Resistance training increases total daily energy expenditure in disabled older women with coronary heart disease

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Ades, Philip A., Patrick D. Savage, Martin Brochu, Marc D. Tischler, N. Melinda Lee, and Eric T. Poehlman. Resistance training increases total daily energy expenditure in disabled older women with coronary heart disease. J Appl Physiol 98: 1280–1285, 2005; doi:10.1152/japplphysiol.00360.2004.—Physical activity energy expenditure (PAEE) is a determinant of prognosis and fitness in older patients with coronary heart disease (CHD). PAEE and total energy expenditure (TEE) are closely related to fitness, physical function, and metabolic risk in older individuals. The goal of this study was to assess effects of resistance training on PAEE, TEE, and fitness in older women with chronic CHD and physical activity limitations \( (N = 51, \text{mean age: } 72 \pm 5 \text{ yr}) \). The study intervention consisted of a progressive, 6-mo program of resistance training vs. a control group condition of low-intensity yoga and deep breathing. The study interventions were completed by 42 of the 51 participants. The intervention group manifested a \( 177 \pm 213 \text{ kcal/day (} +9\% \) increase in TEE, pre- to posttraining, measured by the doubly labeled water technique during a nonexercise 10-day period \( (P < 0.03 \text{ vs. controls}) \). This was due to a \( 50 \pm 74 \text{ kcal/day (} 4\% \) increase in resting metabolic rate measured by indirect calorimetry \( (P < 0.01, P < 0.05 \text{ vs. controls}) \) and a \( 123 \pm 214 \text{ kcal/day (} 9\% \) increase in PAEE \( (P < 0.03, P = 0.12 \text{ vs. controls}) \). Resistance training was associated with significant increases in upper and lower body strength, but no change in fat-free mass, measured by dual X-ray absorptiometry, or left ventricular function, measured by echocardiography and Doppler. Women in the control group showed no alterations in TEE or its determinants. There were no changes between groups in body composition, aerobic capacity, or measures of mental depression. These results demonstrate that resistance training of 6-mo duration leads to an increase in TEE and PAEE in older women with chronic CHD.

Resistance training; coronary heart disease; energy expenditure; physical activity

TOTAL PHYSICAL ACTIVITY IS a predictor of mortality in older individuals with established coronary heart disease (CHD) (39). Total energy expenditure (TEE) and physical activity energy expenditure (PAEE) are closely related to fitness, fatness, and physical function in older individuals (4, 9, 22). However, the effects of exercise training (resistance or aerobic) on measures of TEE and its determinants have not been studied in older individuals with CHD in whom cardiac symptoms and/or fear of cardiac complications might limit its effectiveness compared with healthier individuals. The lack of information in this area is due not only to concern about cardiac complications but to methodological challenges associated with the determination of daily energy expenditure in free-living individuals. The application of the doubly labeled water method, however, provides an unobtrusive and nonbiased approach to determine total and free-living physical activity in disabled populations. An increase in TEE would imply a high likelihood of favorable long-term effects of resistance training on fitness, body composition, metabolic profile, and prognosis. In this study we assessed the effect of resistance training on measures of energy expenditure, including TEE, PAEE, and resting metabolic rate (RMR), in a randomized-controlled trial, in disabled older women with CHD. We also performed echocardiography with Doppler analysis to determine whether resistance training has any measurable effects on cardiac structure or function.

According to the Framingham Disability Study, rates of disability and physical activity limitations for older women with CHD, defined by mobility limitations and inability to perform household work, are extremely high: 67% for women aged 55–69 yr and 79% for women aged 70–88 yr (25). We have previously shown that muscular strength and measures of general fitness levels are important determinants of self-reported physical function in older coronary patients (2). In addition, several investigators have shown that increases in leg strength result in an increase in walking endurance, physical function, and TEE in healthy elders (3, 18, 19, 23). In cardiac patients, strength training has been shown to increase walking endurance and measures of physical function (1, 6, 29). However, its effects on the determinants of TEE in patients with established CHD are unknown. These results would potentially mediate long-term effects of resistance training in the coronary population on clinical outcomes, body weight, body composition, physical function, and the overall metabolic profile. Thus the overall aim of this study is to study the effect of resistance training on TEE and PAEE in older women with CHD and self-reported activity limitations.

