Influence of Exercise Intensity on Abdominal Fat and Adiponectin in Elderly Adults

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Abstract

To examine the influence of moderate-intensity (50% of $\text{VO}_{2\text{peak}}$) exercise training (MI) versus high-intensity (75% of $\text{VO}_{2\text{peak}}$) exercise training (HI) on regional fat distribution and plasma adiponectin, we randomized 18 overweight (body mass index [BMI] = $30 \pm 1 \text{ kg/m}^2$) elderly (71 ± 1 years) to HI, MI, or a control group (CON). Subjects enrolled in HI or MI completed a 12-week exercise training protocol designed to expend 1000 kcal/week. Body composition testing was completed prior to and following the exercise training using dual energy X-ray absorptiometry and a computed tomography scan. Plasma adiponectin was measured using enzyme-linked immunoassay (ELISA). $\text{VO}_{2\text{peak}}$ improved in HI and MI, whereas there was no change in $\text{VO}_{2\text{peak}}$ in CON. No significant change in body weight, BMI, and % fat occurred in MI, HI, or CON. Although there was a significant reduction in visceral fat with HI (-39 cm^2), there was no change in the MI or CON groups. In addition, there was a significant increase in thigh muscle attenuation in the HI group. There were no changes in thigh muscle attenuation in the MI and CON groups. Also, there was no change in plasma adiponectin in the MI, HI, or CON groups. In summary, our direct comparison of exercise intensity without weight loss promotes the efficacy of HI in the reduction in visceral fat, even without changes in adiponectin.

Introduction

THE INCREASE IN OBESITY and inactivity with advancing age are directly associated with the pathogenesis of metabolic abnormalities, including hypertension, dyslipidemia, and insulin resistance. This cluster of interrelated conditions, which increases the risk of type 2 diabetes (T2D) and cardiovascular disease (CVD), is known as the metabolic syndrome.¹ Prevalence of the metabolic syndrome increases with age and exists in an alarming ~43% of people aged over 60 years.² Therefore, from a public health standpoint, efficacious strategies must be developed to prevent and/or treat metabolic complications in our aging population.

For health promotion and disease prevention, the Centers for Disease Control and Prevention (CDC) and the American College of Sports Medicine (ACSM) have recommended 30 minutes or more of physical activity on most, preferably all, days of the week.³ In spite of favorable exercise training-induced changes in adipose tissue and glucose metabolism,^{4–6} training paradigms from these studies used a longer duration and/or a greater exercise intensity beyond the current recommendations for moderate-intensity exercise training.³

In an effort to define the influence of CDC/ACSM recommendations for physical activity on glucose metabolism in elderly, obese individuals, we previously compared the efficacy of 12 weeks of moderate intensity (~50% $\text{VO}_{2\text{peak}}$) (MI) or high-intensity (~75% $\text{VO}_{2\text{peak}}$) (HI) aerobic exercise training (matched with an equivalent caloric expenditure of 1000 kcal/week) on improvements in insulin-stimulated glucose disposal (ISGD). In these studies, MI or HI did not result in weight loss, and only HI was effective in improving ISGD, which was entirely reliant on increased nonoxidative glucose metabolism.⁷ Our results were also quite similar to another study comparing the role of exercise intensity in elderly, obese women.⁸ In addition, O'Leary et al. demonstrated a relationship between exercise training-induced reductions in visceral fat and improvements in glucose metabolism.⁹ However, the optimal intensity of exercise necessary to promote the reduction of visceral fat has not been evaluated in elderly, obese adults.

It is also interesting to note that excess abdominal fat is negatively associated with adiponectin levels.¹⁰ This is important because adiponectin has been shown to improve

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mitochondrial function¹¹ and potentially reduce the level of insulin resistance.¹² Results from exercise training studies have been largely inconclusive, with some supporting the role of exercise training in the modulation of adiponectin^{13–15} and others finding little evidence for a direct exercise-mediated effect.^{16,17} Unfortunately, the training regimens from these studies were extremely variable, had a variable influence on body weight, incorporated a wide variety of exercise intensities and modalities, and also employed a wide range of individuals.

