Original Article

Diabetes Metab J 2011;35:418-426
http://dx.doi.org/10.4093/dmj.2011.35.4.418
pISSN 2233-6079 · eISSN 2233-6087

dmj
DIABETES & METABOLISM JOURNAL

Effects of Resistance Training and Aerobic Exercise on Insulin Sensitivity in Overweight Korean Adolescents: A Controlled Randomized Trial

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Background: Data on the impact of resistance training on insulin resistance in overweight or obese children are inconclusive.
Methods: Thirty overweight South Korean adolescents (mean age of 13.10 years) were divided by sex, and then randomly assigned to one of three treatment groups, which were the diet only (DO), diet with aerobic exercise (AE), or diet with resistance training (RT) group. Physiologic and metabolic parameters were assessed at baseline and after 12 weeks of exercise training and diet modification.
Results: Both exercise groups (aerobic and resistance) showed significant improvements in their insulin area under the curve and insulin sensitivity index values when compared to their baseline values while the DO group showed no significant changes in these variables. Age-, sex-, and body mass index (BMI)-adjusted intergroup comparison analyses showed a marked reduction in BMI and a significant reduction in muscle mass in the AE group when compared to the RT group and the DO group, respectively.
Conclusion: A 12-week exercise training program of either resistance or aerobic activity improved insulin sensitivity in overweight adolescents, although it failed to show superiority over a DO program. Aerobic exercise decreased both body weight and BMI, and it was noted that this group also had a significant reduction in muscle mass when compared to the DO group.

Keywords: Adolescent; Aerobic exercise; Insulin sensitivity; Resistance training

INTRODUCTION

The prevalence of obesity is increasing at an alarming rate [1-3]. Complications of being overweight and obese are becoming major health care issues due to the increasing prevalence of obese and overweight children. The increase in the prevalence of children and adolescents that are overweight or obese implies a substantial increase in related diseases such as type 2 diabetes mellitus (T2DM) in children and adolescents [4-6], which was previously considered a disease of adults. Insulin resistance precedes the development of T2DM [7] and is a reported risk factor for the development of cardiovascular disease. Abdominal adiposity is associated with insulin resistance and T2DM in adults [8-10] and there is growing evidence that this condition is increasingly occurring in childhood [11-14].

Both aerobic and resistance exercise effectively improve in-

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Received: Apr. 29, 2011; Accepted: Jul. 8, 2011
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sulin sensitivity and lead to better glycemic control in patients with T2DM [15]. While aerobic exercise has been extensively investigated and shown to be beneficial for improving insulin sensitivity [16-19], resistance training has not been researched extensively. Interestingly, resistance training could be more effective than aerobic exercise in improving the glycemic profile [20] of patients because isometric contractions produce insulin-like effects on the glucose uptake in skeletal muscle [21], and skeletal muscle is the primary site of glucose disposal in euglycemia. In addition to improvements in insulin sensitivity, resistance training can enhance several other physiologic parameters related to metabolic health such as total and regional body composition, blood pressure, and high density lipoprotein cholesterol levels [22]. Recently, the American Diabetes Association and the American College of Sports Medicine published a joint position statement that both aerobic exercise and resistance training improve insulin action, at least acutely, and can assist with the management of blood glucose levels, lipid levels, blood pressure, cardiovascular risk, mortality, and quality of life [23]. However, data on the impact of resistance training on insulin resistance in overweight or obese children have been inconclusive [24,25] and triple comparison studies that focus on dietary restriction, and aerobic and resistance exercise are lacking.

In the current study, we directly compared the effects of dietary restriction, resistance training and aerobic exercise on insulin sensitivity and body composition in overweight South Korean adolescents.

METHODS

Participants

Thirty (15 male and 15 female) overweight, but otherwise healthy adolescents (as determined by their annual school physical examination), were recruited from the same grade (mean age of 13.10 years) in a middle school in Seoul, South Korea. Identifying an individual as being overweight (body mass index [BMI] >85th percentile) was assessed by using age- and gender-specific BMI reference charts for Korean children and adolescents between 2 to 19 years of age [26]. Two of the enrolled female students had a BMI between the 85th and 75th percentile but were included in this study because there were only 13 girls that had met the criteria for being overweight in the school at the time of the screening procedure. These two female students were separated and assigned in to the diet only group and the resistance exercise group, respectively.

