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Resistance Training Predicts Six-Year Body Composition Change in Postmenopausal Women

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Abstract

Purpose—The aim of this study was to examine the association of exercise frequency (ExFreq) and volume (total weight lifted by military press (MP) and squats (SQ)) with change in body composition among postmenopausal women participating in a progressive resistance training study.

Methods—Previously sedentary women (n=122, age 56.3±4.3 years) were followed for 6yrs. At 6yrs, there were women who had been randomly assigned to resistance training at baseline (n=65) controls that were permitted to cross-over to the exercise program at 1yr (n=32), and 25 true controls. Exercisers and crossovers directed to perform 8 core exercises for two sets of eight repetitions at 70–80% of one repetition maximum, three times weekly, plus progressive weight bearing, stretching, and balance. Body weight and fat were measured at baseline and annually using anthropometry and dual-energy x-ray absorptiometry.

Results—Average change in body weight and total body fat were 0.83±5.39 kg and 0.64±4.95 kg at six years, respectively. In multiple linear regression, ExFreq, MP, and SQ were significantly, inversely associated with change in body weight (standardized beta coefficient (SBC)=−0.22 to −0.28, p<0.01), fat (SBC=−0.25 to −0.33, p<0.01) and trunk fat (SBC=−0.20 to −0.31, p<0.03) after adjusting for age, years on hormone therapy, change in lean soft tissue, baseline body composition, and baseline habitual exercise. The lowest tertile of SQ (equivalent to 2.5% attendance) demonstrated significant gain in weight, fat, and trunk fat over 6 years (p<0.004), whereas the highest tertile SQ (equivalent to 64% attendance) was able to maintain their weight, total and regional fat.

Conclusion—We conclude that resistance training is a viable long-term method to prevent weight gain and deleterious changes in body composition in postmenopausal women.

Keywords

body weight; body fat; strength training; weight training; long-term

Introduction

The dramatic rise in the prevalence of overweight and obesity in the United States from less than 50% to two-thirds over the last 30 years is alarming, and there is little dispute over the medical implications, i.e. heart disease, type 2 diabetes, and certain cancers.(9,10) The impact

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on health care costs will be enormous. Estimates in 2000 put the cost at \$117 billion annually (47) and the costs will rise with an increase in obesity prevalence as “baby boomers” and overweight children become older.

Lifestyle factors, such as lack of portion control, high accessibility of food, and lack of physical activity, as well as many other understudied lifestyle factors, such as sleep debt, endocrine disruptors, pharmaceutical iatrogenesis, and others, have been associated with increasing weight in the United States and around the world.(28) Weight gain in postmenopausal women is of particular interest, due to shifts in adipose distribution after menopause (i.e. increased deposition of highly inflammatory abdominal fat with loss of endogenous estradiol) (29,42) and age related reductions in physical activity.(8,37,43) Midlife women may gain an average of 0.7kg per year and 0.7cm in waist circumference each year.(44) Additionally, it has been estimated that lack of physical activity and excess weight are responsible for 31% of the overall mortality in women. (22)

Although weight loss is often the focus in postmenopausal women and others, barriers to program initiation and maintenance exist. (32) Additionally, high levels of program attrition and weight regain estimated at an average of 77% of the total initial weight lost within 4 to 5 years (2,31) are significant issues in the battle against the obesity epidemic. Within this context, simple prevention of weight gain throughout the lifespan becomes an increasingly attractive strategy for health promotion and disease prevention.

Exercise is a well-accepted contributor to weight loss with caloric restriction and post-weight loss weight maintenance.(10,46) Evidence supports the theory that aerobic exercise is especially effective in controlling weight,(10,14), but little is known about the effects of resistance training on long-term weight management. Theoretically, resistance training may contribute to increased energy expenditure during activities of daily living, as well as intentional physical activity, due to increased energy burning muscle mass and increased ease of physical activity.(23)

The Bone Estrogen Strength Training study, including post-menopausal women blocked by hormone therapy (HT) versus no hormone therapy and randomized to exercise (EX) or no exercise NEX), was designed to examine the effects of resistance training on bone mineral density in postmenopausal women,(11,18,34,45) but also provided an opportunity to examine the effects of training on soft tissue changes and weight maintenance in a group of middle-aged and older women. In a secondary analysis, we tested the hypothesis that women who maintained a higher frequency or volume of training over 6 years would prevent weight gain and slow fat deposition while those with a lower frequency of training would gain weight.

Methods

Study Design

The Bone Estrogen Strength Training (BEST) Study was a block-randomized clinical trial designed to examine the relationship of resistance training exercise to bone mineral density (BMD) in early postmenopausal women.(18) Women were randomized to either exercise or control conditions within groups stratified by hormone therapy. At the end of the first year of intervention (n=266 completers of one year trial), controls were permitted to begin or “cross over to” the prescribed exercise regimen (crossovers) and were followed annually for body composition.(11) The BEST study was reviewed and approved by the University of Arizona Human Subjects Review Committee, and written informed consent was obtained from all subjects prior to study entry.

