RMR, body composition, and plasma catecholamine levels. All analyses were performed with Statview 512+ (BrainPower, Berkeley, CA) or SAS software (28). Data are expressed as means ± SE, and significance was set at the 0.05 level.

RESULTS

Subject characteristics. The women in the RT and RTWL groups were of similar age (range 50–69 yr), and all completed the RT protocol. Because of the study design, the RTWL group had significantly higher weight, percent body fat, fat mass, FFM, and BMI than the RT group (P < 0.05, Table 1). Again, because of the study design, the RT group did not change their total body mass or fat mass with training, whereas the RTWL group significantly lost weight, fat mass, and percent body fat (P < 0.001). FFM increased with training in both groups combined (P < 0.05). VO2max (l/min) or VO2max corrected for body weight (ml·kg−1·min−1; data not shown) did not change significantly in either group, and there was no difference between the two groups.

Dietary analysis. Despite difference in BMI between groups, baseline caloric intakes (first 4 wk of AHA diet) did not differ between the two groups. The analysis of two sets of 7-day food records, one obtained before and one obtained after the intervention, in the RT group revealed no changes in total caloric intake; kilocalories per kilogram between initial and final evaluations (1,642 ± 73 vs. 1,568 ± 94 kcal/day); or percent calories from carbohydrate (61 ± 2 vs. 61 ± 4%), fat (22 ± 2 vs. 23 ± 3%), and protein (19 ± 1 vs. 18 ± 1%). Although total 24-h caloric intake significantly decreased in the RTWL group after the WL program (1,677 ± 163 vs. 1,402 ± 83 kcal/day; P < 0.05), there was no change in kilocalories per kilogram per day, and percent calories from carbohydrate, fat, and protein also remained constant (57 ± 1 vs. 58 ± 2%; 25 ± 1 vs. 23 ± 1%; 20 ± 1 vs. 21 ± 1%, respectively).

Muscular strength. There was a substantial improvement in muscular strength as indicated by increases of 190% in biceps flexion, 63% in triceps extension, and 40 and 20% in leg extension at 30 and 180°/s as a result of training in the RT group (Table 2, all P < 0.01). In the RTWL group there were increases of 56% in biceps flexion, 61% in triceps extension, and 76 and 35% in leg extension at 30 and 180°/s (all P < 0.01). Muscular strength assessed by 3 RM of the leg press, leg extension, latissimus pulldown, and upper back by using the Keiser equipment also increased significantly in both groups (P < 0.01) (data not shown). Strength gains were similar between the two groups.

RMR. RMR repeated after insertion of the indwelling catheter was not significantly different compared with the initial metabolic rate in either group before or after training. Thus, for each patient both RMR values were averaged and are shown in Table 3. There were no significant differences in RMR between the two groups, and RMR (kcal/day) did not significantly change from the initial determination. In addition, no changes were observed in either group when RMR was expressed per kilogram of FFM. When all women were combined into one group (n = 15), RMR significantly increased after

### Table 1. Subject characteristics before and after RT or RTWL

<table>
<thead>
<tr>
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<th>Initial</th>
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<tr>
<td>Age, yr</td>
<td>57±2</td>
<td>59±2</td>
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<tr>
<td>Weight, kg</td>
<td>62.2±2.6</td>
<td>62.3±2.6</td>
<td>78.7±2.1</td>
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<td>Body fat, %</td>
<td>36.0±1.8</td>
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<td>43.0±1.9</td>
<td>38.9±1.3*</td>
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<td>Fat mass, kg</td>
<td>21.9±2.0</td>
<td>21.3±2.1</td>
<td>30.3±1.9</td>
<td>28.2±1.7*</td>
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<td>FFM, kg</td>
<td>38.2±1.0</td>
<td>39.3±1.4</td>
<td>43.7±0.4</td>
<td>44.2±0.5</td>
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<td>BMI, kg/m²</td>
<td>23.2±0.8</td>
<td>23.2±0.8</td>
<td>30.2±1.1</td>
<td>28.4±1.1</td>
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<tr>
<td>VO₂max, μl/min</td>
<td>1.5±0.1</td>
<td>1.6±0.1</td>
<td>1.8±0.1</td>
<td>1.7±0.1</td>
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</table>

Values are means ± SE; n = 8 and 7 subjects for RT and RTWL, respectively. * Significantly different compared with initial values, P < 0.01.

### Table 2. Strength values before and after RT or RTWL

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<tbody>
<tr>
<td>Biceps flexion, Nm</td>
<td>10±3</td>
<td>36±5*</td>
<td>27±4</td>
<td>37±5*</td>
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<tr>
<td>Triceps extension, Nm</td>
<td>31±5</td>
<td>39±5*</td>
<td>34±3</td>
<td>52±4*</td>
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<tr>
<td>Leg extension (30°), Nm</td>
<td>62±3</td>
<td>86±7*</td>
<td>66±9</td>
<td>98±8*</td>
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<tr>
<td>Leg extension (180°), Nm</td>
<td>40±2</td>
<td>49±6*</td>
<td>43±4</td>
<td>57±5*</td>
</tr>
</tbody>
</table>

Values are means ± SE; n = 8 and 7 subjects for RT and RTWL, respectively. * Significantly different compared with initial values, P < 0.01.

