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Exercise-induced reversal of insulin resistance in obese elderly is associated with reduced visceral fat

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O’Leary, Valerie B., Christine M. Marchetti, Raj K. Krishnan, Bradley P. Stetzer, Frank Gonzalez, and John P. Kirwan. Exercise-induced reversal of insulin resistance in obese elderly is associated with reduced visceral fat. J Appl Physiol 100: 1584–1589, 2006. First published December 22, 2005; doi:10.1152/japplphysiol.01336.2005.—Exercise-induced reversal of insulin resistance in obese elderly is associated with reduced visceral fat. A total of 16 subjects (5 men/11 women) who were weight stable (<2 kg/6 mo weight change), sedentary (<20 min exercise twice per week), and obese [body mass index (BMI), 30–40 kg/m2] were recruited to participate in a 12-wk supervised aerobic exercise program. An increase in adiposity is also accompanied by changes in the secretion of adipocyte-derived mediators of insulin resistance, particularly the adipocytokines leptin, tumor necrosis factor (TNF)-α, and adiponectin. Increased circulating leptin and TNF-α and lower levels of circulating adiponectin are associated with insulin resistance (22). While exercise training appears to lower leptin and TNF-α, the effects of exercise on adiponectin are equivocal (18, 26). To date, there are limited data on how exercise alters adipocytokine levels in obese elderly adults (10, 37).

The purpose of our study was to determine the important association between exercise-induced improvements in glucose metabolism, abdominal adiposity, and adipocytokines. The potential for age discrepancy differences between studies has been recognized and suggests that findings may not apply equally to all age groups (13). Therefore, our hypotheses were based on the premise that, by solely focusing on an elderly, obese population, clarity could be drawn as to whether visceral and/or subcutaneous abdominal adiposity could influence cellular glucose uptake and insulin resistance in this age group following compliance with a lengthy, supervised exercise intervention program.

EXPERIMENTAL PROCEDURES

Subjects. A total of 16 subjects (5 men/11 women) who were weight stable (<2 kg/6 mo weight change), sedentary (<20 min exercise twice per week), and obese [body mass index (BMI), 30–40 kg/m2] were recruited to participate in a 12-wk supervised aerobic exercise program (Table 1). The subject mean age was 63 ± 1 yr. Exclusion criteria included evidence of overt Type 1 and Type 2 diabetes, acute or chronic disease (cardiovascular, cerebrovascular, liver, renal, hematological, thyroid, or cancer), smoking, medication

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a heart rate greater than or equal to age-predicted maximum. Intensity oxygen consumption with increasing workloads, volitional fatigue, or percent body fat was estimated using the general equation of Siri, as previously described (24). Fat-free mass was calculated in kilograms as body weight minus kilograms of fat mass. Computed axial tomography (Picker PQ6000 Scanner; Marconi/Picker, Highland Heights, OH) was used to measure the distribution of cross-sectional abdominal fat [total abdominal fat (AT), VF, and SCF] regions, as previously described (1). With subjects placed in a supine position, measurements were made at 120 kV with a slice thickness of 8 mm. Images were digitized and without contrast at the fourth lumbar vertebrae (L4). The images were digitized by optical density to separate bone, muscle, and fat compartments using the National Institutes of Health IMAGE program on a Macintosh platform. Scans were standardized using distances from bony landmarks, and digitized images were analyzed in a blinded fashion. Hydrostatic weight and computed tomography scans were performed at baseline and postintervention.

**Analytical procedures.** All samples for TNF-α, leptin, adiponectin, lipids, insulin, and glucose were run in duplicate in a single assay for each variable. Fasting blood samples were centrifuged at 4°C, and the plasma was stored at −70°C for subsequent analysis. Plasma TNF-α concentrations were measured by ELISA (Quantikine HS; R&D Systems, Minneapolis, MN). The intra-assay coefficient of variation was 14%, and the minimum detectable limit of the assay was 0.18 pg/ml. Plasma leptin samples were measured by radioimmunoassay (Linco Research, St. Charles, MO). Adiponectin levels were measured by an ELISA (R&D Systems). Serum triglycerides and total cholesterol were measured using enzymatic-colorimetric procedures (Hitachi 747, Roche, Indianapolis, IN). Insulin levels were determined by a double-antibody radioimmunoassay (Linco Research, St. Charles, MO). Plasma glucose concentrations were measured by the glucose oxidase method (Yellow Springs Instruments, Yellow Springs, OH).