Therefore, the purpose of our study was to determine the efficacy of MI versus HI on the reduction of regional fat depots and favorable changes in plasma adiponectin using the minimal ACSM/CDC minimal recommendations in elderly, obese adults.

Materials and Methods

Subjects

Men and women aged 65–90 years were recruited from the central Arkansas area using newspaper advertisements. Subjects who reported being overweight or obese (body mass index [BMI] ≥ 26 and < 37 kg/m²), nonsmoking, sedentary (≤ 2 days/week of structured physical activity), weight stable ($\pm \leq 5$ kg) over the past 6 months, and who were not consuming medications known to influence glucose metabolism were invited to our laboratory for a comprehensive medical screening. As part of our medical screening processing, a complete blood count, an oral glucose tolerance test (OGTT), and electrolyte panel were completed. Exclusion criteria included a creatinine >1.4 , and a serum glutamate pyruvate transaminase >2 times normal. All volunteers with a resting blood pressure above 160/90 mmHg were excluded. It is important to realize that obese volunteers often had other medical conditions. Thus, it would have been impractical to exclude all patients taking medications, and we could not ethically discontinue all medications for the duration of the intervention. As a result, we permitted antidepressant selective serotonin reuptake inhibitors and estrogen replacement/oral contraceptives. Subjects that take Gemfibrozil (or other fibrates), niacin, or other pharmaceuticals that have potential effects on lipid metabolism were excluded. We excluded any patient with a chronic rheumatological inflammatory condition or a malignancy, or any patient taking corticosteroids. In addition, volunteers with a history of cardiovascular disease were excluded. Finally, any patient who had a medical condition or was taking a medication that, in the opinion of the study physician, represented an unacceptable risk, was excluded from the study. Our inclusion/exclusion criteria provided us with an opportunity to study the influence of minimal ACSM/CDC recommendations for exercise training under moderate- and high-intensity conditions in elderly, overweight participants under well-controlled conditions without the existence of cardiovascular disease, cancer, or other inflammatory diseases and without the complicating the interpretation of the data through the use of medications/supplements that would impart an independent influence on the regulation of metabolism.

Subjects with a plasma glucose concentration of 100–199 mg/dL 2 hours following the consumption of a 75-gram oral glucose load, but who were otherwise healthy, were eligible for study participation. Each subject provided written

informed consent prior to screening and study participation, and all study procedures were approved by the Institutional Review Board of the University of Arkansas for Medical Sciences and the Central Arkansas Veterans Healthcare System Research and Development Committee.

Experimental protocol

Following completion of screening visit and eligibility evaluation, subjects were randomly assigned to moderate exercise training (MI; $n = 6$), high-intensity exercise training (HI; $n = 6$), or a control (CON) group ($n = 6$). To standardize dietary intake as part of the accurate assessment of peripheral insulin sensitivity (glucose metabolism data has been previously published),⁷ maintain body weight, and prevent differences in dietary intake, each subject was provided a mixed diet (35% fat, 20% protein, 45% carbohydrate) during 4 days of controlled feeding prior to baseline (week 2) and postintervention (week 14) testing period.¹⁸ Subjects were instructed to eat only the food prepared by our metabolic kitchen and to consume them completely.

Subjects who were randomized to one of the exercise training groups were trained 4–5 days a week for 12 weeks at either 50% (MI) or 75% (HI) of their $\text{VO}_{2\text{peak}}$, and caloric expenditure was matched at 1000 kcal/week for each group. Subjects randomized to the control group completed only the screening process and the testing procedures. All subjects were trained under supervision at the Donald W. Reynolds Institute on Aging using a cycle ergometer (Model 818E, Monarch, Varberg, Sweden) as previously described.⁷ Nonexercising subjects were instructed to maintain their habitual physical activity.