This study was approved by an Institutional Ethics Review Board at the Boramae Medical Center. Informed written consents were obtained from the parents of the enrolled children and assent from the children were also obtained. Participants were excluded if they were taking medication or were smokers. Participants who had been diagnosed with a condition that is known to influence body composition or insulin/glucose metabolism, had an orthopedic condition that would limit their ability to perform exercise, or had participated in a structured exercise, nutrition, or weight loss program in the past six months, were also excluded.

Study protocol

The participants were first divided by sex, and were then randomly assigned to one of the three treatment groups with random number table, which were the diet only (DO), diet with aerobic exercise (AE), and diet with resistance training (RT) group. Anthropometric variables (body weight, height and waist circumference), fasting glucose, insulin and 75 g oral glucose tolerance test (OGTT) values were measured prior to and after the 12 weeks of exercise training and diet protocol. Body weight was measured on a balance scale calibrated to 0.1 kg. Barefoot standing height was measured to the nearest 0.1 cm using a wall-mounted stadiometer. The same investigator measured waist circumference before and after the study with a Gullick II measuring tape. Waist circumference was measured, during expiration, at the narrowest point between the lower rib and the iliac crest. BMI was calculated as weight in kilograms divided by the square of the height in meters. Measurements were carried out one week before and after the exercise program. Percent body fat and total body muscle mass were measured by using an Inbody 4.0 bioelectrical impedance meter (Biospace Co., Seoul, Korea). Visceral, thigh and intramuscular fat areas were measured by computed tomography (CT) with a Somatom Sensation 16 (Siemens Medical Solutions, Forchheim, Germany). The CT measurement protocol for fat area was similar to that used in a study by Poehlman et al. [15]. Total thigh fat area (TTFA) and intramuscular fat area (IMFA) were measured using a method that has been reported by Goodpaster et al. [27]. The abdominal bioelectrical impedance analysis (BIA) method [28] was also used to evaluate the visceral fat accumulation in each subject. The insulin sensitivity index was obtained by using the results of the OGTT and Stumvoll's equations [29].

Dietary protocol

Each study participant received an individualized dietary education program that was provided by a professional nutritionist twice a week throughout the 12 weeks of the study. The detailed program is described in Table 1. All three of the groups (DO, AE, and RT) participated in the dietary education program. The basic guidelines of the dietary education program were calorie restriction to avoid obesity (at least >1,200 kcal per day to prevent malnutrition), limiting dietary fat intake to improve blood lipid profiles, having low-salt intake to improve hypertension, eating three regular meals a day (breakfast, lunch and dinner) and avoiding snacks as much as possible. Participants were asked to write daily dietary records and these were reviewed weekly by the nutritionist.

Table 1. Details of the dietary education program

Time		Contents
1st week	Monday	Investigating eating habits and how to write a daily diet record
	Friday	Relation between nutritional habits and disease
2nd week	Monday	Estimating energy requirements
	Friday	Individual interviewing session
3rd week	Monday	Individual interviewing session
	Friday	Food exchange-based meal plan
4th week	Monday	Healthy diet protocol 1 (natural vs. artificial food)
	Friday	Healthy diet protocol 2 (benefits of dietary fiber)
5th week	Monday	Healthy diet protocol 3 (hazard of sugar)
	Friday	Healthy diet protocol 4 (healthy and unhealthy drink)
6th week	Monday	Seminar of guest speaker
	Friday	Healthy diet protocol 5 (essential fatty acids)
7th week	Monday	Mid-term assessment
	Friday	Individual interviewing session
8th week	Monday	Healthy diet protocol 6 (smart protein uptake)
	Friday	Diet to prevent obesity 1
9th week	Monday	Self-assessment and re-planning the diet program
	Friday	Diet to prevent obesity 2
10th week	Monday	Diet to prevent hypertension
	Friday	Diet to prevent DM and hyperlipidemia
11th week	Monday	Assessment and re-planning the diet program
	Friday	Myths about food/Food matching
12th week	Monday	Questionnaire
	Friday	Individual interviewing session

Exercise protocol

The 12-week exercise training program was fully supervised by a trained exercise physiologist from the Department of Physical Education in the College of Education at the Seoul National University.

In addition to the dietary energy restriction, ten participants in the AE group performed aerobic exercise three days a week. The students in the AE group were also told to perform gymnastics every day throughout the second and third month of the program. Modes of aerobic exercise consisted of jumping rope, walking or running on a treadmill and stationary cycling. The daily training duration was 40 minutes which included a 5 minute warm-up and a cool down period with stretching. The training intensity progressed from 60% to 70% of the maximal oxygen consumption (60%, 1st month; 65%, 2nd month; 70%, 3rd month). Maximal oxygen consumption was determined during a ramp treadmill test. The training volume of each session progressed from 300 to 400 kcal/session (300 kcal, 1st month; 350 kcal, 2nd month; 400 kcal, 3rd month) [30].

