

## Effect of a short-term diet and exercise intervention on metabolic syndrome in overweight children

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Received 19 August 2005

### Abstract

Overweight and the metabolic syndrome are increasing radically in children. The present study was designed to examine the effects of lifestyle modification in 16 children who were placed on a high-fiber, low-fat diet in a 2-week residential program where food was provided ad libitum and daily aerobic exercise was performed. In each subject, pre- and postintervention fasting blood was drawn. Insulin ( $27.2 \pm 3.5$  vs  $18.3 \pm 1.7$   $\mu\text{U/mL}$ ,  $P < .01$ ), homeostasis model assessment for insulin resistance ( $5.79 \pm 0.81$  vs  $4.13 \pm 0.38$ ,  $P < .05$ ), and body weight ( $92.0 \pm 7.0$  vs  $88.0 \pm 6.8$  kg,  $P < .01$ ) were reduced significantly. Total cholesterol ( $165 \pm 7.8$  vs  $127 \pm 7.4$  mg/dL,  $P < .01$ ), low-density lipoprotein ( $94.1 \pm 8.2$  vs  $68.5 \pm 6.7$  mg/dL,  $P < .01$ ), triglycerides ( $146 \pm 16.2$  vs  $88.1 \pm 8.1$  mg/dL,  $P < .01$ ), and total cholesterol–high-density lipoprotein ( $4.16 \pm 0.30$  vs  $3.34 \pm 0.30$ ,  $P < .01$ ) and low-density lipoprotein–high-density lipoprotein ratios ( $2.41 \pm 0.3$  vs  $1.86 \pm 0.2$ ,  $P < .01$ ) were reduced, with no change in high-density lipoprotein observed ( $42.3 \pm 2.4$  vs  $40.8 \pm 3.0$  mg/dL). Systolic blood pressure ( $130 \pm 3.1$  vs  $117 \pm 1.8$  mm Hg,  $P < .001$ ) and diastolic blood pressure ( $74.3 \pm 3.0$  vs  $67.2 \pm 2.3$  mm Hg,  $P = .01$ ) also decreased. Most notably, before the intervention, 7 of the 16 subjects were classified with metabolic syndrome. After the 2-week intervention, despite remaining overweight, reversal of metabolic syndrome was noted in all 7 subjects. All of these changes occurred despite only modest improvements in the percentage of body fat ( $37.5\% \pm 1.1\%$  vs  $36.4\% \pm 1.2\%$ ,  $P < .01$ ) and body mass index ( $33.2 \pm 1.9$  vs  $31.8 \pm 1.9$  kg/m<sup>2</sup>,  $P < .01$ ). These results indicate that a short-term rigorous diet and exercise regimen can reverse metabolic syndrome, even in youth without documented atherosclerosis.

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### 1. Introduction

Obesity is a significant public health issue in the United States [1,2], and children and adolescents have not eluded this emerging epidemic. In 2000, more than 15% of children and adolescents in the United States aged 6 to 19 years were classified as overweight (body mass index [BMI] >95th percentile), more than triple the percentage recorded 30 years earlier [3]. In addition, the Centers for Disease Control and Prevention (CDC) reported that 62% of children 9 to 13 years of age do not participate in any organized physical activity during nonschool hours [4]. Consequently, today's overweight children and adolescents are potentially setting the stage for heightened risk of cardiovascular disease, type 2 diabetes mellitus, cancer, osteoarthritis, and premature all-cause mortality later in life [5].

Obesity is highly correlated with a constellation of disorders including dyslipidemia, insulin resistance, and hypertension—hallmarks of the metabolic syndrome and risk factors for cardiovascular disease. Diagnosis of this syndrome is indicated when 3 or more of the following risk factors coexist: central obesity, elevated blood pressure, elevated fasting glucose or insulin resistance/hyperinsulinemia, elevated triglycerides (TG), and reduced high-density lipoprotein (HDL). According to the Third National Health and Nutrition Examination Survey, between 1988 and 1994, it was estimated that the metabolic syndrome was present in more than 6% of overweight adolescents and more than 25% of obese adolescents [6]. Accumulating evidence indicates that the prevalence of these metabolic abnormalities is increasing among the youth of America and other industrialized countries [7–9]. The ramifications are significant, given that overweight children tend to remain overweight or become obese in adulthood [10], and predicts that the percentage of adults at risk for the metabolic

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syndrome and cardiovascular disease will continue to climb if current overweight trends continue [11].

Although it is clear that overweight and obesity prevalence is increasing in children and adolescents in westernized societies, there are few studies examining combined physical activity and diet interventions in this subset of the population. The goal of this study was to investigate the effects of short-term daily physical activity and a low-fat, high-fiber diet on the metabolic syndrome and related coronary artery disease (CAD) risk factors in overweight youth.