Body weight and body composition

Body mass, height, and body composition testing were measured at week 2 and week 14. Fat mass and lean tissue mass were measured by dual-energy X-ray absorptiometry using a Hologic QDR 2000 densitometer (DXA). Images from the computed tomography (CT) scans were completed using a GE High-Speed Advantage (GE Medical Systems, Milwaukee, WI) at 120 kV, 280 mA, a 512×512 matrix, and a scanning duration of 1 second. All volunteers rested for 1 hour before each scan to minimize muscle size changes due to posturally related fluid shifts.¹⁹ For the measurement of visceral adipose tissue, a lateral scout was used to identify a 10-mm scan at the L4–L5 vertebral disc space. Abdominal subcutaneous adipose tissue cross-sectional area was determined by highlighting the area between the skin and the external-most aspect of the abdominal muscle wall. A CT of the thigh was also obtained to examine changes in adipose tissue cross-sectional area. A scout image was used to acquire an orientation of skeletal muscle landmarks. Subsequently, a single 10-mm slice was obtained at a mid-point between the right iliac crest and the patella of the dominant leg. All computed tomographic images were stored on magnetic tape, transferred to a personal computer, and analyzed using medical imaging software (SliceO-Matic version 4.2; Tomovision, Montreal Quebec). The attenuation ranges were -25 to 145 Hounsfield units for muscle, -250 to -40 Hounsfield units for fat, and >150 Hounsfield units for bone. The coefficient of variation for this technique is 1.0–1.5% in our laboratory.

TABLE 1. CLINICAL CHARACTERISTICS OF OLDER OBESE MEN AND WOMEN

	High intensity	Moderate intensity	Control
Age, years	73 ± 2	70 ± 1	67 ± 3
BMI, kg/m ²	30 ± 1	28 ± 1	31 ± 1
Fat-free mass, kg	55 ± 3	50 ± 4	55 ± 4
Percent body fat	38 ± 3	38 ± 2	40 ± 2
Sex, male/female, <i>n</i>	3/3	3/3	3/3
Plasma glucose @ 120 min of oral glucose tolerance test (mg/dL)	155 ± 8	154 ± 8	156 ± 7

Abbreviation: BMI, body mass index.

Plasma adiponectin

Fasting blood samples were collected for analysis of plasma adiponectin prior to and 48–72 hours following the last exercise training session. These blood samples were centrifuged at 4°C, and the plasma was immediately stored at –70°C. Upon completion of the study and using a single assay, all samples were measured in duplicate using enzyme-linked immunoassay (ELISA; Linco Research, Inc., St Charles, MO).

Statistical analysis

To compare changes in regional fat distribution and plasma adiponectin, a repeated-measures analysis of variance (ANOVA) was used. All data were analyzed using Prism 4 for Macintosh (GraphPad software, Inc., San Diego, CA). Data are reported as means ± standard of the mean (SEM).

Results

Baseline characteristics

Eighteen elderly, obese volunteers successfully finished the entire study paradigm. The overall mean age of our volunteers for this study was 71 ± 1 years (see Table 1 for clinical characteristics and Table 2 for a description of maximum work output for the volunteers in this study).

Peak oxygen consumption and maximum work output

Although there was a significant increase in $\text{VO}_{2\text{peak}}$ in the HI (1.4 ± 0.1 to $1.7 \pm 0.2 \text{ mL} \times \text{kg}^{-1} \times \text{min}^{-1}$) and MI (1.3 ± 0.1 to $1.7 \pm 0.1 \text{ mL} \times \text{kg}^{-1} \times \text{min}^{-1}$), there was no significant change in $\text{VO}_{2\text{peak}}$ in the control group. Also, there was a consistent, significant increase in maximum work output in the

HI (positive Δ of 38 ± 11 watts) and MI (positive Δ of 44 ± 14 watts) groups. Maximum work output was not increased in the control group.

