ABSTRACT The purpose of this study was to determine the effect of a 24-wk diet + exercise (DE) or diet-only program on basal metabolic rate (BMR), bone mineral density (BMD), energy expended during daily activities, muscle strength, and maximal oxygen consumption (VO₂max) in 40 postmenopausal women. Daily energy need was determined by measuring BMR and assessing physical activity with 8-d self-reported activity records. The DE group consumed 2092 kJ/d less than the daily energy need and walked and performed strength-training exercises during which they expended an additional 837 kJ/d. The two diet-only groups consumed either 2092 kJ/d (D-2092) or 2929 kJ/d (D-2929) less than the daily energy need. BMD, BMR, muscle strength, VO₂max, and energy expended during lying, sitting, standing, and walking were measured at baseline and after 12 and 24 wk of treatment. A significant decrease in BMR and energy expended during sitting and walking occurred in all groups, with no significant differences observed among groups. Although the declines in BMR were significant, they were small and may not have been physiologically relevant. No changes in BMD or VO₂max occurred, whereas strength increased significantly in the DE group. The results showed that postmenopausal women significantly improved their body composition over a period of 6 mo without experiencing a large decline in BMR, BMD, or select components of energy expenditure. Am J Clin Nutr 1997;66:867-73.

KEY WORDS Basal metabolic rate, postmenopausal women, weight loss, muscle strength, daily energy need, bone mineral density, oxygen consumption, exercise, energy expenditure

INTRODUCTION

It is well known that dietary restriction can cause a significant decline in resting metabolic rate (RMR) (1). Because RMR accounts for 60-75% of total daily energy expenditure (EE) (2), this decrease in RMR can hinder additional weight loss in dieters or lead to difficulty in maintenance of weight loss.

Exercise training has been proposed as a means to prevent this decline in RMR seen with dieting by increasing metabolically active fat-free mass (FFM), and by having a chronic carryover effect on RMR (3, 4). The results of a recent meta-analysis (5) show that RMR declines significantly with diet alone and diet + exercise (DE) programs but the decline with diet alone is greater.

However, these results are based primarily on studies of premenopausal women who had relatively severe dietary restrictions (3347-5021 kJ/d, or 800-1200 kcal/d) for <10 wk. In addition, few studies incorporated strength training into the exercise regimen. Adding strength training to an energy-restriction program could result in improved maintenance of FFM and RMR compared with aerobic exercise alone.

The issue of increased energy efficiency with dieting is extremely important to an aging population, including postmenopausal women. Metabolic rate declines with age whereas the percentage of body fat increases (6-8). Increased body fat and obesity are closely linked to many disease states, such as heart disease, cancer, hypertension, and diabetes (9). In addition, obesity is associated with an increased incidence of orthopedic problems, which limit mobility and the potential to remain physically active. Although it is often recommended that older individuals attempt to maintain a healthy body weight and improve fitness, traditional means of weight loss may cause a further decrease in RMR, preventing significant weight loss in this group. Lack of results with DE programs may lead to poor compliance and an increased dropout rate, which in turn contribute to poor health status.

The purpose of this study was to determine the effects of 24 wk of a moderate energy deficit alone and in combination with aerobic and strength-training exercises on both resting EE and EE during activity in postmenopausal women. Study endpoints included basal metabolic rate (BMR) and EE during lying, sitting, standing, and walking at two speeds. In addition, changes in body composition and bone density were determined. Changes in cardiovascular risk factors in this same group of subjects are reported elsewhere (10).
SUBJECTS AND METHODS

Subjects

Forty postmenopausal women (x ± SD age: 65 ± 3 y) who were 120–140% of ideal body weight according to the 1959 Metropolitan Life Insurance Company weight chart (11) volunteered for this study. None of the women had performed ≥ 2 h of aerobic exercise weekly for 1 y before the start of the study, and none were experienced with strength training. All subjects were healthy and free from any metabolic disorders; none were taking medications known to affect EE. Women who had been receiving estrogen replacement therapy (ERT) for ≥ 6 mo were included. All subjects gave written, informed consent as approved by the Human Subjects Committees of Stanford University and the Palo Alto Veterans’ Affairs Health Care System.

