Even Low-Intensity and Low-Volume Exercise Training May Improve Insulin Resistance in the Elderly

Satoru Kodama¹²³, Miao Shu²³, Kazumi Saito¹²³, Haruka Murakami², Kiyoji Tanaka², Shinya Kuno², Ryuichi Ajisaka¹², Yasuko Sone³, Fumiko Onitake¹, Akimitsu Takahashi¹, Hitoshi Shimano¹, Kazuo Kondo³, Nobuhiro Yamada and Hirohito Sone¹²³

Abstract

Objective Moderate to high intensity exercise training is known to ameliorate the coronary risk factors in relation to an improvement in body composition. However, the benefit of low-intensity and low-volume training for these risk factors remains unclear in elderly people. Therefore, we investigated the effects of low-intensity and low-volume exercise training on blood lipid values and insulin resistance in the elderly.

Methods A total of 56 healthy elderly individuals (42 females and 14 males) aged 64±6 years participated in a 12-week exercise program, comprising aerobic training and resistance training.

Results After the program, there were no significant changes in high-density lipoprotein cholesterol, triglyceride serum levels, or in peak oxygen uptake on average. However, the homeostasis of minimal assessment of insulin resistance (HOMA-IR) value was significantly reduced by 21%. The participants were categorized into tertiles based on initial Body Mass Index (BMI). The Middle-BMI group (non-obese subjects) showed reduced HOMA-IR (2.0±1.3, P<0.01), but this reduction was not associated with the reduction in BMI (r=0.08, P=0.74), whereas the two reductions were significantly associated in the High-BMI group (r=0.61, P=0.01).

Conclusion Even low-intensity and low-volume exercise training, which would ordinarily be insufficient for improving mean lipid values or aerobic fitness, was found to be effective in improving insulin resistance in the elderly. The improvement in insulin resistance was independent of the improvement in obesity.

Key words: elderly, exercise training, low-intensity, insulin resistance, aerobic fitness, obesity

(DOI: 10.2169/internalmedicine.46.0096)

Introduction

Dyslipidemia [i.e. high serum levels of triglycerides (TG) and/or low serum levels of high density lipoprotein cholesterol (HDL-C)] and insulin resistance are major risk factors for coronary heart disease (CHD) in elderly people (1). It is well known that moderate to high intensity exercise training ameliorates these risk factors for CHD. Additionally, the improvements in blood lipids and insulin resistance are associated with loss of body weight and/or body fat (2-5). By contrast, the improvements in physical fitness achieved by exercise training are not necessarily associated with a reduction in these risk factors (2-4).

Regular exercise training can also help to reduce CHD risk factors in the elderly (6). Because elderly people have more physical and/or medical limitations than middle-aged people, however, the intensity of the exercise program is usually lower and the amount of exercise undertaken tends to decline with aging (7-9). Although feasible for most elderly people, such low-intensity and low-volume exercise may be insufficient to improve lipid metabolism and/or insulin resistance. Indeed, few studies have investigated whether a low level of exercise training is also effective in improving insulin resistance and/or blood lipid levels (10). Moreover, the relationship between the improvement in metabolic pa-
rameters and physical fitness remains unknown.

Thus, here we have investigated the effects of a low-intensity and low-volume exercise program suitable for the elderly on lipid and glucose metabolism in this population. Where exercise resulted in metabolic improvements, we also investigated the association between these metabolic improvements and the exercise-related physical improvements in body composition and aerobic fitness.

**Methods**

**Subjects**

A total of 75 older adults (26 males, aged 68±6 years; and 49 females, aged 65±6 years) volunteered to participate in the exercise program through public advertisement. Individuals were excluded if they had 1) cardiovascular disease, renal failure or serious illnesses; 2) orthopedic problems likely to interfere with exercise participation; 3) resting blood pressure >159/99 mmHg; or 4) plasma total cholesterol >300 mg/dL, and triglyceride concentration >500 mg/dL. Individuals on medication, including antihyperlipidemic or antihypertensive drugs, were included if there was no change in the dose throughout the intervention period. Subjects gave their written consent to participate in the study, which had received the approval of the Ethics Committee of University of Tsukuba.