**Statistical analysis.** This intervention trial was designed to compare pre- and postexercise intervention variables. Changes in variables from baseline to the end of the intervention were determined by the paired Student’s t-test and one-way analysis of variance. The relationship between dependent and independent variables was based on univariate correlation analysis. The data were analyzed using the StatView II statistical package (Abacus Concepts, Berkeley, CA). Data are expressed as means ± SE. P < 0.05 was considered significant.

### RESULTS

All subjects completed the 12-wk exercise intervention program. No significant alteration in kilocalorie intake was seen pre- and postintervention (1,948 ± 182 vs. 1,872 ± 306 kcal, P = 0.688).

**Effects of exercise on anthropometric variables.** The average body weight was 94.1 ± 4.3 kg at the preexercise intervention stage. A significant reduction in body weight (~3%) was observed following the 12-wk exercise program (90.9 ± 4.0 kg, P < 0.0001). No significant alteration in fat-free mass occurred during this time period (55.4 ± 3.3 vs. 55.6 ± 3.2 kg, P > 0.05). The observed body weight loss was attributable to the significant reduction in fat mass (38.8 ± 2.0 vs. 35.4 ± 2.2 kg, P < 0.001) (Table 1).

**Insulin sensitivity and glucose tolerance.** Changes in the OGTT-insulin areas were observed following the completion...
of the exercise intervention program (Table 2). It was observed that areas under the insulin curve (70,973 ± 9,291 vs. 55,760 ± 8,951 pmol/l, P < 0.009) significantly decreased with exercise, highlighting an improvement in insulin response and increased insulin sensitivity. Likewise, a significant decrease in the OGTT-glucose areas was observed (547 ± 54 vs. 452 ± 53†) when pre- and postintervention curves were compared. Insulin resistance was estimated from the product of the areas under the insulin and glucose response curves. A significant decrease in insulin resistance (40.1 ± 7.7 vs. 27.6 ± 5.6 units, P < 0.01) was found in participants after the exercise intervention program was completed (Fig. 1).

Correlation of aerobic fitness and insulin resistance. The level of cardiovascular fitness improved with a 14% average increase in V₀₂max postintervention (21.3 ± 0.8 vs. 24.3 ± 1.0 ml·kg⁻¹·min⁻¹, P < 0.0001). The alteration in insulin resistance was negatively correlated with V₀₂max (r = −0.48, P < 0.05), indicating an increase in insulin sensitivity on improvement in participant fitness levels.

Adipose tissue distribution and insulin resistance correlation. Changes in abdominal adiposity as measured by computed axial tomography showed that AT (visceral and subcutaneous) decreased significantly when pre- and postexercise intervention values were compared (525.4 ± 40.3 vs. 442.5 ± 33.9 cm², P < 0.003). The separation of AT into visceral (176 ± 20 vs. 136 ± 17 cm², P < 0.0001) and subcutaneous

<table>
<thead>
<tr>
<th>Variables</th>
<th>Pretraining</th>
<th>Posttraining</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fasting plasma glucose, mg/dl</td>
<td>110±3</td>
<td>109±3</td>
</tr>
<tr>
<td>Fasting plasma insulin, μU/ml</td>
<td>20.8±2.7</td>
<td>16.7±1.8†</td>
</tr>
<tr>
<td>Glucose AUC</td>
<td>547±54</td>
<td>452±53†</td>
</tr>
<tr>
<td>Insulin AUC</td>
<td>70,973±9,291</td>
<td>55,760±8,951†</td>
</tr>
<tr>
<td>Cholesterol, mg/dl</td>
<td>202±9</td>
<td>186±8†</td>
</tr>
<tr>
<td>Triglycerides, mg/dl</td>
<td>195±26</td>
<td>164±19*</td>
</tr>
<tr>
<td>Leptin, ng/ml</td>
<td>26.99±3.61</td>
<td>21.36±3.07</td>
</tr>
<tr>
<td>TNF-α, pg/ml</td>
<td>2.62±0.49</td>
<td>2.55±0.43</td>
</tr>
<tr>
<td>Adiponectin, μg/ml</td>
<td>6.32±0.90</td>
<td>6.05±1.23</td>
</tr>
</tbody>
</table>

Values are means ± SE; n = 16 subjects; 11 women, 5 men. AUC, area under the curve; TNF-α, tumor necrosis factor-α. *P < 0.005. †P < 0.05.

Changes in abdominal adiposity and increased insulin sensitivity associated with exercise training program. Values represent means ± SE for 16 subjects. *The percent change in total abdominal, subcutaneous, and visceral fat was significantly lower compared with the pretraining measures, P < 0.03.

