Effects of Exercise and Weight Loss on Cardiac Risk Factors Associated With Syndrome X

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Background: Patients with high blood pressure (BP) often exhibit syndrome X, an aggregation of abnormalities in carbohydrate and lipoprotein metabolism associated with increased risk of coronary heart disease (CHD). The present study evaluated the effects of a 6-month intervention involving either aerobic exercise training alone (EX only) or exercise combined with a structured weight loss program (EX+WL) on CHD risk factors associated with syndrome X.

Methods: A total of 53 men and women were selected from a larger behavioral intervention trial, who showed the hyperinsulinemia, dyslipidemia, and high BP characteristic of syndrome X. Participants were randomly assigned to EX only (n=21), EX+WL (n=21), or a waiting list control group (n=11). Before and following treatment, participants underwent measurement of glucose tolerance, lipid levels, and clinical BP.

Results: Hyperinsulinemic responses to glucose challenge were significantly reduced in both the EX+WL group (P<.001) and the EX-only group (P=.003). Participants who showed the largest amount of weight loss showed the most robust improvements in abnormal insulin responses (EX+WL group, 47% reduction; EX-only group, 27% reduction). Diastolic BP was significantly reduced in the EX+WL group (96±4 to 87±5 mm Hg [mean±SD]; P=.01), but not in the EX-only group (93±4 to 89±5 mm Hg [mean±SD]; P=.08). Lipid profile was not significantly improved by either intervention.

Conclusion: These results suggest that EX+WL is an effective treatment for hyperinsulinemia and lowering of diastolic BP in patients with the syndrome X.

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Resistance to insulin-mediated glucose disposal is a common phenomenon, occurring in approximately 50% of patients with hypertension and in approximately 25% of the population at large. Insulin resistance has been postulated to predispose individuals to a cluster of associated abnormalities, including hyperinsulinemia, glucose intolerance, high blood pressure (BP), increased plasma triglyceride, and decreased high-density lipoprotein cholesterol (HDL-C) concentrations. The cluster of secondary changes associated with insulin resistance comprise syndrome X (also called the “insulin resistance syndrome” or the “cardiovascular metabolic syndrome”). Although each of the components of syndrome X has been shown to increase the risk of coronary heart disease (CHD), it has been suggested that insulin resistance and compensatory hyperinsulinemia are the primary factors underlying the clustering and increased incidence of atherosclerotic cardiovascular disease associated with syndrome X, an interpretation consistent with insulin’s role as an independent risk factor for CHD.

Despite the risks associated with syndrome X, this syndrome is often unrecognized and untreated, a problem that is especially important in the context of hypertension, in which the prevalence of syndrome X is high. In addition, the benefits of antihypertensive drugs in hypertensive patients with syndrome X are offset by the fact that many antihypertensive agents worsen carbohydrate and lipid metabolism effects that may negate the beneficial effects of a lower BP. In contrast, regular exercise and weight loss (EX+WL) have been demonstrated to improve carbohydrate and lipid metabolism in a number of populations, although surprisingly few studies have evaluated the effects of EX+WL on lipid and carbohydrate metabolism in hypertensive patients or in individuals with syndrome X.

We recently reported that aerobic exercise training alone (EX only) or exercise combined with a structured weight loss program (EX+WL) on CHD risk factors associated with syndrome X.
propriate size. During each session, resting seated BP was taken in triplicate by a trained technician. Following completion of all baseline assessments, subjects were randomized to 1 of 3 treatment conditions for a period of 6 months: (1) EX only, (2) EX+WL, and (3) waiting list control.

GLUCOSE TOLERANCE TESTING

Participants fasted overnight, following which a venous catheter was inserted and blood drawn for assessment of fasting plasma glucose and insulin. Glucose, 75 g, was administered orally, and samples for assessment of plasma glucose and insulin were obtained at 30-minute intervals for 3 hours. For the oral glucose tolerance test (OGTT), glucose was analyzed by Olympus AU 800 (Olympus, Melville, NJ, and Irvine, Tex). Plasma insulin was analyzed by insulin-specific radioimmunoassay (Linco Research, Inc, St Charles, Mo); mean coefficient of variance for within and between assay variation was 3.2% and 3.9%, respectively.