For the present study, 122 women (45.9% of first year completers) who completed baseline and at least the sixth year of annual testing were assessed for changes in weight, total body fat, regional fat, and lean soft tissue. All participants randomized to exercise and crossovers recorded resistance training exercises in daily logs. Six-year controls (n=25) were assigned an exercise frequency (ExFreq) of 0.0%.

Recruitment and Entry Criteria

Subjects were recruited using selected zip codes for direct mailing, medical clinics, community organizations, and media advertisement. Initial telephone screening was followed by small group meetings during which study requirements were explained, informed consent procured, and initial demographic data collected. Inclusion criteria were as follows: 40–65 years of age; surgical or natural menopause (3.0–10.9 years); body mass index (BMI) greater than 19.0 kg/m² and less than 33.0 kg/m²; non-smoking; no history of osteoporotic fracture and an initial BMD greater than Z-score of –3.0; undergoing hormone therapy (HT) (1.0–5.9 years) or not undergoing HT (>one year); no weight gain or loss greater than 13.6 kg (30 lbs) in the previous year; free of cancer and cancer treatment for last five years (excluding skin cancer); not using BMD-altering medications, beta-blockers, or steroids; dietary calcium intake >300 mg/day; performing less than 120 minutes of low intensity, low impact exercise per week and no weightlifting or similar physical activity. Participants agreed to be randomized to exercise or control and continue their usual dietary practices, maintain their HT status, and take daily calcium citrate supplements for the duration of the intervention period. Six years of data were accumulated from 1995 to 2004 in six staggered cohorts.

Hormone Therapy

Women using HT were asked to continue to follow the regimen prescribed by their physicians and to report any changes every year. A variety of hormone combinations were used; at baseline, most women took estrogen plus progesterone (80%), oral estrogen (10%), or estrogen and/or progesterone by patch (10%).

Anthropometry

At baseline and 6 years, standing height and weight were measured with participants wearing lightweight clothing and no shoes. Height (cm) was measured to the nearest 0.1 cm at maximal inhalation with a Schorr measuring board. Weight (kg) was measured using a calibrated scale (SECA, model 770, Hamburg, Germany) accurate to 0.1 kg. The average height and weight from three trials was used to calculate BMI (weight (kg)/height (M²)).

Dual Energy X-ray Absorptiometry

Total and regional body composition were measured at baseline and annually thereafter by dual energy x-ray absorptiometry using a total-body densitometer (model DPX-L; Lunar Radiation Corporation, Madison, WI). Subject positions for total body scans were standardized according to manufacturer's recommendations as previously described. (21) Each subject was scanned twice at baseline and at follow-up and the mean of the two measurements was used in analyses. Initial scan analysis for bone, total body fat, regional fat, and lean soft tissue, including the placement of baselines distinguishing bone and soft tissue, edge detection, and regional demarcations, was done by computer algorithms (Version 1.3y, Lunar Corporation). (45) One certified technician inspected all scans at all intervals and adjustments were made to the analysis when necessary, ensuring proper placement of cut lines for accurate delineation of regions of interest. Calibration of the densitometer was checked daily against a standard calibration block supplied by the manufacturer. Subjects were scanned in duplicate within approximately 2 weeks at baseline (n=320) and for the first 4 years (n=158); technical error between duplicates, which is derived from the standard deviation of within-subject variance,

was 2.04% and 2.64% at baseline (similar at four years) for total body and trunk fat tissue, respectively.

Exercise Program

Participants randomized to the exercise intervention were asked to attend training sessions three days per week, on non-consecutive days, in one of four community facilities under the supervision of study on-site trainers. Sessions lasted 60–75 minutes and included warm-up (5–10 min), progressive weight bearing (25 min, walking and stair stepping with weighted vests and circuit of skipping, hopping, jumping, jogging without added weight), resistance exercises (30 min), abdominal strengthening (5 min), and stretching and balance (5 min).⁽³⁴⁾ ExFreq, weightlifting loads, sets and repetitions, steps with weighted vests, and minutes of progressive weight bearing activity were recorded in exercise logs which were monitored regularly by on-site study trainers for the intervention year. Following the initial intervention year, participants were asked to continue resistance training and record the resistance activities in their study logs; other components of the program were not specifically monitored following the first year of intervention or crossover.

Trainers had a degree (B.S. or M.S.) in exercise science or a related field and certification by a nationally recognized fitness and strength training organization. In addition, a study physical therapist further educated the trainers on the BEST program specifically. The participant-to-trainer ratio was five-to-one in the first year. Supervision was reduced during the second year, and in the third through sixth years, trainers were available at each facility one morning or afternoon per week. Crossover exercisers received supervision comparable to randomized exercisers because new cohorts with trainers were present in all facilities during the entire study.