Another 10 participants in the RT group performed resistance training three days a week in addition to their dietary energy restriction. Training sessions began with a 15 minute warm-up period of jogging, gymnastics, and stretching (5 minutes for each type of exercise). One repetition maximum (1RM) is defined as the maximum amount of resistance that can be moved through the full range of motion of an exercise for no more than one repetition. The 1RM was calculated by using the formula derived by Kuramoto and Payne [31] and resistance training was performed at approximately 60% of 1RM. The resistance training program consisted of one set of each of the following ten exercises: squats, leg extension, lying leg curls, military press, leg press, lateral pulldowns, bench press, crunch, leg raise, and dead lift. These exercises provided a total body resistance training program for all of the major muscle groups of the body. Each subject was given a target load range and they were asked to attempt to keep each set (n=2 to 3) within the target range by adjusting the load to allow the prescribed number (n=10 to 12) of repetitions. The curriculum was personalized to match the skill level of each of the participants and was progressive in nature, by increasing the number of sets, repetitions, and the amount of resistance used as the participant's technique and strength improved. Resting periods were 1 to 1.5 minutes between sets. Each training session lasted approximately 60 minutes, which included a final 5 minute cooling down period of stretching.

Biochemical analysis

A standard OGTT was performed in the overweight children by using 1.75 g/kg of a maximum flavored solution containing 75 g of glucose (Glu-Orange; Lotte Pharm, Seoul, Korea). Samples were drawn at 0, 30, 60, 90, and 120 minutes after the OGTT and the levels of glucose and insulin were measured. Serum insulin levels (μU/mL) were measured using an insulin immunoradiometric assay kit (Biosource Europe S.A., Nivelles, Belgium), which had a cross-reactivity with proinsulin of 0.3%. The reported intra-assay variation was 1.6% to 6.2% and the interassay variation was 6.1% to 6.5%.

Statistical analysis

Data were analyzed using the PASW Statistics version 18.0 for Windows (SPSS Inc., Chicago, IL, USA). Values are presented as mean ± standard deviation. For all statistical analyses a *P* value of less than 0.05 (two-sided) was considered to be statistically significant. The study was powered to detect up to a 25% differences in insulin sensitivity by using a conservative estimate of the standard deviation of the insulin sensitivity index, and using a power of 80%. Statistical significance was tested using the one-way ANOVA with Bonferroni correction in order to evaluate group differences at baseline. Changes in variables following the exercise program were compared with baseline values by using the repeated measures ANOVA for each of the three groups. One-way ANOVA with Bonferroni correction was applied to evaluate the main effects and interactions on all of the dependent variables in each of the three groups by time (prior to and after the 12-week program). Differences in the inter-group analysis were tested with the ANCOVA and the post-hoc analysis was performed by using the Tukey method for multiple comparison tests. All values were adjusted for baseline age, sex, and BMI in the inter-group analysis.

RESULTS

Remarkably, none of the participants dropped out of the study and all of the participants had attended all of the exercise and dietary education sessions, yielding a compliance rate of 100%. The descriptive characteristics for all of the groups are given in Table 2. The three groups did not significantly differ at baseline with respect to any of the anthropometric or metabolic variables, and this suggests a successful randomization of the study participants. Anthropometric and body composition data across the groups are shown in Table 3. All of the participants had a significant growth in height during the study. Significant increases in weight, BMI, body fat, waist circumference, and visceral fat area (VFA) as measured by CT were observed in the DO group while their glucose area under the curve (AUC) decreased from the baseline value. The AE group showed a definite decrease in their glucose AUC when compared to their values measured at baseline. The RT group had increases in body weight, BMI, body fat, muscle mass and VFA as measured by CT following the 12-week program. Both exercise groups (aerobic and resistance) had significant improvements in their insulin AUC and insulin sensitivity index versus their baseline values while the DO group showed no significant changes in these variables. Individual changes in insulin AUC for all three groups are illustrated in Fig. 1. We found significant across group differences in BMI and muscle mass after adjusting for age, sex, and baseline BMI. Waist circumference, VFA as measured by various methods, insulin and glucose AUC, insulin sensitivity index, and the insulinogenic index did not show statistically meaningful distinctions across the groups. Age-, sex-, and BMI-adjusted intergroup comparison analyses showed a marked reduction in BMI and a significant reduction in muscle mass in the AE group when compared to the RT group and the DO group, respectively.