METHODS

Study Subjects

At baseline, the study population consisted of 51 community-dwelling women with established CHD for at least 6 mo. Diagnoses included myocardial infarction in 25, coronary revascularization in 44 (13 bypass surgery, 21 percutaneous revascularization), and a history of stable angina in 21. Diagnoses were not mutually exclusive, and the two study groups did not differ by diagnostic categories. All were age >65 yr of age (mean 72 ± 5 yr) and 23 of 51 (45%) were living alone with no difference between groups in the percentage living alone. Inclusion criteria included a physical function score below 85 assessed from the physical function section of the MOS-SF36 health status questionnaire (38), approximating the criteria used in the Framingham Disability Study (25). For a score of <85 on the SF-36, an individual would have to be at...
least “limited a little” or “limited a lot” for >3 of the following activities: pushing a vacuum cleaner, climbing several flights of stairs, walking a mile, lifting or carrying groceries, bending, or stooping. Exclusion criteria included 1) hospitalization for an acute coronary syndrome within 6 mo, 2) very low threshold angina [<3 metabolic equivalent (MET) workload], 3) exercise-test-limiting noncardiac comorbidity (i.e., orthopedic, neuromuscular, peripheral vascular), 4) uncontrolled hypertension (resting blood pressure >160 systolic or 90 diastolic), 5) sternal nonunon after coronary surgery, 6) recent (<3 mo) participation in a cardiac rehabilitation program, 7) inflammatory arthritis, and 8) dementia.

Study subjects were characterized by a high prevalence (67%) of comorbid conditions. Specific conditions included arthritis (53%), claudication (20%), diabetes (12%), cerebrovascular disease (2%), and other (10%), with no significant differences between groups. Medication use did not differ between the two study groups. Overall, 94% of participants were taking aspirin, 58% were taking calcium-blocking medications. All participants signed an informed consent document approved by the Committee on Human Research at the University of Vermont.

**Strength Measures**

Subjects began resistance training for a week with very light weights to learn proper technique and minimize muscle soreness. At 1 wk, all patients performed single-repetition maximal lifts (1-RM) for the bench press and leg extension on a Universal Gym apparatus (Cedar Rapids, IA) to assess strength. The 1-RM is defined as the maximum resistance a subject can lift, using correct form, through a full range of motion, for no more than one repetition only. After the 1 wk of familiarization, the tester selected a weight and asked the subject to perform the lift. After 3–4 min, the process was repeated with heavier weights until the subject could not complete the full lift. Subsequently, women in the resistance training updated the 1-RM at 2 wk and then on a monthly basis for 6 mo to guide the resistance training intervention.

**Handgrip Strength**

Handgrip strength was measured in the dominant hand with a handgrip dynamometer (Jamar, Jackson, MI), averaging three measures.

**Energy Expenditure Measures**

The use of the stable isotope, doubly labeled water, and indirect calorimetry partitioned daily energy expenditure into RMR, thermic effect of a meal, and free-living PAEE. TEE was measured by using doubly labeled water over a 10-day period preceding and 7 days after completion of the resistance training program; therefore, it did not include the caloric cost of the resistance exercise program. RMR was measured 7 days after the last resistance training session. At baseline, the RMR and thermic effect of a meal measures immediately preceded the 10-day doubly labeled water measurement period. Subjects were given no instructions regarding physical activity during the 10-day collection period other than that they should not continue their resistance training during this time period. All subjects were free living in the community. The doubly labeled water protocol was designed in accordance with technical recommendations (26) and as previously described in our laboratory. CO2 production and total daily energy expenditure were calculated using the equation of Schoeller (30). Briefly, a baseline urine sample was collected before dosing. The following morning, two additional urine samples were collected, and two more samples were collected 10 days later. Urine samples were stored frozen in Vacutainers at −20°C until analyzed for 2H and 18O enrichments by isotope ratio mass spectrometry. 18O isotopic enrichment was determined from the CO2 (CO2) equilibration technique, and 2H enrichment was determined by the zinc catalyst method (43). The daily rate of CO2 production (rCO2) in moles per day) was calculated using the equation of Speakman et al. (37): 