### Table 3. Resting energy expenditure before and after RT or RTWL

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<tbody>
<tr>
<td>KM/K, kcal/day</td>
<td>1,254±46</td>
<td>1,307±56</td>
<td>1,353±50</td>
<td>1,405±48</td>
</tr>
<tr>
<td>RMR, kcal/kg</td>
<td>34.7±1.2</td>
<td>36.1±1.1</td>
<td>32.7±1.0</td>
<td>33.6±0.8</td>
</tr>
<tr>
<td>FFM</td>
<td>0.80±0.02</td>
<td>0.84±0.03</td>
<td>0.83±0.02</td>
<td>0.80±0.02</td>
</tr>
<tr>
<td>RQ</td>
<td>0.80±0.02</td>
<td>0.84±0.03</td>
<td>0.83±0.02</td>
<td>0.80±0.02</td>
</tr>
</tbody>
</table>

Values are means ± SE; n = 8 and 7 subjects for RT and RTWL, respectively. RMR, resting metabolic rate; RQ, respiratory quotient.
training \( (P < 0.05) \). The fasting respiratory quotient did not significantly change after the interventions.

Before training, RMR (kcal/day) correlated with body weight \( (r = 0.73, \ P < 0.01) \), FFM \( (r = 0.56, \ P < 0.05) \), percent fat \( (r = 0.71, \ P < 0.01) \), and fat mass \( (r = 0.74, \ P < 0.01) \) in the total group \( (n = 15) \). These correlations between RMR (kcal/day) and body composition remained significant after training. However, there was no relationship between changes in RMR and changes in body composition after training in the total group.

SNS activity. Resting supine arterialized plasma NE levels showed a trend toward higher levels as a result of 16 wk of training in the RT group \( (1.12 \pm 0.13 \text{ vs. } 1.25 \pm 0.18 \text{ nmol/l}) \) and in the RTWL group \( (0.98 \pm 0.10 \text{ vs. } 1.16 \pm 0.20 \text{ nmol/l}) \), but changes did not reach statistical significance. Epinephrine levels were not statistically different after training in the RT group \( (541 \pm 181 \text{ vs. } 549 \pm 141 \text{ pmol/l}) \) or in the RTWL group \( (193 \pm 49 \text{ vs. } 181 \pm 33 \text{ pmol/l}) \). No significant correlations were observed between supine NE or epinephrine levels with percent fat, fat mass, FFM, \( V_\text{O}2_{\text{max}} \), or RMR before or after training in the total group \( (n = 15) \).

There were no statistically significant effects of RT on Ra \( (1,277 \pm 159 \text{ vs. } 1,047 \pm 165 \text{ nmol} \cdot \text{m}^{-2} \cdot \text{min}^{-1}) \) or Rc \( (1.02 \pm 0.10 \text{ vs. } 0.85 \pm 0.03 \text{ l} \cdot \text{m}^{-2} \cdot \text{min}^{-1}) \) of NE in the RT group. Even in the small number of patients in the RT group, there was a direct significant correlation between plasma NE levels and Ra \( (r = 0.67, \ P < 0.01) \). Thus, in normal healthy postmenopausal women, plasma NE levels are a good estimate of appearance of NE.

**DISCUSSION**

RMR, the largest component of daily energy expenditure, declines with age and WL, which is thought to be due in part to a decrease in FFM and SNS activity. This study adds two important contributions to the literature: 1) it demonstrates that RT accompanied by WL does not result in a decline in RMR in postmenopausal women; and 2) it shows that basal NE levels are unchanged after RT in postmenopausal women. This suggests that RT may be an ideal intervention to include with dietary restriction to attenuate the potential decline in RMR and loss of FFM in older women. This may have important implications for an individual to maintain a reduced body weight over time.