Study design

The study was 26 wk in duration, including 2 wk of baseline measures followed by 24 wk of a diet-only or DE program. Subjects were studied as outpatients, except for 3-d stays in the metabolic unit at each study point. During the initial 2 wk of baseline, subjects completed 8 d of the diet and activity records. BMR, body composition, maximal oxygen consumption (VO₂ max), and EE during lying, sitting, standing, and walking were determined while subjects were in the metabolic unit. These indexes were determined again at 12 and 24 wk of the program.

Group assignment

Subjects were assigned to one of three groups. One group participated in the DE program whereas the other two groups completed a diet-only program. One diet-only group was instructed to consume 2092 kJ/d (500 kcal/d) less than needed for weight maintenance determined during the baseline period (D-2092); the second group consumed 2929 kJ/d (700 kcal/d) less than needed for weight maintenance (D-2929). The subjects in the DE group were instructed to consume 2092 kJ/d less than needed for weight maintenance, and performed exercises that expended an additional 837 kJ/d (200 kcal/d), for a total energy deficit of 2929 kJ/d.

It became apparent during the telephone screening process that many potential volunteers were not able to commit to the DE portion of the program because of time constraints. Thus, only those subjects who were capable of participating regularly in the DE program for the entire 24-wk period were self-selected into that group. Remaining qualified volunteers were randomly assigned to the two diet-only groups. An attempt was made to match the groups for initial age, height, and weight (Table 1).

Assessment of daily energy need

The energy needs of each subject were estimated from self-reported activity records completed during the baseline period and from BMR measured during this same period. The records were completed over 4 weekdays and 4 weekend days. Subjects recorded all activities and time spent at each activity throughout each 24-h period. Investigators tallied the total time spent performing each activity, and daily EE was computed by using individual BMR values and multiplying each subjects’ BMR by energy values reported by Mulligan and Butterfield (12). The average estimated daily energy need was 1.5 × BMR for all subjects. Previous studies completed in our laboratory using a similar technique for postmenopausal women (13, 14) found the estimated daily energy need to be within 837 kJ/d (200 kcal/d) of the actual energy need as determined by feeding to nitrogen balance.

Diet program

All subjects were instructed by a registered dietitian on how to use the American Diabetic Association’s exchange list program. Each woman’s program was individually designed to provide an energy intake that was either 2092 or 2929 kJ/d less than that estimated as needed to maintain body weight at the initiation of the program. The macronutrient content of the diet was prescribed to meet the American Heart Association’s guidelines of 30% of energy as fat, 50–55% as carbohydrates, and 10–15% as protein. Subjects were instructed by the dietitian to self-select foods meeting these criteria. Adherence was monitored by having subjects complete 3-d diet records once per week during the first month of the program and bimonthly for the remaining 5 mo. Subjects met individually with a dietitian or trained diet counselor during these times to discuss dietary issues and to have their body weight measured while in a light hospital gown with an electronic scale (measured to the nearest 0.1 kg). All subjects were encouraged throughout the program to decrease their total and saturated fat intakes and to increase their intake of complex carbohydrates. All subjects attended classes regarding low-fat cooking and eating-out and shopping guidelines.

Exercise program

Subjects participating in the DE program were required to exercise 5 d/wk according to the guidelines recommended by the American College of Sports Medicine (15). All exercise sessions were supervised by a trained exercise counselor. Three of the 5 d of exercise consisted of subjects walking 3 d/wk for 1 h at a heart rate consistent with 60–75% of measured VO₂ max. Heart rate was monitored by each subject at 20-min intervals during the walk. Subjects unable to complete the full hour at the start of the program were allowed to gradually increase exercise time. All subjects were able to complete 1 h of walking by week 5 of the program.
The remaining 2 d of exercise consisted of participation in a strength-training program 2 d/wk. The strength-training program consisted of 12 exercises working the major muscle groups of the upper and lower body. Subjects performed three sets of 10 repetitions of all exercises at 80% of one repetition maximum (1 RM). Workload was assessed once every 2 wk, and any necessary adjustments were made to maintain lifting intensity at 80% of 1 RM.