\[
\text{rCO}_2 = \frac{\text{N}_2}{2} \times (\text{O}^{18} - \text{H}^2), \quad \text{where } N \text{ is the bodywater pool, } O^{18} \text{ and } H^2 \text{ are the elimination rates of } 18O \text{ and } 2H \text{ tracers from the body, and } O^{18} \text{ and } H^2 \text{ are the dilution spaces for } 18O \text{ and } 2H \text{ tracers as recommended by Racette et al. (30).}
\]

RMR was measured for 45 min in the morning by indirect calorimetry using the ventilated hood technique (26) after a 12-h overnight fast in the General Clinical Research Center of the University of Vermont. Respiratory gas analysis was performed using a Deltatrac Metabolic Cart (Sensormedics, Yorba Linda, CA). RMR was calculated by using the equation of Weir (40). Thermic effect of a meal was measured by indirect calorimetry. On the same day, after the measurement of RMR, a standard liquid meal consisting of 10 kcal/kg weight of Ensure Plus (56% carbohydrate, 29% fat, and 15% protein) was administered. This number was multiplied by 3 to estimate the thermic effect of food for the entire day. This standard meal was similar in macronutrient content to that measured in a cohort of older women with CHD from a prior study at our institution (31). The supplemental caloric expenditure measured during the 3-h postprandial period, above and beyond the RMR, was calculated as the thermal effect of a meal. Free-living PAEE was calculated by subtracting RMR and the thermic effect of meals from TEE over a 10-day period and was expressed in kilocalories per day.

**Caltrac**

PAEE was also determined by using a Caltrac uniaxial accelerometer (Muscle Dynamics Fitness Network, Torrance, CA). This accelerometer was worn during all waking hours over a 10-day period. This accelerometer has a ceramic piezoelectric transducer that detects vertical displacement, and this signal is translated into a total activity energy count per day (42). It measures walking energy expenditure in addition to calculating non-weight-bearing activities such as bicycling, rowing, and strenuous upper body motions by incorporating the gender, height, weight, and age of subjects (24, 42). The test-retest correlation coefficient has been shown to be 0.98 for the Caltrac in older women and men (24).

Resting two-dimensional echocardiography with Doppler analysis was performed at rest before and after the resistance training program using an Acuson Sequoia (Mountain View, CA) and analyzed on an Image-Vue Cardiology Workstation (Nova Microsonics, Mahwah, NJ). Echocardiographic measures included systolic and diastolic volumes, left ventricular (LV) mass, LV ejection fraction, and stroke volume. Doppler analysis provided additional measures of LV diastolic inflow including the E/A ratio and the atrial filling fraction where E represents early or passive filling of the left ventricle and A represents atrial systole.

**Body Composition**

Body weight (nearest 0.1 kg) and height (nearest 0.1 cm) were measured and used to calculate the body mass index (BMI; kg/m²). Dual-energy X-ray absorptiometry (DEXA, model DPX-L; LUNAR Radiation, Madison, WI) was used to measure body composition including fat mass, lean body mass, bone mineral content, and percent body fat (16).

**Depression Questionnaire**

The Geriatric Depression Score is a 15-item questionnaire, developed and validated by Yesavage (44), that identifies the presence and severity of depressive symptoms. In general, a score of >5 of 15 is associated with clinical depression.