Abdominal visceral and subcutaneous fat and thigh fat

While abdominal visceral fat decreased ($P = 0.03$) in the HI group (Δ of $-39 \pm 11 \text{ cm}^2$) (Fig. 1), there was no change in abdominal visceral fat in the MI or control group. There was no change in abdominal subcutaneous fat in HI (Δ of $-12 \pm 4 \text{ cm}^2$), MI (Δ of $-13 \pm 4 \text{ cm}^2$) on the control group (Δ of $+10 \pm 6 \text{ cm}^2$). There was a trend toward reduced thigh fat in HI (Δ of $-18 \pm 10 \text{ cm}^2$), but it was not significant.

Plasma adiponectin

Although plasma adiponectin increased in an absolute sense in the HI (Δ of $+2.5 \pm 1.5 \text{ ng/mL}$) and MI (Δ of $+1.6 \pm 2.2 \text{ ng/mL}$) groups, these changes were not significant and there was no change in plasma adiponectin in the control group (Fig. 2).

Discussion

It is a generally well-accepted notion that a positive imbalance between caloric intake and caloric expenditure contributes to the development of insulin resistance.²⁰ Also, the aging process itself may place elderly individuals at an even greater risk for metabolic abnormalities.²¹ This has become an especially relevant issue in our current society with the rapid growth of an aging population and the corresponding increased burden on health-care resources.²² As such, elderly individuals need definitive physical activity recommendations that are based on the results of clinical studies in the geriatric population. Therefore, we chose to evaluate the efficacy of the minimal ACSM/CDC

TABLE 2. PEAK OXYGEN CONSUMPTION AND MAXIMUM WORK OUTPUT

	High intensity		Moderate intensity		Control	
	Pre	Post	Pre	Post	Pre	Post
$\text{VO}_{2\text{peak}}$ ($\text{l/min} \times \text{kg}^{-1} \times \text{min}^{-1}$)	1.4 ± 0.1	1.7 ± 0.1^a	1.3 ± 0.1	1.7 ± 0.1^a	1.5 ± 0.1	1.5 ± 0.1
Maximum work output (watts)	115 ± 10	150 ± 11	110 ± 9	160 ± 8^a	105 ± 12	108 ± 11

^aSignificant training effect ($P < 0.05$).

FIG. 1. Changes in abdominal visceral fat in the high-intensity exercise training, moderate-intensity exercise training, and control groups. Values are means $\pm$ SEM for subjects in each group. *Significant training effect, $P < 0.05$.

recommendations for physical activity on factors potentially responsible for the development of insulin resistance (i.e., excess regional adipose tissue and reduced levels of plasma adiponectin). The results of our supervised exercise training studies using matched caloric expenditure of 1000 kcal/week demonstrated that only HI facilitated a reduction in visceral fat. MI resulted in no change in visceral fat. Also, MI or HI (in the absence of weight loss) had no significant influence on abdominal subcutaneous fat, thigh fat, or plasma adiponectin.

Previous studies in middle-aged individuals with T2D have demonstrated significant reductions in visceral fat and subcutaneous fat as a result of high-intensity exercise training.^{23,24} In these studies, the training period of 8 weeks was 33% shorter, but the relative exercise intensity and mode of exercise training (i.e., cycle ergometer) were relatively

consistent with that employed in the present investigation, except for the addition of interval type exercise within the training paradigm. More specifically, these authors used high-intensity, continuous cycle ergometer training at 75% of VO_{2peak} for 30 minutes on 2 days of the week, and an interval exercise training session consisting of five bouts at 85% VO_{2peak} for 2 minutes separated by intermittent bouts at 50% of VO_{2peak} for 3 minutes. Hence, using a modified interval training design in previously unfit individuals with T2D may have promoted use of fat as an energy source.²⁵ In turn, this could have promoted a combined reduction in abdominal subcutaneous fat and visceral fat, even under conditions of relatively low caloric expenditure and no change in total body mass.