**Measurement of body composition**

Body composition was evaluated by BMI and abdominal fat area. BMI was calculated as the weight/(height)^2 (kg/m^2). Abdominal fat area was determined by computed tomography (CT) scan (Aquilion16, Toshiba, Tokyo, Japan) according to the procedure of Tokunaga et al (16), in which the total fat area (TFA) and visceral fat area (VFA) were measured at the level of the umbilicus.

**Measurement of aerobic capacity**

Aerobic fitness was assessed as peak oxygen uptake (VO2 peak). The subjects sat quietly on a cycle ergometer (75 XLII, Combi Co, Tokyo, Japan) for 3 min and then warmed up at a rate of 0.5 Kp over 4 min. They then pedaled at the higher rate of 0.5 Kp/min. The air expired was analyzed breath-by-breath by using an automatic expired gas analyzer (AE280, MINATO, Osaka, Japan). The VO2 peak tests fulfilled at least one of the following three criteria: 1) systolic blood pressure >250 mmHg; 2) heart rate within 10 beats/ min of the maximal heart rate predicted for age; 3) volitional fatigue. Ventilatory threshold (VT) was determined by the V-slope method (12), using computer regression analysis of the plot of carbon dioxide production versus oxygen consumption.

**Blood sampling**

Blood was drawn in the morning after an overnight fast. Total cholesterol (TC), HDL-C, TG, fasting immunoactive insulin (IRI), fasting plasma glucose (FPG) and glycosylated hemoglobin (HbA1c) were determined. Plasma glucose was measured by the glucose oxidase method. HbA1c was measured by Latex agglutination. Serum TC, TG and HDL-C were determined by enzymatic methods. Low density lipoprotein cholesterol (LDL-C) was calculated by the Friedewald formula (13). However, LDL-C was not calculated if the TG level was >300 mg/dL. Serum insulin was determined by enzyme immunoassay (EIA). Insulin resistance was evaluated by HOMA-IR [FPG (mg/dL)×IRI (μL/U/mL)/405], according to the method developed by Matthews et al (14).

**Measurement of blood pressure (BP)**

BP was not measured for practical reasons, namely, minimizing the variation across measurements calls for five or more BP measurements to be taken in at least two settings (15) and the reproducibility of within-day BP measurements is known to be poor (16).

**Diet evaluation**

Dietary intake was estimated on the basis of consecutive three-day (including one weekday) food diaries at the beginning and the end of the program. Each participant was instructed on how to record detailed descriptions of all foods consumed. Total dietary energy and lipid intake were calculated with the PC software ‘Food Frequency Questionnaire Based on Food Groups’ Ver. 2.3 (Kenpaku Co., Tokyo).

**Exercise training program**

A 12-week supervised training program was designed to improve the aerobic capacity and strength of large muscle groups (back, abdomen, lower and upper bodies). Two different training elements were employed in the program: low-intensity aerobic training three times a week, and resistance training with body weight alone (no external load) twice a week. Aerobic training was carried out for 30 min at 80% VT (corresponding to 50.2±8.6% of VO2 peak) on the basis of an initial maximal graded exercise tolerance test. The resistance exercises selected were seated knee extension, hip extension in the standing position, knee flexion while holding onto a wall, calf raise, bent-knee sit up, back extension in the prone position, and bent knee push up (with knees on the floor). The subjects performed three sets of 10 repetitions.