**Exercise Treadmill Testing**

Patients performed a symptom-limited, electrocardiographically monitored exercise test on treadmill using a modified Balke protocol, which advances exercise intensity at 1-MET intervals, before and after the exercise program (12). The occurrence of any untoward responses such as low threshold angina or >2-mm ST segment depression on the ECG excluded patients from the training protocol. Patients performed this test taking their usual medications. Peak oxygen con-
Exercise Training Protocol

Subjects were randomized to either of two groups. The randomization was stratified by self-reported physical activity level such that groups were matched at baseline (38). Patients performed the exercise training program for 6 mo, meeting three times weekly. Patients in both study groups were required to attend at least 54 of the 72 sessions (75%) over the 6-mo period to be considered in the study analysis. During the first week of the exercise program, after randomization, subjects in both groups were habituated to strength testing for the single-repetition maximal lifts, to avoid injury.

Resistance training intervention. The exercise training program was established on the basis of baseline 1-RM lifts and ratings of perceived exertion (3, 5). Patients performed 1-RM testing for two weight exercises, leg extension and bench press, at the end of the first week. Weight training began at 50% of 1-RM, and 2 wk later maximal strength was restested and training intensity was gradually increased toward 80% of 1-RM, as tolerated. The resistance training program was performed with Universal weights and dumbbells. The 1-RM was updated monthly and supplemented by perceived exertion scores with patients increasing the resistance when perceived exertion scores dropped below a threshold value (14 on the Borg scale of 6 to 20) (5). The eight exercises focused on leg, arm, and shoulder strength. Exercises included 1) leg extensions (quadriceps), 2) leg press (gluteals, quadriceps), 3) leg curls (hamstrings), 4) shoulder press (deltoids, triceps), 5) arm curls (biceps), 6) lateral pulldown (latissimus, biceps), 7) bench press (pectoralis), and 8) triceps extension (triceps).

Subjects began training with one set of 10 repetitions, gradually increasing to two sets with a 2-min rest in between each set. Each training session was under the supervision of an exercise physiologist.

Control group. Control patients met three times per week for 30–40 min at the Cardiac Rehabilitation Center and participated in a program of stretching, calisthenics, deep breathing-progressive relaxation exercises, and light yoga.

Statistics

Values in tables are presented as means ± SD. A nonpaired t-test was used for the comparison between groups at baseline, after 6 mo, and to compare changes between groups for percent changes after the program. ANOVA for repeated measures was used to determine the effect of treatment over the 6-mo period within each group. Univariate linear regression measured associations between variables of interest. Statistical analyses were carried out using Stat View 4.01 (Stat View 5.0.1; SAS Institute, Cary, NC, 1998). A level of significance of $P < 0.05$ was used for hypothesis testing.

RESULTS

At baseline, the two study groups were similar by age, diagnostic category, body weight, BMI, percent body fat, fat-free mass, appendicular muscle mass, and bone mineral content (Table 1). Forty-two of the original 51 patients completed the study interventions. Reasons for dropout included medical problems unrelated to the training program (n = 7) and training noncompliance (n = 2). Study completers did not differ at baseline from study dropouts by baseline measures.

After strength training, intervention patients increased leg strength (47% vs. 11% $P < 0.001$ between groups) and arm

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Table 1. Baseline anthropometric values and response to training

<table>
<thead>
<tr>
<th></th>
<th>Intervention Group (n = 21)</th>
<th>Control Group (n = 21)</th>
<th>P Value Between Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>% Change</td>
</tr>
<tr>
<td>Age</td>
<td>72.9±6.1</td>
<td>71.5±4.8</td>
<td></td>
</tr>
<tr>
<td>Weight, kg</td>
<td>72.4±12.3</td>
<td>71.4±11.4</td>
<td></td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>28.7±4.2</td>
<td>27.8±4.2</td>
<td></td>
</tr>
<tr>
<td>%, Body fat</td>
<td>42.8±6.7</td>
<td>42.5±5.9</td>
<td></td>
</tr>
<tr>
<td>Fat mass, kg</td>
<td>30.1±9.2</td>
<td>29.5±7.7</td>
<td></td>
</tr>
<tr>
<td>Fat-free mass, kg</td>
<td>38.8±5.1</td>
<td>38.8±5.3</td>
<td></td>
</tr>
<tr>
<td>Appendicular muscle mass, kg</td>
<td>16.4±2.4</td>
<td>16.7±2.4</td>
<td></td>
</tr>
<tr>
<td>Bone mineral content, kg</td>
<td>2.2±0.4</td>
<td>2.2±0.4</td>
<td></td>
</tr>
</tbody>
</table>

Values are as means ± SD. There were no significant differences within groups or between groups before and after the study interventions. Pre, before the 6-mo intervention period; Post, after the 6-mo intervention period.