DISCUSSION

The primary finding of this 12-week randomized, controlled exercise trial involving overweight South Korean adolescents is that both resistance training and aerobic exercise improved insulin sensitivity; however, the benefit does not appear to be greater than that of diet alone. In addition, aerobic training produced beneficial effects on body weight and BMI when compared to that of diet alone or resistance training.

Successful randomization was accomplished as the three groups did not differ significantly at baseline with respect to any anthropometric or metabolic variables. Body weight along with BMI increased in the DO and RT groups, while both of these variables remained constant in the AE group. This relative weight reduction indicates that aerobic exercise is good

Table 2. Descriptive characteristics of the study participants

Variable	Diet only (*n*=10)	Aerobic (*n*=10)	Resistance (*n*=10)	Adjusted *P* value
Sex	Male 5, Female 5	Male 5, Female 5	Male 5, Female 5	NS
Age, yr	13.10±0.57	13.10±0.52	13.10±0.32	NS
Height, cm	163.85±7.97	165.75±1.87	165.25±8.63	NS
Weight, kg	72.95±13.96	72.61±10.32	69.76±15.88	NS
BMI, kg/m^2	27.08±4.10	26.32±2.45	25.31±3.73	NS
Waist, cm	92.11±11.45	91.07±9.45	89.49±11.42	NS
Body fat, %	25.22±7.03	24.52±3.64	22.15±7.04	NS
Muscle mass, kg	26.15±6.07	26.41±5.14	26.08±7.92	NS
V_{O2max}, mL/kg/min	24.80±3.88	25.77±7.10	25.46±5.65	NS
VFA_CT, cm^2	80.51±33.70	78.64±26.54	70.22±30.82	NS
VFA_abd BIA, cm^2	68.64±54.00	60.36±25.60	40.19±13.75	NS
TTFA, cm^2	162.27±34.86	152.28±21.30	152.40±38.09	NS
IMFA, cm^2	8.61±2.81	7.23±2.76	5.99±2.30	NS
Fasting glucose, mg/dL	91.60±9.69	89.30±7.30	94.00±7.26	NS
Fasting insulin, μIU/mL	14.15±10.32	31.04±31.33	14.61±8.60	NS
HOMA-IR	3.18±2.43	7.23±7.91	3.29±1.75	NS
Glucose AUC, μIU/mL	16,592.33±2,598.88	16,549.07±2,453.09	15,796.97±1,562.11	NS
Insulin AUC, μIU/mL	9,305.70±4,187.33	14,125.17±7,423.26	7,733.85±2,723.74	NS
Insulin sensitivity index	0.07±0.03	0.05±0.06	0.09±0.02	NS
Insulinogenic index	1.35±0.76	1.97±2.54	1.17±0.55	NS

Data are presented as mean±standard deviation. *P* values were analyzed using the one-way ANOVA with Bonferroni correction.
BMI, body mass index; VFA, visceral fat area; VFA_CT, VFA measured by CT; VFA_abd BIA, VFA measured by abdominal bioelectrical impedance analysis; TTFA, total thigh fat area; IMFA, intramuscular fat area; HOMA-IR, homeostasis model assessment of insulin resistance; AUC, area under the curve; NS, not significant.

for lowering body weight in overweight adolescents that may lead to an improvement in their insulin sensitivity. However, this relative weight loss also resulted in reduced muscle mass in the AE group when compared to that of the DO group. This finding implies that even if the RT group failed to lose weight or VFA, resistance training may provide an important way to counteract the decrease in resting metabolic rate and loss of muscle mass often accompanying dietary restrictions [32,33]. Muscle mass increased in the RT group ($P=0.039$), but this benefit did not reach significance in the post-hoc analysis with the Tukey method due to the rather small number of participants ($n=10$) in the group. We presume that with a larger sample size, this increase in muscle mass could have reached significance.

Increased BMI in both the DO and RT groups may be due to the normal growth of adolescents or due to poor diet control. As a matter of fact, every participant grew in height during the 12-week study. Although little is known about the effects of energy compensation in response to exercise in children, research in adults have shown that when individuals exercise they often compensate with increased energy intake [34] or reduced physical activity outside of the training session [35]. Thus, the participants in the exercise groups may have altered their intake in response to the exercise they were performing throughout the program. However, the dietary records collected during the intervention would have minimized this acute compensatory intake.