BMR and activity energy expenditure

BMR was measured by indirect calorimetry over three consecutive mornings. Subjects were gently awakened at 0600 and breathed into a Hans-Rudolph three-way valve attached to a Douglas bag (Warren E Collins, Braintree, MA). Expired gases were collected for 10 min and subsequently analyzed for oxygen and carbon dioxide contents with oxygen and carbon dioxide analyzers (Ametek, Pittsburgh) calibrated previously by using gases of known concentration. Volume was measured with a Parkinson-Cowen gasometer (Instrumentation Associates, Inc, New York). BMR (kcal/min) was calculated by using the Weir equation (16). The means of the BMR values that most closely matched were taken to represent BMR for each subject. Reliability of the BMR measures in this group of subjects, as determined by intraclass correlation, was 0.95.

After the BMR measurement, subjects were allowed to rise and void and then returned to bed. Subjects rested in the supine position for ≥30 min after returning to bed, after which expired gases were collected for 10 min and subsequently analyzed. Subjects then dressed, and expired gases were collected while they were sitting in a chair, standing on a treadmill, and walking at 37.5 m/min (1.4 mph) and 64.3 m/min (2.4 mph) on the same treadmill. All gases were analyzed by using equipment and procedures identical to those used to measure BMR.

Body composition and VO_{2max}

Body composition and total bone mineral density were determined with dual-energy X-ray absorptiometry (Hologic 2000, version 5.54; Hologic Inc, Waltham, MA). The CV for replicate measures in our laboratory was <1%. Bone mineral density was reported as g/cm². VO_{2max} was measured by using indirect calorimetry and a treadmill-walking protocol in which subjects warmed up for 2 min at 37.5 m/min, after which speed was increased to 59.0 m/min (2.2 mph), and the slope was increased 1%/min. Heart rate was monitored continuously and blood pressure was recorded every 3 min. Subjects were strongly encouraged to walk until VO_{2max} plateaued and a respiratory exchange ratio >1.1 was reached. Achievement of VO_{2max} was assumed given these parameters at volitional cessation of walking.

Follow-up measurements of body weight

After completion of the program, 29 of the original 40 subjects agreed to return to our laboratory for a measurement of body weight. This weight measurement was done on a day that corresponded to a 3–5-mo period between program completion and follow-up. All women were weighed under conditions similar to those during study participation. This follow-up measurement was done to determine whether subjects maintained, lost, or gained weight after completion of the program.

Statistical analyses

Data were analyzed by using Statistical Analysis Software for Personal Computers (SAS-PC, version 6.2; SAS Institute Inc, Cary, NC). Data were compared by using a 3 X 3 X 2 (group × time × ERT) analysis of variance (ANOVA) with repeated measures. Tukey’s post hoc tests were used to determine significant differences. Multiple-regression analyses were performed to examine the relation between changes in the select EE components relative to changes in FFM among the treatments. In addition, analysis of covariance (ANCOVA) was used to test for any treatment effects on the components of EE whereas differences in FFM were adjusted for. Significance was set at an α level of \( P ≤ 0.05 \).

RESULTS

Descriptive characteristics of the three treatment groups were reported previously (10). All groups were well matched for all characteristics; thus, the average values for all treatment groups are reported in Table 1.

There was no effect of ERT on any of the dependent variables; thus, the data for those women receiving ERT were combined with the data for the other women in the same treatment group. As reported previously (10), body weight, body fat mass, and percentage body fat decreased significantly in all groups (\( P < 0.05 \)). FFM also showed a small but significant decrease (\( P < 0.05 \)) (10). There was no change in bone mineral density for any of the groups over the treatment period (Figure 1).