**Statistical analysis**

The results are expressed as the mean ± standard deviation (SD). Analysis of variance (ANOVA) was used to compare variables between males and females or among stratified groups. Duncan’s multiple range test was used to identify the difference across stratified groups if the ANOVA was significant. Pearson’s correlation coefficient (r) was used to assess the relationship between changes in physical and metabolic parameters. A P value of less than or equal to 0.05 was considered to be statistically significant. SPSS 13.0
Table 1. Physical and Metabolic Profiles before and after Training

<table>
<thead>
<tr>
<th>variable</th>
<th>before</th>
<th>after</th>
<th>Mean Relative Changes (%)</th>
<th>Confidence Interval (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>age (yr)</td>
<td>64 ± 6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body mass index (kg/m$^2$)</td>
<td>23.4 ± 2.4</td>
<td>22.9 ± 2.3</td>
<td>-1.9 ± 2.9$^b$</td>
<td>[-2.7, -1.1]</td>
</tr>
<tr>
<td>Total fat area (cm$^2$)</td>
<td>202 ± 75</td>
<td>187 ± 72</td>
<td>-1.0 ± 3.3</td>
<td>[-10.0, 8.0]</td>
</tr>
<tr>
<td>Visceral fat area (cm$^2$)</td>
<td>72 ± 45</td>
<td>63 ± 40</td>
<td>-1.8 ± 4.9</td>
<td>[-15.2, 11.7]</td>
</tr>
<tr>
<td>VO$_2$ peak (mL/kg/min)</td>
<td>22.5 ± 4.2</td>
<td>22.8 ± 3.6</td>
<td>2.7 ± 12.4</td>
<td>[-0.7, 6.1]</td>
</tr>
<tr>
<td>Triglycerides (mmol/L)</td>
<td>1.20 ± 0.66</td>
<td>1.12 ± 0.58</td>
<td>0.3 ± 33.1</td>
<td>[-8.7, 9.3]</td>
</tr>
<tr>
<td>HDL cholesterol (mmol/L)</td>
<td>1.55 ± 0.37</td>
<td>1.59 ± 0.37</td>
<td>3.2 ± 13.2</td>
<td>[-0.4, 6.8]</td>
</tr>
<tr>
<td>LDL cholesterol (mmol/L)</td>
<td>3.31 ± 0.70</td>
<td>3.12 ± 0.65</td>
<td>-4.1 ± 14.8$^a$</td>
<td>[8.2, -0.0]</td>
</tr>
<tr>
<td>Fasting plasma glucose (mmol/L)</td>
<td>5.81 ± 0.72</td>
<td>5.73 ± 0.78</td>
<td>-0.9 ± 7.2</td>
<td>[-2.9, 1.0]</td>
</tr>
<tr>
<td>Fasting plasma insulin (pmol/L)</td>
<td>58.0 ± 36.2</td>
<td>44.5 ± 36.3</td>
<td>-20.6 ± 31.5$^b$</td>
<td>[-29.2, -12.0]</td>
</tr>
<tr>
<td>HOMA-IR</td>
<td>2.2 ± 1.5</td>
<td>1.7 ± 1.4</td>
<td>-18.4 ± 34.7$^a$</td>
<td>[-27.7, -9.0]</td>
</tr>
<tr>
<td>HbA$_1c$ (%)</td>
<td>5.2 ± 0.5</td>
<td>5.1 ± 0.5</td>
<td>-1.0 ± 4.0</td>
<td>[-2.1, 0.1]</td>
</tr>
</tbody>
</table>

Data were mean±SD. $^a$Relative changes are post-training to pre-training values. $^b$p < 0.01, $^c$p < 0.05

J for Windows software (SPSS Institute, Chicago, IL) was used for the analysis.

Results

Effect of exercise on physical and metabolic profiles

Of the 75 participants enrolled in the trial, 56 (14 males and 42 females; mean age, 64±6 years) who attended more than 85% of the 12-week training program and provided all of the pre- and post-training data were included in the analysis. Dietary intake did not change significantly during the intervention (data not shown). The physical and metabolic characteristics of the subjects at the beginning and the end of the 12-week training program are shown in Table 1. There were no differences between the genders in the baseline values or in the responses to the 12-week exercise program, except that women had significantly higher LDL-C than men (3.46±0.60 mmol/L vs. 2.85±0.81 mmol/L; P = 0.02). There were no significant changes in TFA, VFA, VO$_2$ peak, HDL-C, TG, FPG, or HbA$_1c$. The reduction in BMI was small but highly significant (P<0.001). A borderline-significant reduction was seen in LDL-C (-4%, P=0.05). By contrast, the relative changes in IRI and HOMA-IR were larger (-20% and -21%, respectively) than those in the other variables and were statistically significant (P<0.001 for both).