DIET, WEIGHT, AND BODY COMPOSITION ASSESSMENT

Assessment of dietary content was obtained at baseline and at the conclusion of the intervention. Patients recorded all food intake over 4 consecutive days in a diet diary that was analyzed for caloric and nutritional content using Nutritionist IV software (N-Squared Computing, Salem, Ore). Body fat measurements were performed using the BIA-101Q (Quantum, Highland Heights, Ohio) bioelectrical impedance analyzer in conjunction with bioelectrical impedance analyzer interpretation software (RJL Systems, Inc, Clinton Township, Mich). Fat-free mass was calculated as body weight minus fat mass. Measurements were conducted between 1500 and 1700 hours at ambient temperature using standard right-sided, tetrapolar electrode placement with each subject in a supine position. All participants refrained from food and water for the 3 hours prior to body fat assessment.

Plasma triglycerides, HDL-C, and total cholesterol were measured enzymatically (Lab Corp, Research Triangle Park, NC). High-density lipoprotein cholesterol was estimated by assay of the supernatant remaining after precipitation of serum low-density lipoprotein (LDL) and very-low-density lipoprotein (VLDL) with dextran sulfate plus magnesium chloride. The following equation was used to estimate LDL-C:

\[
LDL \ (mg/dL) = [Total \ Cholesterol \ (mg/dL) − HDL \ (mg/dL) − Plasma \ Triglycerides \ (mg/dL)]/5
\]

The reported values for plasma lipids are the means from blood samples drawn on 2 separate days under fasting conditions.

MEASUREMENT OF MAXIMAL OXYGEN CONSUMPTION

Maximal oxygen consumption (\(V_{\text{O2}}\max\)) was determined by exercise stress testing using the Duke-Wake Forest protocol, in which graded exercise began at 3.2 km/h (2.0 miles/h) and 0% grade and workload was increased at a rate of 1 MET/min (MET is the ratio of the metabolic rate during exercise to the metabolic rate at rest). Expired gases were collected for determination of \(V_{\text{O2}}\max\) using a SensorMedics Metabolic Cart (SensorMedics, Yorba Linda, Calif). To control for differences in fat-free mass, \(V_{\text{O2}}\max\) is expressed in units of milliliter per kilogram of fat-free mass per minute. Blood pressure was obtained at each workload using a Suntech 4240 BP monitor (Suntech Medical instruments, Raleigh, NC).
INTERVENTIONS

EX-Only Group

Participants exercised 3 to 4 times per week for 26 weeks at a level of 70% to 85% of their initial heart rate reserve determined at the time of the baseline treadmill test. The exercise routine consisted of 10 minutes of warm-up exercises, 35 minutes of cycle ergometry or walking (and eventually jogging), and 10 minutes of cool-down exercises. Most patients spent the 35-minute exercise period walking or jogging; however, any patient with musculoskeletal complaints was allowed to cycle during the full exercise period. The main emphasis was placed on maintaining heart rates at or above target heart rates for at least 30 minutes. All patients were instructed in how to monitor their radial pulses, and a trained exercise physiologist supervised all exercise sessions and performed 3 checks of heart rate at 10-minute intervals to ensure that patients were exercising at a sufficient intensity. Participants were instructed to maintain their usual diets.

EX+WL Group

Patients exercised 3 to 4 times per week using the identical protocol as described in the EX-only group. In addition, patients participated in a weight management program in small groups of 3 to 4 members. The weight management program was a behavioral intervention based on the LEARN manual,22 which focuses on 5 elements: lifestyle, exercise, attitudes, relationships, and nutrition. The primary goal of the intervention was a weight loss of 0.5 to 1 kg per week, achieved gradually by decreasing calorie and fat intake through permanent lifestyle changes. Initial dietary goals were set at approximately 1200 cal for women and 1500 cal for men, with about 15% to 20% of calories coming from fat.

The program format consisted of approximately 26 weekly sessions. Record keeping was a key part of the intervention, and meetings started with each participant recording their weight. This was followed by a review of each member’s food diary and behavior modification targets from the previous week. After this review, new material from the LEARN manual focusing primarily on behavior change strategies was introduced. During the last part of each session, goals for the coming week were developed for each member and strategies to help achieve these goals were assigned.