Resistance exercises were done using free weights and machines. Eight core exercises focused on major muscles. These exercises included the seated leg press, lat (*latissimus dorsi*) pull down, weighted march, seated row, back extension, one-arm military press (right and left), squats (wall squats initially, progressing to Smith or hack squats), and the rotary torso machine.

Women completed two sets of six to eight repetitions (four to six repetitions for the military press to decrease injury to the shoulder) at 70% (two days per week) or 80% (one day per week) of the one-repetition maximum (1-RM), determined by monthly testing during year 1. Further details regarding the exercise program can be found elsewhere. (18,34,45)

An essential part of the intervention program was a comprehensive social support program designed to foster continued resistance training beyond the 1 year study design and to avoid poor adherence which may bias results, as described by Metcalfe et al. (34) The program was based on social cognitive/social ecological theory constructs and encompassed a variety of interpersonal, intrapersonal and environmental reinforcement strategies to motivate participants and promote the high levels of retention (83%) the study experienced for the Year 1 intervention. Primary components of the social cognitive constructs underlying the program included: education and skill development, self-efficacy, incentive programs, social support, and modeling. Within this context, participation was based on individual improvement rather than competition among participants and a fun, social environment that challenged the women to improve their daily exercise performance. Some examples of the intervention support programs included: orientation workshops, monthly newsletters, Personal Best testing every two months to monitor progress, yearly evaluation results, goal-setting logs, personal contracts, motivational meals scheduled every two months, and two major promotional events held at the exercise facilities each year.

Habitual Physical Activity

Baseline habitual exercise was assessed with the 7-day physical activity recall questionnaire developed by Blair et al. (5) Participants were interviewed using a standardized protocol about their time spent in moderate, hard and very hard activities during the preceding week. Self-reported minutes of activity and the metabolic equivalents (METs) for specific activities, classified by the Ainsworth, et al Compendium of Physical Activities, (1) were then used to calculate the average daily energy expenditure (kcal/d). Participants were also asked if their recorded week included more or less than their usual amount of exercise.

Statistical Analysis

At baseline and once per year for the following 4 years, two measurements of body composition were taken and the mean of the two values was then used in subsequent analyses; for years 5 and 6 single DXA scans were taken to limit radiation exposure, thus only the individual scan values were used for those years. Change in weight and body fat over six years was calculated as the difference between the kilograms at the end of each of the six years minus baseline kilograms.

ExFreq and volume of exercise were computed from the detailed BEST program exercise cards provided to each participant throughout the six years and filled out by the women at each session. Annual frequency was expressed as a percent by dividing the number of sessions performed by the number prescribed for that year and multiplying by 100. ExFreq for controls was set at 0%. Crossovers were assigned 0% frequency in the first year and then their actual percent frequency for the subsequent years. ExFreq used in analysis was the average over the entire six years regardless of intervention group assignment. Volume of exercise was determined by selecting representative resistance exercises for upper and lower body (military press, MP and squats, SQ) and multiplying the weight lifted per repetition by number of repetitions and by number of sets completed for each of these exercises per session (i.e. kg lifted per rep x reps x sets), as recorded by participants. Session totals were then summed for annual total weight lifted for MP and SQ, as well as summed across all six years.

Crossovers may have been affected by the date of exercise initiation, since total frequency of exercise over 6 study years was used in this analysis and their year 1 total was zero by design; thus the date of exercise initiation was evaluated for exercisers versus crossovers. The results for regression models to evaluate the effect of date of exercise initiation, based on data for exercisers and crossovers, demonstrated that the relationship between ExFreq and outcome variables was not altered therefore, date of exercise initiation was not included in the final analytical models presented herein.

Four women with recorded ExFreq were missing DXA values for body composition at year 6. One woman had a scan at 5 years and also returned for a seventh year; in this case, the average of her year 5 and year 7 results were imputed. In the other three cases, last observation carried forward (LOCF) was used, imputed from year 5. Four different women were missing habitual exercise energy expenditure. The mean of the remaining 118 women was imputed in these cases. There were no discernable changes in the findings before and after imputation.