There was a significant time effect for BMR (\( P = 0.0001 \)), with values at 12 and 24 wk being significantly lower than values at baseline for all groups (Figure 2, panel A for DE, panel B for D-2092, and panel C for D-2929). The consistent change in BMR for each subject in each treatment group is illustrated in Figure 3. ANOVA revealed no significant
FIGURE 2. Changes in basal metabolic rate relative to changes in fat-free mass of 40 postmenopausal women participating in a 24-wk program of diet plus exercise (A; n = 16), a diet providing 2092 kJ/d less than the energy need (B; n = 13), or a diet providing 2929 kJ/d less than the energy need (C; n = 11). Values at baseline were significantly higher than those at weeks 12 and 24 of treatment (P ≤ 0.05).

DISCUSSION

This study is one of only a few studies to measure the effects of a moderate-dietary-restriction program combined with aerobic and strength-training exercises on EE in postmenopausal women. The experimental treatment was longer than treatments in other published studies, and a follow-up measurement of body weight was also made to determine potential weight changes 3–5 mo after the end of a diet-only or DE program. One limitation of this study was that only select components of total daily EE were measured. Without the use of the doubly labeled water method, it is difficult to assess the effects of the present treatments on 24-h, free-living EE. It is possible that unmeasured components of total daily EE were affected, influencing the present findings.
The results of this study support the contention that a moderate-energy-deficit diet in combination with exercise training can assist in the maintenance of BMR in postmenopausal women. Although BMR decreased significantly in all groups, the decline was slight. The maintenance of BMR was most likely due to a very small decline in FFM in these subjects (10). One explanation for the small but significant decrease in BMR observed in the present study was the high precision of the method used to measure this variable. This small change may not be physiologically relevant even though it was significant.

The average decreases in BMR for the DE and diet-only groups were 297 kJ/d (71 kcal/d) and 326 kJ/d (78 kcal/d), respectively. These data are in marked contrast with data from other diet-only and DE studies, in which more severe energy restrictions were prescribed (< 5021 kJ/d, or < 1200 kcal/d) to premenopausal women over 8–12 wk. The average decreases in BMR in these studies were 573 kJ/d (137 kcal/d) and 753 kJ/d (180 kcal/d) for DE and diet-only groups, respectively (5).

It is difficult to compare the results of the present study with those of premenopausal women because of differences in methodology between the studies. In one of the few studies in which premenopausal women participated in a program of relatively moderate energy deficit (280 kJ, or 1170 kcal/d) and walking exercise, FFM and BMR were reported to be maintained (17).

Only one study of diet-only and DE groups of postmenopausal women could be found in the literature (18). Both FFM and RMR were measured after 12 wk of a diet-only (4200 kJ)
TABLE 3
Maximal oxygen uptake (\(\dot{V}O_{2\text{max}}\)) and muscular strength in 16 postmenopausal women participating in a 24-wk diet + exercise program

<table>
<thead>
<tr>
<th>Muscle Tested</th>
<th>Baseline</th>
<th>Week 12</th>
<th>Week 24</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\text{(mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}))</td>
<td>(\text{(mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}))</td>
<td>(\text{(mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}))</td>
</tr>
<tr>
<td>Triceps extension</td>
<td>15.4 ± 3.4</td>
<td>15.2 ± 3.2</td>
<td>15.3 ± 3.2</td>
</tr>
<tr>
<td>Biceps curl</td>
<td>10.4 ± 3.2</td>
<td>10.2 ± 3.0</td>
<td>10.3 ± 3.1</td>
</tr>
<tr>
<td>Latissimus dorsi pull</td>
<td>21.7 ± 7.7</td>
<td>21.5 ± 6.5</td>
<td>21.7 ± 6.3</td>
</tr>
<tr>
<td>Military press</td>
<td>22.0 ± 5.5</td>
<td>21.8 ± 4.1</td>
<td>21.9 ± 4.2</td>
</tr>
<tr>
<td>Leg curl</td>
<td>7.5 ± 3.0</td>
<td>7.3 ± 4.1</td>
<td>7.5 ± 4.2</td>
</tr>
<tr>
<td>Leg extension</td>
<td>17.0 ± 6.4</td>
<td>16.8 ± 5.9</td>
<td>17.0 ± 6.5</td>
</tr>
<tr>
<td>Leg press</td>
<td>45.3 ± 13.5</td>
<td>45.2 ± 15.2</td>
<td>45.4 ± 15.5</td>
</tr>
<tr>
<td>Back extension</td>
<td>30.1 ± 14.2</td>
<td>29.7 ± 17.9</td>
<td>30.0 ± 14.3</td>
</tr>
</tbody>
</table>