(351.4 ± 34.1 vs. 304.8 ± 27.7 cm², P < 0.03) adipose tissue revealed that both depots were significantly reduced following the exercise intervention program (Fig. 2). Insulin resistance was not correlated with abdominal fat, SCF, or body weight (data not shown). However, the change in insulin resistance correlated with alterations in VF (r = 0.66, P < 0.006), indicating that insulin resistance was reversed when VF decreased (Fig. 3).

**Biomarkers of insulin resistance.** As shown in Table 2, fasting insulin levels were lower (P < 0.02) after the exercise intervention, while glucose levels remained unchanged. Fasting leptin levels were reduced (P < 0.003), but TNF-α and adiponectin were unaffected by exercise training (P > 0.05). Dyslipidemia was significantly reversed, as evidenced by marked reductions in circulating triglycerides (P < 0.03) and cholesterol (P < 0.01).

**DISCUSSION**

Aging increases the susceptibility to insulin resistance as a consequence of obesity and/or a sedentary lifestyle, leading to...
potentially serious health risks (5, 25). The importance of body composition in determining insulin-resistant states cannot be overemphasized, as the abdominally obese are especially at risk of developing impaired glucose tolerance and reduced cellular responses to insulin (30). To determine whether resistance to insulin-mediated glucose disposal can be alleviated or even reversed, this investigation examined the affects of increased physical activity on inactive, abdominally obese, elderly individuals. The metabolic consequences of abdominal adiposity were shown to be alleviated following compliance with a supervised daily exercise intervention program of 12-wk duration. Glucose tolerance, insulin resistance, and physical fitness in all participants improved significantly when comparisons were made between pre- and postintervention levels. Even though AT, SCF, and VF were all found to be significantly reduced in size, it was the loss of VF within the abdominal region that proved to be the primary correlate with improved glucose control, which suggests it may be the main factor governing the reduction of insulin resistance in our obese, elderly participants. Therefore, by solely focusing on an elderly, obese population, visceral abdominal adiposity could be clearly seen to influence cellular glucose uptake and insulin resistance in this age group following compliance with a lengthy, supervised exercise intervention program.

Our results support previous findings showing that weight loss, particularly due to increased daily exercise, improves insulin sensitivity in overweight and obese individuals (35). By attaining an ~3% weight loss, our participants greatly improved their insulin sensitivity postexercise intervention, as shown by the 31% reduction in insulin resistance, despite higher therapeutic recommendation weight loss levels previously reported (5–10%) to be necessary for improvements in insulin sensitivity (11). In other studies in which reductions in BMI and waist circumference measurements were controlled, the investigators still noted the beneficial effect to be partially due to the corresponding reduction in abdominal fat, particularly visceral tissue (19). Furthermore, studies examining the effects of therapeutic interventions (e.g., hormone replacement therapy and dehydroepiandrosterone replacement) independent of exercise in elderly populations have also reported that decreases in abdominal fat are inversely correlated with insulin sensitivity (8, 41). Thus, even in the absence of elevated physical activity, there is a strong relationship between decreased visceral adipose tissue and the reversal of insulin resistance in elderly adults.

There is no clear consensus on how increased VF contributes to insulin resistance. It has been suggested that VF is highly sensitive to lipolytic stimuli, which may, in turn, induce insulin resistance by increasing gluconeogenesis in the liver, thus promoting hyperglycemia and also facilitating an increase in free fatty acids (FFA) (32). While there is no direct evidence to support this mechanism in humans, recent data from dogs in which insulin resistance was induced by a high-fat diet show a concomitant increase in the hepatic gluconeogenic enzymes phosphoenolpyruvate carboxykinase and glucose-6-phosphatase (21). Furthermore, it is also known that increased fatty acid oxidation in the liver can stimulate gluconeogenesis (4). Alternative mechanisms may be acting through FFA-induced inhibition of hepatic insulin clearance (39). These mechanisms have been invoked in previous studies to explain the association between central obesity and the insulin resistance of aging (5, 25). More recent elegant studies by Nielsen et al. (29) have revealed that hepatic FFA delivery is raised in individuals in proportion to increasing amounts of VF. Thus it is likely that increased hepatic insulin resistance may be directly attributed to VF. Furthermore, individuals with greater amounts of VF release more FFA from the liver. It is now well established that elevated FFAs contribute to peripheral insulin resistance (2). Thus the observation that exercise can reduce VF is significant and suggest a mechanism whereby exercise may reverse both hepatic and peripheral insulin resistance in abdominally obese individuals.