In addition to the previously mentioned studies incorporating the use of interval training, the studies by O'Leary

FIG. 2. Changes in plasma adiponectin in the high-intensity exercise training, moderate-intensity exercise training, and control groups. Values are means $\pm$ SEM for subjects in each group.

et al. demonstrated an exercise training-induced reduction in visceral fat,⁹ abdominal subcutaneous fat, and total abdominal fat. In these studies, the volunteers exercised at ~70% of $\text{VO}_{2\text{max}}$ 5 days of week for 50–60 minutes and lost ~7 pounds over the course of the study. As such, these results have raised an interesting question as to whether weight loss may be required to initiate a reduction in the levels of visceral fat. In studies where the influence of exercise training (with and without weight loss) were compared, exercise training with weight loss (~8 pounds) resulted in a 26% reduction in visceral fat while exercise training without weight loss (complete caloric compensation for the energy expenditure of exercise training) still promoted a 17% reduction in visceral fat.²⁶ Although the duration of the exercise training bouts were significantly longer (~40–60 minutes per session versus ~30 minutes in our study) in this study, the intensity of the exercise training was almost identical to the HI group in our present study. Therefore, we were able to demonstrate an exercise training-induced reduction in visceral fat (~20%) at the same relative exercise intensity, even with a 20–40% reduction in total exercise training duration.

Abdominal adiposity has been suggested as a more powerful predictor of insulin resistance than fitness, especially among older individuals.²⁷ Although visceral fat decreased in HI, the lack of a change in abdominal subcutaneous fat in either exercise training group may be linked to a negligible or nonexistent change in adiponectin, due to the strong relationship between abdominal fat deposition and the dysregulation of adiponectin gene expression in adipose tissue.¹⁰ It is also interesting that an inverse relationship between adiponectin mRNA expression and tumor necrosis factor- α (TNF- α) has been demonstrated, potentially substantiating the importance of adiponectin as a suppressive mediator of proinflammatory cytokines.²⁸

In short-term aerobic exercise training studies that incorporated a variety of exercise modalities, Blüher et al. demonstrated improvements in plasma adiponectin and Adipo R1/R2 mRNA expression without weight loss in persons with impaired glucose tolerance and T2D.¹³ In our studies, plasma adiponectin did increase in an absolute sense in MI and HI, and we recognize that the lack of a significant increase in adiponectin might be influenced by the relatively small sample size of our well-controlled, supervised study. However, other studies with either moderate- or high-intensity exercise training also did not find an improvement in plasma adiponectin.^{16,29} These authors were able to show that changes in visceral adipose tissue and TNF- α were indicative of efficacious changes in the degree of insulin resistance¹⁶ and support the contention that changes in the relationship between adiponectin and proinflammatory cytokines such as TNF- α represent their key contribution in the modulation of glucose metabolism.³⁰

In conclusion, the results of studies support the efficacy of short-term, high-intensity aerobic exercise training for the reduction of visceral fat in elderly, overweight adults. The lack of a significant change in abdominal subcutaneous or thigh fat indicate that high-intensity exercise training exerts a preferential influence on the oxidation of visceral fat. Also, the lack of significant changes in plasma adiponectin suggests that moderate- or high-intensity exercise training in the absence of weight loss does not normalize metabolic dysfunction in a short-term intervention. However, the efficacy of long-term, high-intensity exercise training toward the amelioration of insulin resistance

has not been well tested, and future studies are needed to identify potential changes in the expression of proinflammatory cytokines in abdominal adipose tissue and their relationship to changes in hepatic and peripheral insulin sensitivity.