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Table 2. Strength, fitness, and energy expenditure responses

<table>
<thead>
<tr>
<th></th>
<th>Intervention Group (n = 21)</th>
<th>Control Group (n = 21)</th>
<th>P Value Between Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>% Change</td>
</tr>
<tr>
<td>Strength measures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-RM leg, kg</td>
<td>29.6±9.8</td>
<td>43.6±10.8</td>
<td>47†</td>
</tr>
<tr>
<td>1-RM arm, kg</td>
<td>20.0±8.8</td>
<td>31.5±10.4</td>
<td>57†</td>
</tr>
<tr>
<td>Handgrip, kg</td>
<td>21.9±5.3</td>
<td>23.2±5.0</td>
<td>6</td>
</tr>
<tr>
<td>Fitness measures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak VO$_2$, ml·kg$^{-1}$·min$^{-1}$</td>
<td>14.2±2.9</td>
<td>15.1±4.2</td>
<td>6</td>
</tr>
<tr>
<td>Submaximal VO$_2$, ml·kg$^{-1}$·min$^{-1}$</td>
<td>11.5±1.8</td>
<td>11.5±2.7</td>
<td>0</td>
</tr>
<tr>
<td>Energy expenditure measures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total daily energy expenditure, kcal/day</td>
<td>2.007±402</td>
<td>2.185±417</td>
<td>9†</td>
</tr>
<tr>
<td>Resting metabolic rate, kcal/day</td>
<td>1.279±186</td>
<td>1.330±183</td>
<td>4†</td>
</tr>
<tr>
<td>Thermic effect of meal, kcal/day</td>
<td>230±80</td>
<td>234±73</td>
<td>2</td>
</tr>
<tr>
<td>Physical activity energy expenditure, kcal/day</td>
<td>498±314</td>
<td>621±294</td>
<td>25*</td>
</tr>
</tbody>
</table>

Values are as means ± SD. 1-RM, single repetition maximal lift; VO$_2$, oxygen consumption. *$P < 0.05$; †$P < 0.01$ pre- vs. postexercise.
strength (57 vs. 3% \( P < 0.0001 \) between groups) compared with the control group, measured by single-repetition maximal lifts (Table 2). Handgrip strength tended to increase in the intervention group (21.9 ± 5.3 to 23.1 ± 5.0 kg, \( P = 0.07, P = 0.13 \) between groups) but not in the control group (23.0 ± 7.2 to 22.4 ± 8.2 kg, \( P = 0.32 \)). After the study interventions, neither group experienced a significant change in body weight, BMI, percent body fat, fat mass, fat-free mass, appendicular muscle mass, or bone mineral density (Table 1).

Peak aerobic capacity (peak \( \dot{V}O_2 \)) tended to increase in the strength training group (\( P = 0.06 \)) but not in the control group. There was no difference in change of peak \( \dot{V}O_2 \) between groups after the study intervention. Submaximal \( \dot{V}O_2 \) measured after 4 min of the treadmill protocol was not altered in either group after the study intervention.

TEE and its determinants were measured before and after conditioning, over a 10-day doubly labeled water collection period, while the formal exercise training program was held in abeyance (Table 2). During this time period, subjects who had performed strength training increased total daily energy expenditure by 177 ± 213 kcal/day from 2,007 ± 402 to 2,185 ± 417 kcal/day (\( P < 0.002, P < 0.03 \) vs. controls). There was no change in TEE in the control patients. The increase in TEE after strength training was due to both an increase in RMR, which increased from 1,279 ± 186 to 1,330 ± 183 kcal/day (\( P < 0.01, P < 0.05 \) vs. controls), and an increased PAEE within the intervention group from 498 ± 314 to 621 ± 294 kcal/day (\( P < 0.03, P = 0.12 \) vs. controls). There was no change in either group in the measure of thernmic effect of meals. There was no change in the Geriatric Depression Score in either study group.