Consequent to aerobic exercise training, the effects of body fat loss on insulin metabolism have been shown to be gender independent (12, 20). While there are distinct sex-dependent differences in the regional fat distribution, others found that, after controlling for tissue size, reductions in visceral adipose tissue were not different between the sexes (20). After weight loss, there were no apparent statistically significant sex-related effects in the improvement in insulin sensitivity in obese men and women (12). These results support our observations from a nonstratified mixed-gender sample group.

The subdivision of visceral into intra- and extraperitoneal tissue and SCF into deep and superficial depots was not carried out in this study. It was shown previously that subdivision of VF and subcutaneous tissue provided no additional insight into the relationship between abdominal obesity and metabolic risk in obesity. Subdivision did not alter the observation that VF alone correlated strongly with insulin resistance, independent of abdominal SCF depots (34).

Significant improvement in aerobic fitness (14%) was evident in our elderly, obese participants. The reduction in insulin resistance was associated with the increase in physical fitness, such that those who experienced the greatest improvement of \( \text{VO}_2 \text{max} \) also experienced the greatest decrease in insulin resistance. While a reduction in insulin sensitivity is commonly described during aging (6, 36), it has recently been shown that the age-related decline in insulin sensitivity may principally result from muscle deconditioning due to physical inactivity (33). Similar insulin sensitivity levels have been recorded for young and elderly individuals when matched for physical activity levels (33). Despite the lack of follow-up in our study, the long-term effects of sustained benefits from physical activity on insulin resistance are encouraged by findings such as ours involving regular daily exercise.

Recent discoveries in fat cell biology have led to the suggestion that adipocytokines secreted from the adipocytes may act as mediators of insulin resistance (15). Although increased circulating TNF-\( \alpha \) levels have been associated with insulin resistance in obesity, aging, and exercise-induced muscle damage, reports of change in TNF-\( \alpha \) levels after exercise training are equivocal (7, 17, 24). Data from the present study suggest that circulating TNF-\( \alpha \) may not change in obese elderly adults after exercise training. This does not preclude the possibility that changes in locally secreted TNF-\( \alpha \) do not occur, and a decrease in TNF-\( \alpha \) at the tissue level could have a profound effect on altering insulin sensitivity (14). Leptin was first identified as a product of the ob gene in adipose tissue and is thought to regulate energy balance through central hypothalamic pathways, but it may also play a role in insulin resistance by promoting lipid oxidation and inhibiting lipid synthesis (27, 43). There are several reports of decreased circulating leptin...
after exercise training, and the present study confirms these results. Despite the decrease in leptin, we did not see an association between the change from pre- to postintervention and improvements in insulin resistance. This suggests that, under the present study conditions, the decrease in leptin may not have been sufficiently robust and could have only contributed indirectly to the reversal of insulin resistance. Likewise, total adiponectin, which is another candidate biomarker of insulin resistance, did not change with exercise training, despite improvements in insulin sensitivity. However, in the case of adiponectin, it is likely that changes in the multimeric forms of the protein may be more important than changes in total adiponectin multimer (42). Indeed, we recently presented a preliminary report in which exercise training led to increases in the adiponectin multimer ratio in obese elderly, even though the total adiponectin concentration was unchanged (28). Further studies are needed to examine the effects of exercise training on these adiponectin multimers and any consequent relationship this may have with changes in insulin resistance. Our observations of decreased triglycerides and cholesterol following exercise training are consistent with previous reports and reinforce the positive effect of exercise training on these important risk factors for metabolic syndrome, Type 2 diabetes, and cardiovascular disease (16).

To conclude, we report the novel observation that the loss of abdominal VF alone through exercise correlates with improved glucose control in an elderly, obese subject group. The influence of the SCF depot can be ruled out in this regard. In this way, clarity can be drawn as to whether visceral and/or subcutaneous abdominal adiposity could influence cellular glucose uptake and insulin resistance. The improvement in physical fitness, glucose tolerance, and body composition reduces the risk of developing Type 2 diabetes in this at-risk population. Our association data suggest that the physiological mechanisms that cause age-related insulin resistance include a low-exercise capacity and accumulation of visceral adipose tissue. Fortunately, exercise successfully targets and reduces VF and enhances glucose tolerance, making it a highly effective treatment strategy for insulin resistance in the elderly, obese.

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GRANTS

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