Independent t-tests were used to compare baseline characteristics between completers (n=122) and those lost to follow-up (n=198). Means and standard deviations were calculated for baseline characteristics and six-year changes. The significance of six-year changes in body weight, fat, and lean soft tissue was tested using paired t-tests. Pearson correlations were conducted to assess the associations among dependent and potential independent variables to be used. Analysis of variance (ANOVA) was used to test for difference in body weight, body composition, and exercise frequency and volume between controls, crossovers, and exercisers

with Tukey HSD post-hoc test for multiple comparisons. Analysis of covariance (ANCOVA) was used to compare weight and body composition variables between tertiles of exercise volume (i.e. weight lifted in the squats exercise over 6 years). ANCOVA models produced adjusted means and standard errors adjusted for age, years taking hormones over the 6 year period, baseline weight, baseline lean soft tissue (LST), change in LST, baseline exercise energy expenditure, and whether or not it was representative of more, less, or usual activity (self report)

Variables chosen for multiple linear regression models were based on “a priori” hypotheses and correlations. Models were constructed for change in body weight and change in total and regional body composition as the dependent variables and mean percent six-year ExFreq, weight lifted in military press, and weight lifted in squats (i.e. exercise volume for upper and lower body respectively) as the independent variables of interest; they were adjusted for age, years on HT during the 6-year follow-up, baseline BMI, 6-year change in lean soft tissue (LST) for models of change in total and regional fat (change in fat tissue was used for the change in LST model), baseline habitual exercise energy expenditure and self-reported indicator as to whether the habitual physical activity was more or less than usual. Two variables were given indicator values for less or more activity in reference to usual activity.

Type 1 error was set at $\alpha=0.05$ (two-sided) for all analyses, which were conducted using SPSS 16.0.

Results

Baseline Characteristics

Baseline characteristics for the participants are given in Table 1. Women were, on average, 56.3 ± 4.3 years old and 6.2 ± 3.4 years postmenopausal. They had a mean weight of 67.9 ± 11.6 kg and a mean BMI of 25.5 ± 3.8 kg/m². Percent body fat, body fat and LST were $38.7 \pm 6.4\%$, 26.5 ± 8.3 kg and 38.3 ± 4.5 kg, respectively. The average habitual exercise energy expenditure at baseline was 182.7 ± 166.9 kcal/day. There were no differences at baseline among the controls, crossovers, and exercisers. A comparison of baseline characteristics, including age, hormone therapy use, years postmenopausal, height, weight, BMI, and total body fat, between those included in the present analysis (6 year completers, $n=122$) and those lost to follow-up ($n=198$) was also performed (Table 2). Completers were highly representative of the total study population, although older (56.3 ± 4.3 versus 54.6 ± 4.9 years, $p<0.05$) and had been menopausal slightly longer (6.2 ± 3.4 versus 5.6 ± 3.0 years, $p=0.09$).

6-Year Change Characteristics

Changes in body composition, ExFreq, and volume of weight lifted for representative lifts (MP for upper body and SQ for lower body) are shown in Table 3. On average, women gained 0.83 ± 5.4 kg in body weight, 0.64 ± 5.0 kg of body fat, 0.64 ± 2.60 kg trunk fat, and 0.1 ± 1.7 kg of LST by 6 years. Over the 6 years, the number of controls was reduced to $n=25$, while those with some exercise totaled 97 (cross-over + exercisers). Over the same time period, ExFreq averaged $30.9 \pm 29.8\%$, with significant difference between controls, crossovers, and exercisers ($0.0 \pm 0\%$, $24.0 \pm 22.6\%$, $46.2 \pm 28.3\%$, respectively, $p<0.001$). Weight lifted in military press and squats was also significantly different between controls, crossovers, and exercisers ($p<0.001$). Body composition differences among the three groups were not significant; however, weight gain over the 6 year period occurred in stepwise fashion with controls gaining the greatest amount of weight (2.1 ± 4.3 kg controls, 0.7 ± 4.4 kg crossovers, 0.4 ± 6.2 kg exercisers). Significant gains in weight and total body fat were found between baseline and 6 years in controls only ($p<0.05$).

Linear regression models evaluated ExFreq and volume of weight lifted for upper and lower body (MP and SQ respectively) as contributors to 6 year change in weight, total body fat, trunk fat, arm fat, leg fat, and lean soft tissue (Table 4). Models for weight and total and regional fat were robust, accounting for 12–27% of the variance after adjusting for the following: age, baseline body composition by outcome variable, 6 year change in LST for models of weight, total and regional fat (6 year change in fat tissue for LST models), baseline exercise energy expenditure, and years on hormone therapy to account for hormonal influences on body composition. In contrast, the model evaluating change in LST only accounted for 4–7% of the variance. Baseline energy expenditure and years hormone therapy did not significantly contribute to the models.

In the regression models, ExFreq and volume of weight lifted were all significant, independent predictors of body weight, total body fat, and regional body fat (trunk, arm, and leg) over 6 years. These associations were inverse, indicating that increased training resulted in decreased weight and fat ($p < 0.03$ across models of weight and fat, standardized beta coefficients ranging from -0.20 to -0.33). ExFreq was less predictive of change in six year LST ($p = 0.13$) than volume of weight lifted for upper and lower body (MP and SQ positively associated with change in LST from baseline to 6 years, $p < 0.04$). From the unstandardized regression coefficient for ExFreq, we estimated the increase in LST for those who maintained 67% attendance over six years ($n = 24$; 20% of 6 year completers), which was equivalent to 2 days per week. LST increased 0.51 kg (1.3%) for exercisers with 67% attendance compared to 0.2 kg for all exercisers.