Relationship between physical and metabolic profiles

To investigate whether there was an association between the improvement in insulin resistance and physical changes, we tested for a correlation between the reduction in HOMA-IR and other physical changes. We found a borderline significant correlation between the reduction in HOMA-IR and the reduction in BMI (r=0.26, P=0.06). However, neither the improvement in VO$_2$ peak nor that in VFA was significantly related to the reduction in HOMA-IR (r= -0.19, P=0.17, and r=0.06, P=0.65, respectively).

To investigate in more detail the relationship between the reduction in HOMA-IR and the physical changes, we divided the data into tertiles on the basis of the baseline BMI and VO$_2$ peak values. The data stratified into tertiles by baseline BMI are shown in Table 2. The reduction in BMI was small but statistically significant in all groups. A paired t-test confirmed that there was a significant reduction in HOMA-IR in the Middle- and High-BMI groups (P<0.01 and P<0.04, respectively). In the High-BMI group, there was a significant correlation between the reduction in HOMA-IR and the reduction in BMI (r= 0.61, P= 0.01) (Fig. 1), and the association between the reduction in HOMA-IR and the reduction in VFA was borderline significant (r= 0.47, P= 0.06). In the Middle-BMI group, however, the reduction in HOMA-IR was independent of the reduction in BMI (r=0.08, P= 0.74) (Fig. 1) or VFA (r= 0.07, P= 0.79).

The data categorized into tertiles by baseline VO$_2$ peak are shown in Table 3. Exercise training led to a significant improvement in VO$_2$ peak in the Middle- and Low-VO$_2$ peak groups (P=0.02 and P=0.02, respectively), but there was no significant improvement across all three groups (see Table 1) or in the High-VO$_2$ peak group.

ANOVA did not reveal a difference in the reduction in HOMA-IR among the three groups (P=0.69). In the Middle-VO$_2$ peak group, we did not find a significant relationship between the reduction in HOMA-IR and the improvement in VO$_2$ peak, as in the overall analysis. In the Low-VO$_2$ peak group, however, the reduction in HOMA-IR was related to the improvement in VO$_2$ peak (Fig. 2).

Discussion

Previous reports have noted that exercise training may improve insulin resistance and lipid metabolism in elderly subjects (17-21). However, it is doubtful whether the exercise training programs studied are feasible for most elderly people. Thus, here we implemented a low-intensity (~50% VO$_2$ peak) and low-volume (90 min/wk in aerobic training) exercise training program that, to our knowledge, has not previously been studied.
Table 2. Mean Values of the Subjects Stratified into Tertiles of BMI

<table>
<thead>
<tr>
<th>BMI tertile</th>
<th>No. of participants (women)</th>
<th>Mean ± SD</th>
<th>Significance (at baseline)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pre</td>
<td>post</td>
<td>pre</td>
</tr>
<tr>
<td>Low</td>
<td>19 (15)</td>
<td>20.9±1.1</td>
<td>23.4±0.7</td>
</tr>
<tr>
<td>Middle</td>
<td>19 (13)</td>
<td>20.7±1.2</td>
<td>23.0±1.3</td>
</tr>
<tr>
<td>High</td>
<td>18 (14)</td>
<td>21.1±1.3</td>
<td>22.5±1.4</td>
</tr>
</tbody>
</table>

Data were mean±SD. * Significant difference (P<0.01) between pre- and post-training value by the paired t test.

b Significant difference (P<0.05) between pre- and post-training value by the paired t test.