\(\dot{V}O_{2\text{max}}\) was measured on more than one occasion in the previous study and the reliability of the RMR measures for the subjects in the previous study were not reported. These limitations make comparisons of changes in metabolic rate between the studies difficult to interpret.

The addition of exercise to the moderate-energy-deficit diet prescribed to subjects in the present study did not seem to have a significant protective benefit as evidenced by the small decrease observed in BMR. However, there was a trend for those in the DE group to experience a smaller decrease in BMR and EE while walking than those in the D-2929 diet-only group. Because the theoretical energy deficit for both of these groups was 2929 kJ/d, these findings may support some protective benefit of exercise training added to a diet regimen. A recently published meta-analysis (5) of diet-only and DE studies of predominantly premenopausal women showed that the addition of exercise to a diet program can help prevent some of the decrease observed in BMR and results in a smaller decrease in FFM, despite similar weight loss, compared with diet alone.

Many of the subjects in this study experienced a plateau in weight loss after 12 wk of participation (10). This plateau could be directly attributed to lack of compliance with the dietary program as well as to the decrease in EE observed at rest and during sitting and walking. Although reported activity levels remained consistent throughout the program, it is possible that these women compensated for the increase in EE during exercise training by increasing the amount of time spent in more sedentary activities such as lying, sitting, and sleeping. Such a change in activity pattern has been shown to occur in energy-restricted men (20) and obese premenopausal women (21). In addition, many of the subjects in the present study reported eating significantly more food, and in particular, selecting more fat exchanges than were prescribed after the first 12 wk of treatment.

The ability of postmenopausal women to increase their muscle strength with strength training has been reported by others (22, 23). Contrary to the findings of Pyka et al (22) and Charette et al (23), our subjects did not experience a plateau in strength observed previously in elderly women after 8 wk of strength training. The only exercises in the present study that resulted in such a plateau were the leg press and back extension. However, the strength gains for all exercises in the present study were more dramatic over the first 12 wk of training; a similar pattern was reported by Pyka et al (22) and Charette et al (23).

Exercise participation was associated with continued weight loss 3–5 mo after the program ended. Both the subjects in the DE group who continued to exercise and those in the diet-only groups who initiated an exercise program experienced additional weight loss after completion of the program. Weight gain occurred in those who discontinued exercise or who never initiated an exercise program. van Dale et al (24) reported a significant increase in body weight from 6 to 42 mo after a DE program in premenopausal women. The follow-up in the present study was relatively short, and it is unknown whether the body weight of the subjects in the present study would have increased with a longer follow-up period. However, these short-term findings emphasize an added benefit of exercise to weight loss and maintenance of weight loss in overweight postmenopausal women.
The results of this study show that postmenopausal women can lose significant body weight and body fat without experiencing a large decline in BMR. Because there was a trend for the women in the D-2929 group to experience a greater decrease in EE than the DE and D-2092 groups at rest and during walking, it may be that the addition of exercise to a moderate-energy-deficit diet is somewhat protective of the maintenance of EE. The addition of exercise was also beneficial in subjects achieving continued weight loss after the end of the program. These findings are important because it is critical for overweight postmenopausal women to maintain BMR and bone mass while reducing body fat.

We thank the nursing staff and David Guido of the Aging Study Unit at the Palo Alto Veterans’ Affairs Health Care System; Dorothy Parker, Lisa Savage, Amanda Blake, Amanda Fox, and Jane Borchers for providing excellent dietary counseling and exercise supervision; and all of the women who participated in this program and contributed to its success.

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