Waiting List Control

Patients were asked to maintain their usual dietary and exercise habits for 6 months until they were reevaluated. Compliance was monitored monthly, and any patient who reported diet or exercise modifications was encouraged to return to their normal dietary and exercise habits.

DATA ANALYSIS

Baseline differences among treatment groups were assessed using 1-way analysis of variance for categorical variables and χ² tests for categorical variables. Treatment effects were evaluated using a 1-way analysis of covariance, with posttreatment value serving as the dependent variable, pretreatment value as a covariate, and treatment group as the between-subjects factor. Separate analysis of covariance models were evaluated for each variable. Significant findings were evaluated using the Tukey honestly significant difference test to compare each treatment group vs the control group, and to compare the EX group with the EX+WL group. The relationship between continuous variables was assessed using correlational analyses. Multiple regression analysis was used to evaluate the independent effects of fitness and weight loss on the insulin responses to glucose.

RESULTS

ADHERENCE

Of the 53 subjects, 41 completed the full intervention (67% of the EX-only group, 76% of the EX+WL group, and 100% of the control group); these 41 subjects were the focus of the present study. There were no differences in baseline characteristics between those who completed the study and those who dropped out of the study prematurely.

Participants who completed the full 26-week exercise program in the EX-only group exercised an average of 3.4 times each week, attending an average of 88 exercise training sessions; no difference in exercise frequency was observed between the EX-only group and the EX+WL group. Both groups exercised at or above their target heart rate training range most of the time (EX only, 90% of time; EX+WL, 95% of time).

Participants who completed the 26-week EX+WL program consumed less fat compared with the control group (P=.03) or the EX-only group (P<.001), and consumed fewer calories compared with the EX-only group (P=.003). Compared with pretreatment levels, estimated daily calorie consumption was reduced by approximately 25% in the EX+WL group and fat consumption was reduced by approximately 50%. Approximately 80% of participants in the EX+WL group reduced their calorie consumption by 15% to 45% and their fat consumption by 35% to 75%.

The control group maintained their dietary and exercise habits, as indicated by monthly adherence ratings as well as by the lack of change in daily calorie, fat, protein, and carbohydrate intake (Table 1) and the lack of change in VO₂max (Table 2) at the end of the 6-month waiting period. There were also no changes in medication use over the 6-month period in the control group.

RESPONSE TO EXERCISE AND WEIGHT LOSS PROGRAMS

Comparisons of the effects of group assignment showed that posttreatment VO₂max, weight, body mass index, waist circumference, and hip circumference were lower in both treatment groups compared with the control group. The degree of improvement in VO₂max was statistically similar in the 2 treatment groups, but the degree of weight loss and change in body mass index was greater in the EX+WL group than in the EX-only group (Table 2). There were no significant differences between the 3 groups in posttreatment percent body fat, waist-hip ratio, peak heart rate, or peak BP.

Comparison of treatment effects revealed that posttreatment 2-hour insulin concentration was significantly reduced in both the EX group (P=.003) and the EX+WL group (P<.001) compared with the control group (Table 2). Compared with pretreatment levels, the 2-hour insulin response to oral glucose was reduced by
Table 1. Effects of Treatment on Dietary Variables*

<table>
<thead>
<tr>
<th></th>
<th>EX Only (n = 14)</th>
<th>EX + WL (n = 14)</th>
<th>Control (n = 9)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretreatment</td>
<td>Posttreatment</td>
<td>Pretreatment</td>
</tr>
<tr>
<td>Energy, cal</td>
<td>2221 ± 109</td>
<td>2403 ± 157</td>
<td>2277 ± 145</td>
</tr>
<tr>
<td>Fat, g</td>
<td>83 ± 7</td>
<td>92 ± 10</td>
<td>88 ± 8</td>
</tr>
<tr>
<td>Protein, g</td>
<td>89 ± 6</td>
<td>103 ± 9</td>
<td>86 ± 5</td>
</tr>
<tr>
<td>Carbohydrates, g</td>
<td>281 ± 19</td>
<td>290 ± 21</td>
<td>292 ± 23</td>
</tr>
</tbody>
</table>

Abbreviations: EX, exercise; WL, weight loss.
*Values represent mean ± SEM.
†Change from initial value different from EX-only group at P < .05.
‡Change from initial value different from control group at P < .05.