Analysis of variance (ANOVA) and Duncan’s multiple range test was performed to investigate the difference in initial values among tertiles. NS, not significant.

This exercise training did not result in an improvement in serum HDL-C or TG levels in the elderly. Several studies suggest that there is a dose-response relationship between exercise training volume and blood lipid changes in the general population (22). Our result indicates, however, that low-volume exercise training is not sufficient to alter lipid values in the elderly.

The American College of Sports Medicine (ACSM) has stated that exercise training at an intensity of less than about 50% maximal oxygen uptake (VO2 max) is generally not sufficient for developing fitness in healthy adults (23). In the present study, the VO2 peak did not significantly increase after training on average (Table 1) or in those individuals with an initially high VO2 peak (Table 3), consistent with the statement by the ASCM. This finding suggests that low-intensity (i.e. 50% of maximal aerobic capacity or less) exercise training is also not necessarily effective in improving aerobic capacity in healthy elderly people. By contrast, a large reduction in mean IRI and HOMA-IR was seen after the exercise training program. This finding indicates that even a low level of exercise that fails to improve lipid values and/or aerobic fitness can improve insulin resistance in elderly subjects.

Several studies have indicated that an improvement in insulin resistance is associated with weight and/or fat loss but not with an exercise-induced improvement in aerobic capaci-
Table 3. Mean Values of the Subjects Stratified into Tertiles of VO2 Peak

<table>
<thead>
<tr>
<th>VO2 peak tertile</th>
<th>pre</th>
<th>Low</th>
<th>post</th>
<th>Middle</th>
<th>post</th>
<th>High</th>
<th>post</th>
<th>Significance (at baseline)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of participants (female)</td>
<td>19 (13)</td>
<td>18 (14)</td>
<td>19 (15)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>age (yrs)</td>
<td>62±5</td>
<td>64±6</td>
<td>66±6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VO2peak (mL/kg/min)</td>
<td>27.0±3.2</td>
<td>25.1±2.5</td>
<td>22.2±0.8</td>
<td>23.7±2.6</td>
<td>18.4±1.9</td>
<td>19.7±3.1</td>
<td>H&lt; L</td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>22.8±2.1</td>
<td>22.3±2.0</td>
<td>22.7±0.9</td>
<td>22.3±1.9</td>
<td>24.7±2.7</td>
<td>24.2±2.6</td>
<td>M, H&lt; L</td>
<td></td>
</tr>
<tr>
<td>TFA (cm²)</td>
<td>181±66</td>
<td>175±57</td>
<td>161±43</td>
<td>149±53</td>
<td>255±76</td>
<td>229±71</td>
<td>M&lt; L</td>
<td></td>
</tr>
<tr>
<td>VFA (cm²)</td>
<td>195±45</td>
<td>65±42</td>
<td>54±31</td>
<td>43±24</td>
<td>88±51</td>
<td>76±45</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>TG (mmol/L)</td>
<td>1.18±0.82</td>
<td>1.06±0.69</td>
<td>1.06±0.58</td>
<td>0.91±0.41</td>
<td>1.36±0.54</td>
<td>1.36±0.54</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>HDL-C (mmol/L)</td>
<td>1.58±0.41</td>
<td>1.63±0.43</td>
<td>1.60±0.39</td>
<td>1.68±0.36</td>
<td>1.48±0.32</td>
<td>1.47±0.29</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>LDL-C (mmol/L)</td>
<td>3.26±0.71</td>
<td>3.09±0.65</td>
<td>3.26±0.83</td>
<td>2.97±0.68</td>
<td>3.41±0.58</td>
<td>3.29±0.61</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>FPG (mmol/L)</td>
<td>5.98±0.90</td>
<td>5.88±1.12</td>
<td>5.57±0.48</td>
<td>5.50±0.53</td>
<td>5.87±0.69</td>
<td>5.81±0.52</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>IRI (pmol/L)</td>
<td>55.2±30.6</td>
<td>40.6±24.4</td>
<td>53.3±33.8</td>
<td>42.7±54.6</td>
<td>65.1±43.4</td>
<td>49.9±23.4</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>HOMA-IR</td>
<td>2.1±1.4</td>
<td>1.6±1.1</td>
<td>1.9±1.3</td>
<td>1.5±2.0</td>
<td>2.5±1.7</td>
<td>1.9±0.9</td>
<td>NS</td>
<td></td>
</tr>
<tr>
<td>HbA1C (%)</td>
<td>5.2±0.7</td>
<td>5.2±0.8</td>
<td>5.1±0.3</td>
<td>5.1±0.4</td>
<td>5.2±0.4</td>
<td>5.1±0.3</td>
<td>NS</td>
<td></td>
</tr>
</tbody>
</table>