**Regression Analyses**

At baseline, for the entire study population, there were no significant correlations between fat-free mass, strength, peak \( \dot{V}O_2 \), or depression score and PAEE or TEE, measured with doubly labeled water. Fat-free mass showed a marginal correlation with RMR (\( r = 0.32, P = 0.07 \)) but not with peak \( \dot{V}O_2 \). The Caltrac-derived measure of physical activity correlated with TEE (\( r = 0.44, P < 0.01 \)). After the study intervention, the Caltrac measure of PAEE again correlated with the doubly labeled water measure of PAEE (\( r = 0.44, P < 0.01 \)). Over the course of the study, the change in the Caltrac measure of physical activity correlated with change in the doubly labeled water measure of PAEE (\( R = 0.68, P < 0.001 \)), suggesting that the Caltrac measure is sensitive to changes in physical activity. There was also a correlation between the change in doubly labeled water measure of PAEE and the questionnaire-based measure of physical function using the MOS SF-36 (\( R = 0.49, P < 0.005 \)). Within the strength training group, change in leg strength was associated with the change in TEE (\( R = 0.50, P < 0.02 \), Fig. 1) and PAEE (\( R = 0.50, P < 0.05 \)).

Echocardiographic and cardiac Doppler data were unaffected by the study interventions. Specifically there were no effects of the study intervention or control status on LV ejection fraction, LV mass, LV end-diastolic and end-systolic volumes, stroke volume, or indexes of LV diastolic inflow such as the E/A ratio or the atrial filling fraction (Table 3).

**DISCUSSION**

Aging, particularly in the setting of chronic diseases such as CHD or arthritis, is associated with diminished muscle mass, or sarcopenia, with its attendant detrimental effects on strength, physical activity profile, and physical function (20, 32, 35, 45). Resistance training has been shown to increase RMR, TEE, PAEE, lean body mass, and strength in studies of healthy elders (7, 19). The goal of this study was to assess the effect of strength training on TEE, spontaneous PAEE, and physical function in older individuals burdened with coronary heart disease. The effects of strength training on TEE and PAEE in patients with CHD are important because they impact on long-term effects on body composition, physical function, the

**Table 3. Echocardiographic data**

<table>
<thead>
<tr>
<th>Echocardiographic data</th>
<th>Intervention Group (n = 21)</th>
<th>Control Group (n = 21)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>64 ± 10</td>
<td>64 ± 8</td>
<td>66 ± 12</td>
</tr>
<tr>
<td>LV diastolic volume, ml</td>
<td>120 ± 31</td>
<td>116 ± 26</td>
<td>133 ± 37</td>
</tr>
<tr>
<td>LV systolic volume, ml</td>
<td>42 ± 22</td>
<td>40 ± 22</td>
<td>49 ± 26</td>
</tr>
<tr>
<td>Stroke volume, ml</td>
<td>78 ± 23</td>
<td>76 ± 24</td>
<td>84 ± 28</td>
</tr>
<tr>
<td>LV mass, g</td>
<td>164 ± 41</td>
<td>168 ± 37</td>
<td>154 ± 49</td>
</tr>
<tr>
<td>E/A ratio</td>
<td>1.0 ± 0.5</td>
<td>1.0 ± 0.5</td>
<td>1.0 ± 0.5</td>
</tr>
<tr>
<td>Atrial filling fraction, %</td>
<td>40 ± 8</td>
<td>43 ± 11</td>
<td>40 ± 6</td>
</tr>
</tbody>
</table>

Values are means ± SD. LV, left ventricular; LVEF, LV ejection fraction. \( P \) value compares changes pre-post between groups. There was no significant change pre-post within groups.
metabolic profile, and prognosis. In the present study, we assessed the effect of resistance training on the determinants of energy expenditure in older women with coronary heart disease and self-reported activity limitations. Our laboratory has previously reported in this same study population that resistance training increases measures of physical functional performance for a range of household activities with increases in domains of upper and lower body strength, coordination, and flexibility compared with a control group (1, 6).