An additional analysis was run to depict weight, total body fat, and trunk fat by tertile of weight lifted in the squats exercise for each of the 6 years (Figure 1). Weight lifted in the squats exercise compares well with weight lifted in the MP or ExFreq; the correlation between ExFreq and MP was 0.82, between ExFreq and squats was 0.85, and between squats and MP was 0.87. The average percent ExFreq for the lowest, middle, and highest tertiles of weight lifted in the squats exercise was $2.5 \pm 4.2\%$, $25.3 \pm 20.8\%$, and $64.2 \pm 16.2\%$ respectively, where the highest tertile represents resistance training approximately 2 days per week, each week for 6 years.

Baseline body weights were 67.0 ± 11.6 kg for the lowest ($n = 40$), 68.7 ± 12.2 kg for the middle ($n = 41$), and 69.5 ± 11.8 kg for the highest ($n = 41$) tertiles of total weight lifted in squats ($p = 0.65$ between groups), and over each of six years body weight was not significantly different among tertiles of weight lifted in the squats exercise. However, the lowest tertile of weight lifted in the squats exercise significantly increased total body weight, total body fat, and trunk fat ($p < 0.004$) over 6 years, while the middle tertile showed a trend towards increased trunk fat over 6 years ($p = 0.06$). Only the highest tertile of weight lifted in the squats exercise showed no difference over 6 years for total body weight, total body fat, or trunk fat, i.e. body weight and fat were maintained over 6 years postmenopausally. Results were similar for weight lifted in MP and for ExFreq (data not presented).

Discussion

The results of this secondary analysis demonstrated that frequency and volume of resistance training exercise predicted 6-year changes in body weight and fat in postmenopausal women and support the use of regular resistance training as a means of weight management. Although the BEST resistance training program was designed to be performed 3 days per week, an average of 2 days per week for 6 years was enough to maintain body weight, total body fat, and trunk fat. Significant weight, total and regional body fat losses were achievable with higher frequencies of resistance training, as demonstrated by the results of regression analyses. Importantly, age related losses of lean soft tissue were also assuaged with resistance training.

While aerobic training has been established as a strategy for weight maintenance throughout the lifespan(19), resistance training as a contributor to weight loss and maintenance is not well studied (14,19), particularly with respect to long-term weight maintenance. Some studies suggest that resistance training alone does not induce significant weight loss or enhance weight loss with caloric restriction (14). A 12-week study comparing a very low calorie diet combined with aerobic training or resistance training for weight loss, primarily in women, favored aerobic training for weight loss and resistance training for the preservation of lean mass which blunts weight loss; both groups improved VO₂max significantly (7). The greater weight loss experienced in the aerobic training group may be viewed as more advantageous; however, they also experienced an accompanying decrease in resting metabolic rate (RMR, $p < 0.05$), which potentially limits the ability to maintain lost weight(7).

Although no other studies of the size and duration of the present study could be located to confirm our weight and body composition results, a study by Schmitz, et al conducted with 60 midlife women randomized to control or strength training twice per week for 39 weeks demonstrated similar results.(40) Exercisers lost significantly more fat (-0.98 kg or -1.63%) and gained significantly more fat free mass (0.89 kg) compared to controls, without weight loss. A long-term (6 year) follow-up assessing the association between frequency or volume of exercise and weight maintenance has not been reported.

Resistance training should also be considered important beyond its effects on weight and fat mass; preservation of lean soft tissue with aging is emerging as an important area of study. Loss of skeletal muscle mass (SMM) or lean soft tissue occurs is a consequence of normal aging.(3,27) Low levels of skeletal muscle mass or lean soft tissue can lead to impaired physical functioning,(12) disability,(26) and loss of independence in older age.(15) In addition to the positive influence of resistance training on lean mass reported for the primary intervention year of the BEST study(45), others have shown that relatively short term resistance training (8–24 weeks) can improve lean mass in middle-aged men and women,(30,36) the elderly, (16,24, 25) and frail (4) This study supports the use of long-term resistance training for LST preservation during mid-life aging in women.