Insulin resistance is thought to be a critical factor in the pathogenesis of T2DM in both adults [9] and children [36]. Therefore, identifying interventions that can improve insulin sensitivity are critical for defining effective approaches for preventing metabolic diseases associated with obesity, especially in at-risk individuals, such as overweight adolescents. In this study, insulin sensitivity improved in both of the exercise groups

Table 3. Changes in characteristics of the study participants

Variable	Diet only (n=10)	Aerobic (n=10)	Resistance (n=10)	Adjusted P value[d]
Height, cm	0.62±0.64[a]	0.67±0.76[a]	0.38±0.43[a]	NS
Weight, kg	1.82±1.32[a]	-0.61±3.16	1.63±0.80[a]	NS
BMI, kg/m^2 [b]	0.45±0.46[a]	-0.45±1.15	0.49±0.33[a]	0.0128
Waist, cm	1.62±1.86[a]	-0.76±3.64	-0.05±2.57	NS
Body fat, %	0.88±0.74[a]	-0.28±2.42	0.92±0.75[a]	NS
Muscle mass, kg[b]	0.65±0.98	-0.20±0.80[c]	0.50±0.45[a]	0.039
VFA_CT, cm^2	3.28±4.09[a]	-0.94±7.64	5.24±2.98[a]	NS
VFA_abd BIA, cm^2	11.47±12.0	-5.44±11.04	3.28±7.88	NS
VFA_BIA, cm^2	-11.16±58.30	-10.69±36.15	-0.36±19.50	NS
TTFA, cm^2	-0.33±9.97	-7.81±12.29	-0.01±9.12	NS
Insulin AUC, μIU/mL	318.75±5,070.95	-3,007.85±8,005.09[a]	-1,646.40±2,155.41[a]	NS
Glucose AUC, μIU/mL	-2,481.83±1,877.80[a]	-2,330.73±2,229.41[a]	-970.97±1,652.72	NS
Insulin sensitivity index	0.01±0.03	0.04±0.04[a]	0.01±0.01[a]	NS
Insulinogenic index	-1.38±6.52	0.28±0.94	-3.49±11.26	NS

Data are presented as mean±standard deviation. P values were analyzed using ANCOVA and the post-hoc analysis using the Tukey method. BMI, body mass index; VFA, visceral fat area; VFA_CT, VFA measured by CT; VFA_abd BIA, VFA measured by abdominal bioelectrical impedance analysis; TTFA, total thigh fat area; AUC, area under the curve; NS, not significant.
[a]Significantly different from baseline value (P<0.05), [b]Significantly different across groups (P<0.05), [c]Significantly different from the diet only (DO) group (P<0.05), [d]Age, sex, and baseline BMI were adjusted for the analysis of [b] and [c] above.