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References

1. Grundy SM, Brewer HBJ, Cleeman JI, Smith SCJ, Lenfant C. National Heart, Lung and Blood Institute, American Heart Association: Definition of metabolic syndrome: report of the National Heart, Lung, and Blood Institute/ American Heart Association conference on scientific issues related to definition. *Circulation* 2004;109:433–438.
2. Ford ES, Giles WH, Dietz WH. Prevalence of the metabolic syndrome among US adults: finding from the third National Health and Nutrition Examination Survey. *JAMA* 2002;16:356–359.
3. Pate RR, Pratt M, Blair SN, Haskell WL, Macera CA, Bouchard C, Buchner D, Ettinger W, Heath GW, King AC, Kriska A, Leon AS, Marcus BH, Morris J, Paffenbarger RS Jr, Patack K, Pollock ML, Rippe JM, Sallis J, Wilmore JH. Physical activity and public health: a recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *JAMA* 1995;273:402–407.
4. Evans ME, Van Pelt RE, Binder EF, Williams DB, Ehsani AA, Kohrt W. Effects of HRT and exercise training on insulin action, glucose tolerance, and body composition in older women. *J Appl Physiol* 2001;90:2033–2040.
5. Kahn SE, Larson VG, Beard JC, Cain KC, Fellingham GW, Schwartz RS, Veith RC, Stratton JR, Cerqueira MD, Abrass IB. Effect of exercise on insulin action, glucose tolerance, and insulin secretion in aging. *Am J Physiol* 1990;258:E937–E943.
6. Stewart KJ, Bacher AC, Turner K, Lim JG, Hees PS, Shapiro EP, Tayback M, Ouyang P. Exercise and risk factors associated with metabolic syndrome in older adults. *Am J Prev Med* 2005;28:9–18.
7. Coker RH, Hays NP, Williams RH, Brown AD, Freeling SA, Kortebein PM, Sullivan DH, Starling RD, Evans WJ. Exercise-induced changes in insulin action and glycogen metabolism in elderly adults. *Med Sci Sports Exerc* 2006;38:433–438.
8. DiPietro L, Dziura J, Yeckel CW, Neuffer PD. Exercise and improved insulin sensitivity in older women: evidence of the enduring benefits of higher intensity exercise training. *J Appl Physiol* 2006;100:142–149.
9. O'Leary VB, Marchetti CM, Krishnan RK, Stetzer BP, Gonzalez F, Kirwan JP. Exercise-induced reversal of insulin resistance in obese elderly is associated with reduced visceral fat. *J Appl Physiol* 2006;100:1584–1589.
10. You T, Yang R, Lyles MF, Gong D, Nicklaus BJ. Abdominal adipose tissue cytokine gene expression: relationship to obesity and metabolic risk factors. *Am J Physiol Endocrinol Metab* 2005;588:E741–E747.
11. Civitarese AE, Ukropcova B, Carling S, Hulver M, DeFronzo RA, Mandarino LJ, Ravussin E, Smith SR. Role of adiponectin in human skeletal muscle bioenergetics. *Cell Metab* 2006;4:75–87.