It is also important to consider that maintaining physical functioning may be an important factor in the protection of quality of life. Resistance training and prevention of weight gain may preserve physical function and vitality, as well as decrease bodily pain in women, enhancing quality of life (17). Although measures of physical function were not conducted across treatment and control groups at 6 years, we anticipate that future long-term studies of resistance training will show a positive association between LST preservation and physical function scores, as has been indicated in short term trials.(24,25,30)

Potential mechanisms relating long-term resistance training with weight and fat mass stabilization

Resistance training can improve body composition independent of changes in weight or BMI and helps to preserve lean mass in the context of weight loss (14,40,45). While somewhat controversial, it has been suggested that resistance training may be an effective strategy for weight maintenance in postmenopausal women due to its positive effects on RMR (23,38). In the study by Bryner et al (7) a significant increase in RMR, in spite of weight loss, was demonstrated in the resistance trained group compared to the aerobically trained group (7). Similarly, in another study, postmenopausal women who completed 16 weeks of resistance training demonstrated increased fat free mass and RMR, with and without weight loss (38). Although we did not measure RMR, we estimated the increase in LST for those who maintained 67% attendance over six years (2 days per week), (from the unstandardized regression coefficient for ExFreq, ($n = 24$; 20% of 6 year completers), to be increased by 0.51 kg (1.3%) which would equate to roughly to a 10 kcal increase in resting metabolic rate, as indicated by

cross-sectional studies (1kg increase = 21kcal BMR) (33). This small potential increase in our population of most compliant exercisers may have contributed somewhat to the weight maintenance observed in this group, particular since the increased caloric burning capacity may have been enhanced by as much as 3650 kcal per year.

On the other hand, Hunter and Byrne have shown that 77% of the difference in weight (measured by DXA) between gainers and maintainers, 1 yr after weight loss, was accounted for by activity-related energy expenditure. Muscle oxidative capacity, measured by ^{31}P MRS, and quadriceps strength were also independently related to weight maintenance during that period. Based on these findings, Hunter and Byrne suggested that such changes in muscle may lead to increased ease of physical activity and thus higher levels of physical activity (23) contributing to weight maintenance.

Our resistance training program significantly improved muscle strength at all sites ($p < 0.001$) and total body lean mass ($p < 0.05$ between EX and NEX, within HT; $p < 0.001$ between EX and NEX within NHT) following the primary intervention (1yr) (45). Although muscle metabolic economy and strength at 6 years were not measured, our results reinforced the hypothesis proposed by Hunter and Byrne, that improvement in strength and lean mass supports weight maintenance. Research into the potential mechanisms of resistance training's role in weight maintenance is largely based on short-term results. Long-term studies (3–5 years) examining mechanisms would contribute substantially to this field.

We may postulate that the combination of increased lean mass and greater ease of activity, lending themselves to more activity, would not only have an effect on overall energy expenditure, but may also contribute to decreased reliance on insulin for glucose homeostasis. Glucose transport into cells should occur to a greater extent via exercise induced translocation of GLUT4 proteins independent of insulin in those training versus those not training.(41) It is also known that training increases sensitivity of insulin-mediated glucose uptake in muscle by local mechanisms, at least with aerobic training, (13) and such mechanisms may also be in play with an emphasis on resistance training. These combined reasons for decreased reliance on insulin may lower its secretion and temper the anabolic effects on fat mass, which may act as a moderator of overall body weight. We know that resistance training can improve insulin sensitivity, which can be partially, but not entirely, attributed to changes in body composition. (39) Thus, conversely it is possible that insulin sensitivity improvements, described above, may also partially contribute to body composition stabilization.

Other potential mechanisms relating resistance training to weight and body fat maintenance may include changes in adipokines with training. Both adiponectin and leptin are associated with changes in body composition, as well as metabolism. Although not tested in this study, limited evidence suggests that resistance training may have an effect on these biomarkers. However, change in leptin and adiponectin may vary with intensity of training and should be adjusted by changes in body composition. Additionally, studies of chronic resistance training effects on leptin and adiponectin greater than 1 year have not been conducted, most are less than 6 months and downstream effects of these adipokines related to training have yet to be elucidated (6). These and other proposed mechanisms that may be involved in long-term weight and body fat stabilization with resistance training require new long-term studies with substantial repeated measures and biosample collection at least annually.

Limitations

Long-term intervention studies carry with them several burdens. One challenge in this 6-year behavioral intervention was participant retention. Retention in our first year was high (83%) (18) while we conducted a robust intervention support program based on social cognitive/social ecological theory constructs, encompassing a variety of interpersonal, intrapersonal and

environmental reinforcement strategies to motivate participants and promote retention. Many women continued to participate in the support program after year one and, since recruitment continued over a four year period, all exercising women were encouraged to continue to exercise and attend the social support events. Allowing controls to cross over to exercise may have ameliorated some attrition, as well. Nevertheless, higher attrition occurred in later years, perhaps because trainers were less available to work with participants after the initial two years.