Table 2. Effects of Treatment on Outcome Variables*

<table>
<thead>
<tr>
<th></th>
<th>EX Only (n = 14)</th>
<th>EX + WL (n = 16)</th>
<th>Control (n = 11)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pretreatment</td>
<td>Posttreatment</td>
<td>Pretreatment</td>
</tr>
<tr>
<td>V̇O₂max†</td>
<td>41 ± 8</td>
<td>49 ± 7‡</td>
<td>39 ± 7</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>96 ± 17</td>
<td>94 ± 17†</td>
<td>100 ± 19</td>
</tr>
<tr>
<td>BMI</td>
<td>32.3 ± 3.2</td>
<td>31.6 ± 3.3†</td>
<td>33.4 ± 4.5</td>
</tr>
<tr>
<td>% Body fat</td>
<td>33 ± 6</td>
<td>32 ± 9</td>
<td>33 ± 10</td>
</tr>
<tr>
<td>SBP, mm Hg</td>
<td>140 ± 10</td>
<td>133 ± 11</td>
<td>139 ± 8</td>
</tr>
<tr>
<td>DBP, mm Hg</td>
<td>93 ± 4</td>
<td>89 ± 5</td>
<td>96 ± 4</td>
</tr>
<tr>
<td>Fasting glucose, mg/dL</td>
<td>86 ± 6</td>
<td>87 ± 7</td>
<td>87 ± 13</td>
</tr>
<tr>
<td>2-h glucose, mg/dL</td>
<td>123 ± 33</td>
<td>124 ± 27</td>
<td>136 ± 34</td>
</tr>
<tr>
<td>2-h insulin, µU/mL</td>
<td>124 ± 53</td>
<td>90 ± 53‡</td>
<td>152 ± 78</td>
</tr>
<tr>
<td>Total cholesterol, mg/dL</td>
<td>207 ± 63</td>
<td>198 ± 53</td>
<td>212 ± 43</td>
</tr>
<tr>
<td>Triglycerides, mg/dL</td>
<td>223 ± 94</td>
<td>195 ± 92</td>
<td>258 ± 198</td>
</tr>
<tr>
<td>LDL-C, mg/dL</td>
<td>119 ± 40</td>
<td>123 ± 51</td>
<td>141 ± 45</td>
</tr>
<tr>
<td>HDL-C, mg/dL</td>
<td>33 ± 10</td>
<td>37 ± 11</td>
<td>31 ± 8</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by the square of height in meters); DBP, diastolic blood pressure; EX, exercise; HDL-C, high-density lipoprotein cholesterol; LDL-C, low-density lipoprotein cholesterol; V̇O₂max, maximal oxygen consumption; WL, weight loss.
§Change from initial value different from control group at P < .05.
*Values represent mean ± SD.
†Milliliters per kilogram of fat-free mass per minute.
‡Change from initial value different from control group at P < .05.
§Change from initial value different from EX-only group at P < .05.

27% in the EX-only group and by 47% in the EX+WL group. Although there were no significant effects of treatment on 2-hour glucose response to the OGTT, the group who also participated in the weight management program showed a significantly lower glucose response at 30 minutes (P = .02), 60 minutes (P = .02), and 90 minutes (P = .01) post–glucose loading, and tended to show a decreased glucose response at 2-hour post–glucose loading (P = .10), relative to the control group. Posttreatment cholesterol, triglyceride, LDL-C, and HDL-C levels were not significantly different in the active treatment groups compared with the control group (Table 2).