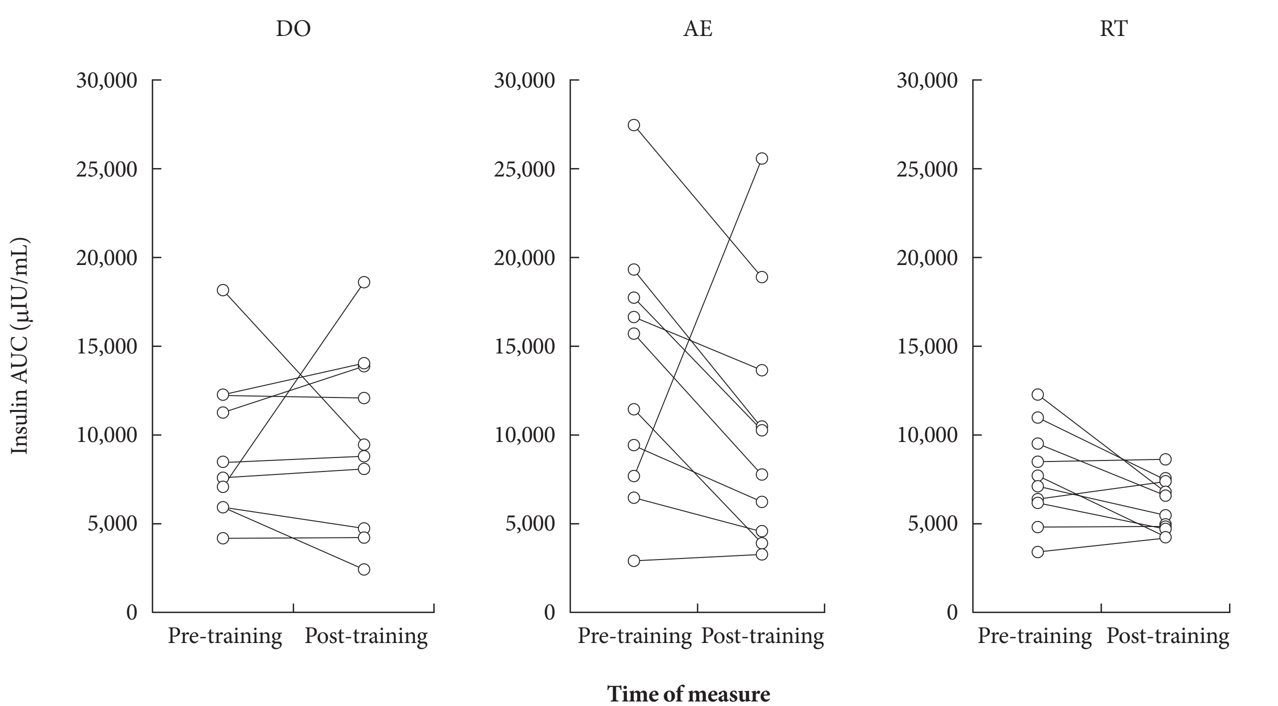

Fig. 1. Individual changes in insulin area under the curve (AUC) of each group. DO, diet only; AE, diet with aerobic exercise; RT, diet with resistance training.

(AE and RT) when compared to their baseline values, as reflected by adecreased insulin AUC values and an increased insulin sensitivity index. This improvement in the RT group is consistent with the results published by Bell et al. [37] which reported that increases in insulin sensitivity is independent of changes in body composition. However, inter-group analysis did not show significant differences when compared to the other groups, but we presume that this is due to the small number of participants in each of the three groups. Puberty is normally associated with a mild increase in insulin resistance, and in susceptible children it is a high-risk developmental period for both obesity and T2DM [38]. An assumption could have been made that three months after starting the intervention the insulin resistance would have increased as the children matured, if it was assumed that puberty is likely to influence the results of this study since the groups were comparable in sex distribution and age.

We admit that there are limitations to our selected method of evaluating insulin sensitivity. It is known that the euglycemic clamp technique is the recognized gold standard for measurement of insulin sensitivity. Even though fasting or OGTT insulin levels are strong correlates of insulin sensitivity when measured by the euglycemic clamp method, the explained variance is approximately 50% [39]. Thus, our results of how a given exercise influences OGTT insulin values provide only an estimate of how insulin acts. However, if we had measured the OGTT insulin response within 24 hours of the last exercise session (instead of the following week), then it would have been likely that the enhanced insulin action observed in response to diet and exercise would have been even more impressive. Because insulin responsiveness is higher in trained individuals compared to untrained individuals 24 hours after exercise [40]. In addition, we did not observe significant changes in the insulinogenic index. This is not surprising because the youth in this study were all non-diabetic and presumably had, for the most part, healthy β-cells.

We attempted to balance the limitations of this study with corresponding advantages. Maturation and/or age should be considered during stratification and during analysis in order to minimize potential confounding variables since they may influence metabolic factors in growing children and adolescents. Therefore, we adjusted for age, sex, and baseline BMI in our statistical analysis. Aerobic components (warm up and cool down periods) in the resistance training protocol and dietary manipulations in both of the exercising group may have led to some changes that make it more difficult to distinguish the independent effects of each group. Furthermore, data on dietary outcomes such as total energy intake and dietary fat were not available for use in the analysis. To further validate our results, we recommend additional studies that include a larger sample size, longer program duration and consideration of the maturation level and age of the study subjects. The strength of this study includes the involvement of a trained exercise physiologist and the enrollment of enthusiastic students that had succeeded in a remarkable 100% attendance rate. Unlike other studies offering rewards or gifts, we did not offer any kind of economic compensation or penalty.

In conclusion, a 12-week exercise training (both resistance and aerobic) program improved insulin sensitivity in overweight adolescents, although it failed to show superiority over a DO program. Aerobic exercise decreased both body weight and BMI, and a significant reduction in muscle mass was also noted when compared to the DO group.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

ACKNOWLEDGMENTS

This study was supported by a grant from the Seoul National University Hospital Research Fund 04-2005-024. We are grateful to the staff of the Department of Physical Education of the College of Education at the Seoul National University for their support in the exercise programs. Additionally, we thank the participants and their families for their involvement in the study.

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