Program attrition left us with 45.9% of the sample of one year completers available for inclusion in this analysis of 6 years of follow-up. However, there was enough range in frequency of resistance training and change in weight to capture differences in exercise association with changes in body composition, despite analyzing less than half of our original sample,

Throughout the 6 years, participants were asked not to alter their diets, however an evaluation of dietary intake out to six years is not available. Habitual activity may have varied as well. Although initial measures of these factors were included in regression models, the analysis was limited somewhat by the lack of a measurement of diet and habitual activity over time. The demonstration that resistance training volume and attendance were associated with weight and body composition does not eliminate the possibility that some of the effects seen here may be due to other habitual physical activities or aerobic exercise. Certainly, tracking changes in dietary and overall exercise patterns would be helpful in future research.

Although years on hormone therapy was not a significant contributor to the regression models evaluating changes in body composition and weight, it is possible that hormone levels may have influenced changes in weight and body composition over 6 years. Blood samples were not available beyond year 1 to evaluate circulating levels of estrogen and progesterone, but would be recommended in future studies.

Summary

In spite of the limitations inherent in a long-term study, results were significant and this study is one of the first to show the association of resistance training and prevention of weight gain. In light of the positive effects of resistance training on BMD, muscle function and lean mass, (18) and its potential for contributing to the prevention of osteoporosis and debilitating fractures, resistance training for weight loss and maintenance is particularly attractive for overall chronic disease prevention in postmenopausal women.

Beyond the present study results, it is important to assert that comprehensive physical activity programs (stretching, balance, aerobic and resistance training combined), as indicated by the American College of Sports Medicine/American Heart Association guidelines for physical activity, (35) intended to address overall health benefits, not weight management alone, should be the goal. However, few of the recommendations in the above guidelines are based on long-term studies and the public at large is not currently meeting these physical activity goals. We have shown that there may be some benefit from 2 days per week of resistance training and perhaps greater benefit if the population meets the ACSM guidelines. More long-term studies are needed to evaluate frequency of training relative to various health outcomes.

Conclusion

The present study demonstrated that higher levels of weight bearing physical activity over the long-term are associated with stabilization of total and central adiposity, preservation of lean mass, and weight maintenance. Including resistance training along with aerobic exercise may allow for better tailoring of interventions and long-term adherence (20). Additionally, since both aerobic and resistance training have been shown to diminish risk factors for cardiovascular

disease and diabetes, it is important to present resistance training as an option for improved health outcomes independent of weight loss (14).

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Figure 1. Annual Measure of Body Composition by Tertiles of Weight Lifted in the Squats Exercise over 6 Years (adjusted means $\pm$ SE; n=122)

Means were adjusted for age, years taking hormones over the 6 year period, baseline weight, baseline lean soft tissue (LST), change in LST, baseline exercise energy expenditure, and whether or not it was representative of more, less, or usual activity (self report) by ANCOVA. A. Increase in weight from baseline to 6 years for lowest tertile ($p=0.002$); B. Increase in total body fat from baseline to 6 years for lowest tertile ($p=0.004$); C. Increase in trunk fat from baseline to 6 years for lowest ($p=0.001$) and middle ($p=0.06$) tertiles (paired t-tests between baseline and 6 years by tertile).

Table 1

Baseline Characteristics of 122 Women participating in 6 years of the BEST study (mean±SD)

	All (n=122)	Controls (n=25)	Crossovers (n=32)	Exercisers n=(65)	P*
Age (years)	56.3±4.3	55.9±3.9	56.2±4.8	56.4±4.2	0.88
Years Postmenopausal	6.2±3.4	6.8±4.6	5.6±2.7	6.3±3.1	0.41
Height (cm)	162.8±7.3	161.0±7.6	163.6±6.5	163.1±7.5	0.37
Weight (kg)	67.9±11.6	65.4±10.7	69.8±11.3	67.9±12.1	0.37
BMI (kg/M ²)	25.5±3.8	25.2±3.9	26.1±4.3	25.4±3.6	0.63
% Body Fat	38.7±6.4	37.4±6.7	40.5±6.1	38.3±6.3	0.14
Total Body Fat (kg)	26.5±8.3	24.6±7.7	28.5±8.5	26.2±8.4	0.21
Trunk Fat (kg)	4.4±1.8	4.0±1.0	4.7±1.1	4.4±1.3	0.18
Arm Fat (kg)	2.5±1.0	2.3±1.0	2.7±1.1	2.4±0.9	0.22
Leg Fat (kg)	10.4±3.3	9.8±3.3	11.0±3.1	10.4±3.4	0.38
Total Body LST (kg)	38.3±4.5	37.7±4.6	38.3±4.1	38.4±4.8	0.74
Exercise Energy Expenditure (kcal/day)	182.7±166.9	178.8±136.4	176.4±167.0	187.2±166.9	0.95

*
for ANOVA

Table 2

Baseline characteristics of women with measurements at 6 years compared* to women who dropped or were lost to follow-up (mean±SD)