Comparison of posttreatment mean values revealed a significant reduction in diastolic BP (DBP) for the active treatments groups (P < .001) and a marginally significant reduction for systolic BP (SBP) (P = .09). Planned contrasts revealed that the EX+WL group had significantly lower DBP compared with the control group (P = .01); however, posttreatment DBP was not significantly different from controls in the EX-only group (P = .08). Participants in the EX+WL group showed an average reduction in SBP/DBP of 9/9 mm Hg compared with an average reduction of 7/5 mm Hg in the EX-only group and a 3/0 mm Hg reduction in the control group. Multiple regression analyses of the pooled data (EX-only, EX+WL, and control patients combined) showed that improved V̇O₂max and reduced body weight independently predicted improvement in hyperinsulinemic OGTT responses (V̇O₂max change, β = −0.37 [P < .01]; weight change, β = 0.52 [P < .001]). Degree of improvement in V̇O₂max was correlated with degree of improvement in the 2-hour insulin response (r = −0.61; P < .001) and degree of reduction in DBP (r = −0.38; P = .04) and marginally correlated with improvement in SBP (r = −0.33; P = .07). Improvement in lipid levels was not related to improved V̇O₂max (cholesterol, r = −0.21 [P = .26]; triglycerides, r = −0.12 [P = .52]; LDL-C, r = 0.12 [P = .51]; and HDL-C, r = −0.10 [P = .56]). In contrast, the degree of weight loss was correlated with the improvement in 2-hour insulin responses (r = 0.61; P < .001), the change in DBP (r = 0.38; P < .001) and SBP (r = 0.37; P = .02), as well as the improvement in cholesterol (r = 0.33; P = .04).
LDL-C ($r=0.34; P=.04$), and triglycerides ($r=0.37; P=.02$). Weight loss was unrelated to improved HDL-C ($r=−0.20; P=.20$).

A tertile split of the pooled data based on percent change in weight showed that weight loss was linearly related to improvement in hyperinsulinemia ($P<.001$), with post hoc analysis showing significantly larger effects with increasing tertile of weight loss (Figure 1). The amount of weight loss required to achieve maximal improvements was marked; patients in tertile 3 (ie, with the greatest weight loss) lost an average of 11 kg (range, 6-19 kg). Most patients from this tertile (12/14) underwent EX+WL and exercised an average of 3.3 times a week for 26 weeks. In contrast, separation of the pooled data based on tertile of the degree of improvement in $\dot{V}O_2_{max}$ showed that although there was an overall effect of exercise on improved maximal improvement in hyperinsulinemic responses to oral glucose and demonstrate that the addition of a structured weight loss program to an exercise intervention produces a larger degree of improvement in insulin responses and in DBP reduction compared with exercise alone.

The present findings that increased $\dot{V}O_2_{max}$ and decreased body weight independently contributed to improved insulin responses support a synergistic effect of EX+WL. These findings are consistent with evidence that EX+WL improve insulin sensitivity through separate mechanisms of action. Exercise training is thought to im-

**COMMENT**

Previous studies have demonstrated that approximately half of patients with high BP also have hyperinsulinemia and dyslipidemia characteristic of syndrome X. The present study confirms these findings and demonstrates that even individuals with mild elevations in BP are at increased risk of showing the hyperinsulinemia and dyslipidemia characteristic of syndrome X. In addition, the current findings emphasize the importance of weight loss in achieving maximal improvement in hyperinsulinemic responses to oral glucose and demonstrate that the addition of a structured weight loss program to an exercise intervention produces a larger degree of improvement in insulin responses and in DBP reduction compared with exercise alone.

Separation of the pooled sample into tertiles based on degree of weight loss or fitness change was used to evaluate the dose-response nature of the weight loss and fitness effects. The degree of weight loss predicted stepwise increases in improvement in DBP and in the exaggerated insulin responses to oral glucose. In contrast, improvement in $\dot{V}O_2_{max}$ showed a nonlinear relationship with insulin responses; patients who showed moderate improvements in $\dot{V}O_2_{max}$ showed the same degree of improvement as patients with the largest improvements in $\dot{V}O_2_{max}$. Although these findings reaffirm the importance of weight loss in improving hyperinsulinemia, it should be noted that the weight loss was achieved in the context of an exercise intervention.

The present findings that increased $\dot{V}O_2_{max}$ and decreased body weight independently contributed to improved insulin responses support a synergistic effect of EX+WL. These findings are consistent with evidence that EX+WL improve insulin sensitivity through separate mechanisms of action. Exercise training is thought to im-

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**Figure 1.** Percent reduction in the concentration of plasma insulin at the 2-hour point of the oral glucose tolerance test in patients separated by tertile of weight loss. Error bars represent SEM.