12. Kelley DE, Goodpaster BH. Skeletal muscle triglyceride. An aspect of regional adiposity and insulin resistance. *Diabetes Care* 2001;24:933–941.
13. Bluher M, Bullen Jr. JW, Lee JH, Kralisch S, Fasshauer M, Klöting N, Niebauer J, Schön MR, Williams CJ, Mantzoros CS. Circulating adiponectin and expression of adiponectin receptors in human skeletal muscle: associations with metabolic parameters and insulin resistance and regulation by physical training. *J Clin Endocrinol Metab* 2006;91:2310–2316.
14. Kondo T, Kobayashi I, Murakami M. Effect of exercise on circulating adipokine levels in obese young women. *Endocrine J* 2006;53:189–195.
15. Oberbach A, Tonjes A, Klöting N, Fasshauer M, Kratzsch J, Paschke R, Stumvoll M, Bluher M. Effect of 4 week physical training program on plasma concentrations of inflammatory markers in patients with abnormal glucose tolerance. *Eur J Endocrinol* 2006;154:577–585.
16. Giannopoulou I, Fernhall B, Carhart R, Weinstock RS, Baynard T, Figueroa A, Kanaly JA. Effects of diet and/or exercise on the adipocytokine and inflammatory cytokine levels of postmenopausal women with type 2 diabetes. *Metabolism* 2005;54:866–875.
17. Monzillo LU, Hamdy O, Horton ES, Ledbury S, Mullooly C, Jarema C, Porter S, Ovalle K, Moussa A, Mantzoros CS. Effect of lifestyle modification on adipokine levels in obese subjects with insulin resistance. *Obes Res* 2003;11:1048–1054.
18. Hays NP, Starling RD, Sullivan DH, Fluckey JD, Coker RH, Williams RH, Evans WJ. Effect of an ad libitum, high carbohydrate diet and aerobic exercise training on insulin action and muscle metabolism in older men and women. *J Gerontol A Biol Sci Med Sci* 2006;61:299–304.
19. Berg HE, Tedner B, Tesch PA. Changes in lower limb muscle cross-sectional area and tissue fluid volume after transition from standing to supine. *Acta Physiol Scand* 1993;148:379–385.
20. Ivy JL, Zderic TW, Fogt DL. Prevention and treatment of non-insulin-dependent diabetes mellitus. *Exerc Sport Sci Rev* 1999;27:1–35.
21. Holloszy JO, Greiwe JS. Overview of glucose metabolism and aging. *J Sport Nutr Exerc Metab* 2001;11(Suppl):S58–S63.
22. Besidine R, Boulton C, Brangman S, Coleman EA, Fried LP, Gerety M, Johnson JC, Katz PR, Potter JF, Reuben DB, Sloane PD, Studenski S, Warshaw G, Medicine AGSTFoFoG. Caring for older Americans: the future of geriatric medicine. *J Am Geriatr Soc* 2005;53:S245–S256.
23. Mourier A, Gautier JF, De Kerviler E, Bigard AX, Villette JM, Garnier JP, Duvallet A, Guezennec CY, Cathelineau G. Mobilization of visceral adipose tissue related to the improvement in insulin sensitivity in response to physical training in NIDDM. Effects of branched chain amino acid supplements. *Diabetes Care* 1997;20:385–391.
24. Poudou P, Sobngwi E, Mauvais-Jarvis P, Vexiau P, Gautier J-F. Absence of exercise-induced variations in adiponectin levels despite decreased abdominal adiposity and improved insulin sensitivity in type 2 diabetic men. *Eur J Endocrinol* 2003;149:421–424.
25. James DV, Doust JH. Oxygen uptake during moderate intensity running: response following a single bout of interval training. *Eur J Appl Physiol Occup Physiol* 1998;77:551–555.
26. Ross RR, Dagnone D, Jones PJ, Smith H, Paddags A, Hudson R, Janssen I. Reduction in obesity and related comorbid conditions after diet-induced weight loss or exercise-induced weight loss in men. A randomized, controlled trial. *Ann Intern Med* 2000;133:92–103.
27. Racette SB, Evans EM, Weiss EP, Hagberg JM, Holloszy JO. Abdominal adiposity is a stronger predictor of insulin resistance than fitness among 50–95 year olds. *Diabetes Care* 2006;29:673–678.
28. Kern PA, DiGregorio GB, Lu T, Rasouli N, Ranganathan G. Adiponectin expression from human adipose tissue: relation to obesity, insulin resistance, and tumor necrosis factor- α expression. *Diabetes* 2003;52:1779–1785.
29. Ryan AS, Nicklas BJ, Berman DM, Elahi D. Adiponectin levels do not change with moderate dietary induced weight loss and exercise in obese postmenopausal women. *Int J Obes Relat Metab Disord* 2003;27:1066–1071.
30. Bruun JM, Lihn AS, Verdich C, Pedersen SB, Toubro S, Astrup A, Richelsen B. Regulation of adiponectin by adipose tissue derived cytokines: in vivo and in vitro investigations in humans. *Am J Physiol Endocrinol Metab* 2003;285:E527–E533.

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