In this study, TEE was measured inobtrusively by doubly labeled water, stable isotope methodology. This carries clear advantages over the use of activity questionnaires, accelerometers, or pedometers because subjects are largely unaware that exercise-related energy expenditure is being measured. Compared with accelerometers and pedometers, energy expenditures related to all physical activities is measured, not just those that occur in the plane of measurement of the device. PAEE was calculated by subtracting RMR and thermic effect of food from TEE, both measured directly by indirect calorimetry.

In the present analysis, we found that, despite the frailty, the high prevalence of comorbidities, and the physical disability of the older female coronary patients, strength training was performed at an intensity sufficient to increase strength, TEE, and RMR, despite no change in lean body mass, compared with a control group. Women in our intervention group also had a significant increase in spontaneous PAEE compared with baseline measures. It should be noted that the measurement of the components of energy expenditure were measured unobtrusively with doubly labeled water during a 10-day period after strength training was terminated and thus did not include the training sessions themselves. Patients were given no instructions regarding physical activity, thus were not counseled to consciously alter their home activity profiles. Rather, the physical activity profiles of the individuals studied were spontaneous. These changes in TEE, BMR, and PAEE occurred in the absence of a discernable change in fat-free mass measured by dual X-ray absorptiometry. This is consistent with a study by Pu et al. (29) in older women with chronic heart failure but contrasts with the studies of Hunter (19), Fiatarone (11), Frontera (13), and Charette (8) and their coworkers in elders without CHD, where strength training of a similar or lesser duration was associated with an increase in muscle mass.

Differences in training protocols, in patient populations (healthy, 8, 13 vs. nursing home (11) vs. CHD in the present study), and in methods of measuring muscle mass [computed tomography scan of thigh (11, 13) vs. 4-compartment model (19), vs. muscle biopsy (8, 29) vs. dual X-ray absorptiometry in the present study], may also explain the seemingly different response of muscle mass to resistance training in these studies. Whereas an increase in fat-free mass has been shown to explain a substantial component of the increase in RMR after resistance training, a study of healthy men age 50–65 found that RMR increased after resistance training independent of changes in fat-free mass (27). The means by which resistance training can increase RMR in the absence of an increase in muscle mass relates to the following potential mechanisms: Skeletal muscle turnover (syntheses and degradation) is an energy-requiring process that accounts for roughly 30% of whole body protein turnover whereas whole-body protein turnover accounts for 20% of RMR (41). In that resistance training has been shown in healthy elders to increase muscle protein syntheses after just 2 wk of training, a substantial increase in RMR occurs independent of change in overall muscle mass (17). In addition, an increase in sympathetic nervous system activation, reflected by plasma norepinephrine levels, has been described, which could explain a component of the increased RMR, even in the absence of body composition changes (27). Thus it is possible that the increase in RMR observed in our study may in part be sympathetically mediated, although norepinephrine levels were not measured.

If resistance training were to be widely adopted as part of a healthy lifestyle for elders with CHD, it could potentially lead to wide ranging functional effects that include increased daily caloric expenditure and improved walking endurance and physical functioning (6, 29). The resistance training protocol utilized in this study is similar to resistance training programs studied in healthy elders with chronic conditions and popularized in the “Strong-for-Life” program widely disseminated in senior centers across America for generally healthy elders (21, 35). Longer-term effects of resistance training on increasing daily caloric expenditure and physical activity profiles may also include a diminished fat mass, increased insulin sensitivity (10, 33, 36), and improved lipid profiles (14), with potentially a mortality benefit (39), although these will all require further studies of long duration for confirmation.

ACKNOWLEDGMENTS

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GRANTS

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