**Figure 2.** Percent reduction in the concentration of plasma insulin at the 2-hour point of the oral glucose tolerance test in patients separated by tertile of improved maximum oxygen consumption ($\dot{V}O_2\_{max}$). Error bars represent SEM.
prove insulin sensitivity by increasing oxidative enzymes and glucose transporters in muscle. Long-term exercise training interventions have therefore been shown to reduce the insulin response to glucose, without altering the plasma glucose response to the OGTT. In contrast, weight loss programs are associated with reduced glucose and insulin responses to the OGTT in sedentary men and in men and women with high BP. The present findings confirm these earlier findings by demonstrating that participants in the EX-only group showed reduced plasma insulin concentration in the presence of unchanged glucose concentrations and the participants in the EX+WL group showed reduced glucose and insulin responses to the OGTT.

In contrast to the effects on BP and hyperinsulinemia, lipids were resistant to the effects of the interventions, with patients in the active treatment groups showing similar changes as those exhibited by the patients in the waiting list control group. However, findings of a significant correlation between degree of weight loss and improvement in lipid levels in the pooled sample of all 3 groups suggests that the lack of differences in the active groups vs the controls may be due in part to the lack of power to detect relatively small differences in the individual groups. Although, to our knowledge, this is the first study that has evaluated the effects of aerobic exercise training on lipid profile in patients with components of syndrome X, previous studies in other populations have reported mixed findings. Most studies report no significant effects of habitual exercise on lipid levels in middle-aged and older men. In contrast, EX+WL interventions have generally been associated with improved lipid levels, although reported effects on triglyceride level are inconsistent, with one study showing similar changes as those exhibited by the obese women and other studies reporting average reductions in triglyceride level ranging from 17% to 37%. Together, these findings suggest that weight loss, in the context of exercise training, is an important factor in achieving improvement in dyslipidemia. The present findings of a significant correlation between degree of weight loss and degree of reduction in total cholesterol, LDL-C, and triglyceride level in the pooled sample are consistent with a role for weight loss in the improvement of lipid profile.

One limitation of the present study is the lack of a direct measure of insulin resistance. Although the plasma concentration of insulin at 2 hours of the OGTT is correlated with insulin sensitivity measured using an euglycemic-hyperinsulinemic clamp, insulin concentration at 2-hour post–glucose loading is limited because it reflects the integrity of processes related to both the secretion of insulin and the response to insulin. However, previous classification of patients using clamp-derived measures of insulin resistance vs the OGTT-derived measure of insulin resistance (2-hour insulin concentration > 80 µU/mL [≥556 pmol/L]) define groups with similar abnormalities in lipid profile and blood pressure. A second limitation is that the sample size of the subgroups may have been insufficient to detect clinically meaningful treatment group differences on some of the measures. Moreover, it is also known that subgroup selection can in some cases exaggerate even subtle biases in randomization, which may influence the results of group comparisons.

Despite its limitations, the present study indicates that EX+WL is a useful treatment for the abnormal insulin profile characteristic of syndrome X. A need for alternate modes of treatment of the insulin resistance component of the metabolic syndrome is underscored by the adverse effects of many antihypertensive drugs on carbohydrate and lipid metabolism. Furthermore, according to several recent prospective studies, lowering BP via antihypertensive drug use produces less than the expected 20% to 25% reduction in CHD risk predicted by longitudinal studies of the impact of elevated BP, although the risk of stroke is reduced by the full predicted 35% to 40%. Findings that hyperinsulinemia independently predicts a 2-fold increase in CHD-related mortality suggest that hyperinsulinemia may be a marker or a mechanism underlying this increased CHD risk. Recent findings that men with the dyslipidemia characteristic of the metabolic syndrome do not show improvement in CHD risk following BP reduction support a relationship between syndrome X and the residual CHD risk.

In summary, the present data are consistent with the Adult Treatment Panel III recommendations that EX+WL is a valuable form of therapy for syndrome X and suggests that EX+WL will likely reduce both hyperinsulinemia and elevated BP in overweight men and women with high BP, hyperinsulinemia, and dyslipidemia characteristic of syndrome X. Exercise in the absence of weight loss is likely to result in more limited improvements in the CHD risk factors characteristic of syndrome X.

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