	Included (n=122)	Not Included (n=198)	P*
Age (years)	56.3±4.3	54.6±4.9	0.003
HT Use (years)	1.4±1.5	1.3±6.7	0.39
Weight (kg)	67.9±11.6	68.5±11.5	0.63
BMI (kg/M ²)	25.5±3.8	25.7±3.8	0.76
% Body Fat	38.7±6.4	38.9±6.8	0.76
Total Body Fat (kg)	26.5±8.3	26.8±8.4	0.70

* by independent t-test

Table 3

6-Year changes in body composition and measures of exercise for 122 women participating in the BEST study (mean±SD)

	All (n=122)	Controls (n=25)	Crossovers (n=32)	Exercisers n=(65)	P*
Weight (kg)	0.83±5.39	2.08±4.25	0.70±4.38	0.43±6.16	0.44
Total Body Fat (kg)	0.64±4.95	1.84±4.30	0.43±3.42	0.28±5.74	0.40
Trunk Fat (kg)	0.64±2.60	1.28±2.27	0.54±2.00	0.44±2.95	0.40
Arm Fat (kg)	0.42±0.62	0.63±0.68	0.48±0.52	0.32±0.63	0.10
Leg Fat (kg)	-0.45±1.9	0.08±1.4	-0.63±1.3	-0.56±2.3	0.27
Lean Soft Tissue (kg)	0.10±1.71	-0.01±1.29	0.06±2.32	0.19±1.51	0.84
Mean 6-year Exercise Frequency (%)	30.9±29.8	0.0±0.0	24.0±22.6	46.2±28.3	<0.001
Weight Lifted in Military Press (right, 1000kg)	16.91±21.49	0.0±0.0	6.58±9.26	28.49±23.05	<0.001
Weight Lifted in Squats (right, 1000 kg)	183.62±217.21	0.0±0.0	109.62±155.18	287.71.62±226.16	<0.001

*. for ANOVA. Annual exercise frequency = sessions performed/sessions prescribed for that year. These annual exercise frequencies were then averaged over the 6 years. Weight lifted in military press and squats represents annual kilograms multiplied by repetitions and by sets and then summed for 6 years.

Table 4

Results from linear regression of 6-year change in body weight and total and trunk fat, and lean soft tissue (LST) regressed on measures of exercise* (n=122).

Outcome Variables	Model 1			Model 2			Model 3			Model 4			Model 5			Model 6		
	Change in Weight			Change in Total Body Fat			Change in Trunk Fat			Change in Arm Fat			Change in Leg Fat			Change in Total Body Lean Soft Tissue		
	SBC	P-value	Adj. R ²	SBC	P-value	Adj. R ²	SBC	P-value	Adj. R ²	SBC	P-value	Adj. R ²	SBC	P-value	Adj. R ²	SBC	P-value	Adj. R ²
<i>Model A</i>			0.26			0.19			0.23			0.17			0.23			0.04
Mean 6year Exercise Frequency	-0.27	0.001		-0.31	<0.001		-0.28	0.001		-0.31	0.001		-0.25	0.007		0.15	0.13	
Change in Lean Soft Tissue**	0.30	0.001		0.08	0.35		0.08	0.39		0.07	0.48		-0.02	0.87				
Change in Fat Tissue**																0.10	0.36	
<i>Model B</i>			0.24			0.15			0.18			0.12			0.21			0.07
Weight Lifted in Military Press	-0.22	0.01		-0.25	0.006		-0.20	0.03		-0.24	0.02		-0.20	0.03		0.21	0.03	
Change in Lean Soft Tissue**	0.31	0.001		0.09	0.31		0.07	0.45		0.06	0.55		-0.02	0.84				
Change in Fat Tissue**																0.10	0.33	
<i>Model C</i>			0.27			0.20			0.24			0.17			0.24			0.06
Weight Lifted in Squats	-0.28	0.001		-0.33	<0.001		-0.31	0.001		-0.32	0.001		-0.28	0.003		0.20	0.04	
Change in Lean Soft Tissue**	0.31	<0.001		0.10	0.25		0.10	0.26		0.09	0.39		0.00	0.98				
Change in Fat Tissue**																0.12	0.26	

* Additionally adjusted for age, baseline and 6-year change in body composition (see **), years taking hormones over the 6-year period, baseline exercise energy expenditure and whether or not it was representative of more, less, or usual activity (self report);

** baseline weight used in all models; covariates for lean soft tissue used in Models 1–3 and fat tissue in Model 4. Annual exercise frequency = sessions performed/sessions prescribed for that year. These annual exercise frequencies were then averaged over the 6 years. Weight lifted in military press and squats represents annual kilograms multiplied by repetitions and by sets and then summed for 6 years.

SBC=Standardized Beta-Coefficient