Weight reduction interventions result in an \(~75\%\) loss in fat mass and a \(25\%\) loss in FFM \( (16) \). In addition, weight reduction alone accompanied by losses in FFM results in a decline in RMR and 24-h energy expenditure \( (11, 12, 26, 35) \). Because of the deleterious effects of WL on RMR and FFM, exercise is often recommended to accompany diets. In our study, the RTWL group had an \(~5\kg\) WL, which was due entirely to a loss in fat mass with no loss in lean tissue; rather, there was an increase of \(0.6\ kg\) of FFM with training. Our study confirms the results of earlier endurance training studies that show that small but significant losses in weight and fat mass \( (~1 \text{ to } -4 \text{ kg}) \) and no change in FFM do not reduce RMR \( (2, 11, 30) \). When increases in FFM and a loss in fat mass occur with RT, the decline in RMR is reversed \( (2) \). When RT in older adults was accompanied by small decreases in fat mass and increases in FFM \( (~2 \text{ kg}) \), there was an increase in RMR \( (3) \). Furthermore, a combined endurance plus RT protocol preserved lean tissue and increased RMR even with a \(10\-kg\) WL in overweight women \( (29) \). Collectively, these results emphasize the importance of exercise and the maintenance of FFM to sustaining energy expenditure after WL. However, when losses in body weight are large \(~20 \text{ kg})\) and FFM is lost as well \( (~4 \text{ to } 5 \text{ kg}) \), RMR significantly declines regardless of the intervention \( (i.e., \text{diet alone, diet } + \text{ aerobic exercise, or diet } + \text{ RT}) \) \( (5, 33) \). We anticipate that a more restrictive caloric regimen from the one we used \( (~10 \text{ to } 20 \text{ kg}) \) along with a long intense RT program might reduce or prevent the loss of \(~4 \text{ to } 5 \text{ kg}) FFM observed with WL alone programs. Similarly, if FFM could be maintained or minimally reduced with a WL of \(~10 \text{ to } 20 \text{ kg})\), reductions in RMR would not be as significant. The decline in RMR with a combination of diet and aerobic exercise has been confirmed \( (14, 34) \); the magnitude of this decline in RMR is probably dependent on the amount of WL and FFM lost, the degree of caloric restriction, and both the frequency and intensity of the exercise program. Studies are needed to examine the protective effect of RT on FFM with greater WL.

Our data suggest that combining RT with caloric restriction in postmenopausal women may offset a decline in resting energy expenditure by maintaining FFM. This suggests that RT may be a better exercise modality than aerobic exercise to preserve or increase FMR during training; this combined intervention would attenuate the drop in RMR associated with WL alone. Because a low metabolic rate may be a risk factor for future weight gain \( (25) \), the addition of RT may be even more beneficial in older individuals attempting to lose weight because of their low initial resting energy expenditure. Thus, a small increase or even a maintenance of RMR by combining RT and WL could influence whether postmenopausal women would be susceptible to regaining the lost weight in the future. Furthermore, despite a decrease in energy intake in the RTWL group, the RTWL group was able to substantially increase strength. RT programs begun and continued through the postmenopausal years or even across the life span may attenuate the decline in strength observed in the very old.

The results of our study indicate that RT increases FFM, decreases percent fat, and shows a trend toward increasing RMR regardless of whether the women are weight stable \( (\text{RT}) \) or lose weight \( (\text{RTWL}) \). Although RMR increased by \(~4\%\) in both groups, these changes were not statistically significant. This increase in RMR was less than the \(7.1\%\) increase we observed in \(13 \text{ older men who performed an identical RT protocol} \) \( (24) \). However, when data from all women were combined, the increase in RMR after training was statistically significant. It is possible that statistical significance would have been achieved in each group with a larger sample size. FFM was positively and significantly associated with RMR before the intervention, explaining \(32\%\) of the variance. After the intervention both groups in-
creased their FFM and the association was stronger, explaining 49% of the variance. It is unclear whether gender, hormonal status (i.e., estrogen deficiency), FFM, or sample size contributed to the differences observed in increases in RMR between older men and women. In postmenopausal women, the small increases in RMR in each group (RTWL and RT) of ~50 kcal/day could be physiologically very significant if maintained over a lifetime.

This is the first study to examine the effects of RT on basal NE levels in postmenopausal women. Although resting NE levels increased in the RT and RTWL groups by ~14 and 19%, the changes did not reach statistical significance. Furthermore, neither Ra nor Rc of NE changed in the RT group. Plasma NE levels did not fall as expected with WL as shown in other studies (4, 20, 37), which suggests that RT is not entirely without effects on SNS activity in older women. We previously showed that strength training increased basal arterialized NE levels by 36% in healthy 50- to 65-yr-old men (24). Similarly, aerobic training increased basal arterialized NE levels in older males (18, 23), although some endurance-training studies have failed to demonstrate changes (6, 21) or report a reduction in plasma NE concentration (15) in young and older males. It is possible that there is a gender difference in the response of the SNS activity to RT that may also explain the difference in response of RMR to RT. Further research is warranted to examine and compare the effects of aerobic and RT on SNS activity in obese postmenopausal women entering a WL program, since maintenance of SNS activity may be important in the prevention of a regain of lost weight.

In summary, RT increases strength with or without WL. The WL with RTWL is attributed entirely to a loss in fat mass and not to a loss in FFM. Our study confirms that small and significant losses in body weight and fat mass do not reduce RMR. In addition, RT results in increases in RMR and FFM levels.

Our appreciation is extended to the women who participated in this study. We also thank Pat Gordon, Wayne Graham, Patricia Rhea, Brian Tracy, Kim Vaitkevicius, and the nurses in the Geriatrics Service at the Baltimore Veterans Affairs Medical Center for technical assistance.

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REFERENCES


23. Poehlman, E. T., and E. Danforth, Jr. Endurance training
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