*p Significant difference (P<0.01) between pre- and post-training value by the paired t test.

*p Significant difference (P<0.05) between pre- and post-training value by the paired t test.

*p Analysis of variance (ANOVA) and Duncan’s multiple range test was performed to investigate the difference in initial values among tertiles. NS, not significant.
participants on this association and, in addition, the exercise intensity in those studies was higher than that in our study. Because differences in the initial aerobic capacities of the subjects affect the physical fitness response to the exercise training (particularly when the exercise intensity is low) (25), as indicated in the present study (see Table 3), it seems to be necessary to categorize the subjects on the basis of their initial fitness level in order to investigate the association between the improvement in insulin resistance and the improvement in aerobic capacity. Therefore, we categorized the participants into tertiles based on VO2 peak.

In the overall study population, there was no significant correlation between the improvements in HOMA-IR and in VO2 peak ($r=0.19, P=0.17$), in support of previous studies. In the stratified analysis, by contrast, the improvement in HOMA-IR was associated with the improvement in VO2 peak for the Low-VO2 peak group. The present findings suggest that exercise training can be effective/important/indicative, especially for elderly people with a low fitness level, because it improved insulin resistance in parallel with an increase in aerobic capacity.

The present study has the following strengths. First, the exercise level of the training program employed was low, and thus it would be suitable for most elderly people. Second, there was no dietary restriction. Some studies indicate that not only intentional but unintentional weight loss in elderly adults may lead to a decrease in total body mineral density (26), or the development of disease and an increase risk of mortality (27). The mean body weight loss during the intervention period was small (1.2 kg), and thus safe from a medical viewpoint.

Some limitations of the current study should be emphasized. First, the subjects recruited might be healthier than the general elderly population, who may possibly be more fragile and have barriers to exercise training. Second, we did not determine the effect of exercise training on BP. More than half the population over 60 years of age has hypertension (defined as systolic blood pressure of at least 140 mmHg and/or diastolic pressure of at least 90 mmHg) (28), and elevated BP leads to a number of cardiovascular complications (29). Although it is well known that exercise lowers resting blood pressure (30), there is little evidence that low-intensity, low-volume exercise training also has a BP-lowering effect. Further research is therefore needed to determine the effect on resting BP of a low-level exercise training program that is feasible for most elderly people. Third, no sedentary control group was included. Thus, we might not have adequately demonstrated the benefits of the exercise training program itself.

In conclusion, even low-intensity and low-volume exercise training, which would ordinarily be insufficient to improve aerobic fitness and lipid metabolism in healthy elderly subjects, was found to be effective in reducing insulin resistance in the elderly. In non-obese elderly subjects, exercise training can improve insulin resistance independent of weight loss; in obese subjects, by contrast, the improvement in insulin resistance and weight loss were found to be mutually associated. Furthermore, in elderly people with low aerobic fitness, insulin resistance was improved in relation to an exercise-induced improvement in their fitness level.

This study was funded by the Research Grant of the Ministry of Education, Culture, Sports, Science and Technology, Japan. Thanks are also extended to Tsukuba Advanced Research Alliance (TARA) Projects, University of Tsukuba, Japan.

References