## 2. Methods

### 2.1. Subjects

Children and adolescents ( $n = 16$ ) between the ages of 10 and 17 years participated in a 2-week residential lifestyle modification program at the Pritikin Longevity Center in Aventura, FL. In the summer of 2002, the Pritikin Longevity Center offered a special program where parents were permitted to bring their children for a 1- or 2-week session. Eighteen children were enrolled in the 2-week session. Two families left early for unknown reasons, and thus pre and post data were obtained from 16 children, 10 males and 6 females. None of the subjects were using drugs or therapies for obesity, and none had prior histories of disease or injury that would prevent daily exercise. Consent to participate in a research program was obtained from the parents, all subjects agreed to provide data for the study, and the project was approved by the University of California, Los Angeles (UCLA) Human Subjects Protection Committee.

### 2.2. Diet and exercise intervention

Participants in the program received a complete physical examination and underwent a 14-day diet and exercise intervention. Prepared meals, which were well tolerated by the subjects, contained 12% to 15% of energy from fat (polyunsaturated-saturated fatty acid ratio, 2.4:1), 15% to 20% of energy from protein, and 65% to 70% of energy from primarily unrefined carbohydrate, high in dietary fiber ( $>40$  g/d). Carbohydrates were primarily in the form of high-fiber whole grains ( $\geq 5$  servings per day), vegetables ( $\geq 4$  servings per day), and fruits ( $\geq 3$  servings per day). Protein was primarily derived from plant sources, with nonfat dairy (up to 2 servings per day) and fish and fowl served (in 3 1/2 oz portions) 4 d/wk and in soups or casseroles (2 d/wk). The diet contained less than 100 mg of cholesterol, and caffeinated beverages were not allowed during the program. Sodium intake was limited to less than 1600 mg/d. All foods except animal-derived protein sources were served ad libitum. Subjects participated in 1 to 2 cooking classes daily, where small snacks were sampled. In addition, participants in the study attended twice-daily lectures discussing nutrition, exercise, and general wellness.

The exercise intervention consisted of 2 to 2.5 hours of supervised activity per day, including tennis, beach games,

and gym-based exercises intended to encourage physical activity in the subjects. This deviates from the standard Pritikin program recommendations for adults of 45 to 60 minutes of exercise at the training heart rate (70%–85% of maximal heart rate as determined by a graded exercise stress test) because of the young ages of the subjects and the desire to have the subjects enjoy physical activity. The goal was to increase activity and energy expenditure, and, as such, heart rate was not measured during exercise.

Fasting blood samples were drawn on days 1 and 12 of the intervention. The blood was separated by centrifugation and sent on dry ice to the UCLA laboratory and stored at  $-80^{\circ}\text{C}$  until analysis. Height, body weight, waist circumference, body fat percentage, resting heart rate, and blood pressure measures were also assessed on these days.

### 2.3. Determination of serum lipids, glucose, insulin, homeostatic model assessment for insulin resistance, and quantitative insulin-sensitivity check index

Total cholesterol, triglycerides (TG), HDL, and glucose levels were measured at a national commercial laboratory (Quest Diagnostics, Miami, FL) using standardized techniques as previously described [12]. Low-density lipoprotein (LDL) was calculated as described by the Friedewald formula [13]. Insulin was quantified in duplicate using enzyme-linked immunosorbent assay (Diagnostic Systems Laboratories, Webster, TX). The degree of insulin resistance was determined with the use of the homeostatic model assessment for insulin resistance (HOMA-IR). Scores typically range from 0 to 15, with higher scores indicating greater insulin resistance, and are calculated as the product of the fasting plasma insulin level ( $\mu\text{U/mL}$ ) and the fasting plasma glucose level ( $\text{mmol/L}$ ), divided by 22.5. The estimate obtained with HOMA-IR correlates well with measures of insulin resistance obtained from overweight and non-overweight children and adolescents with the use of the hyperinsulinemic-euglycemic clamp technique [14]. Insulin sensitivity was determined by the quantitative insulin-sensitivity check index (QUICKI), as defined by  $1/\{\log[\text{fasting insulin } (\mu\text{U/mL})] + \log[\text{fasting glucose } (\text{mg/dL})]\}$ . The QUICKI has also been shown to correlate well with the hyperinsulinemic-euglycemic clamp in both obese and nonobese individuals [15].

### 2.4. Determination of body composition and BMI classification

Body composition was measured by dual-energy x-ray absorptiometry (DEXA, Hologic QDR4500 Fan Beam X-ray Densitometer, Hologic, Waltham, MA). The mean weight was measured using a scale from Pennsylvania Medical Scales (model no. 7500, Pennsylvania Scale Co, Leola, PA). The scale was not recalibrated during the 2-week study. Weights were taken in the morning before breakfast, with subjects in a T-shirt and shorts. Subjects were asked to remove their shoes. Height was measured using a Seca stadiometer (Seca Corp, Hanover, MD), attached to the wall. Body mass

index was calculated as the weight in kilograms divided by the square of height in meters. Equations provided by the CDC (<http://www.cdc.gov/nchs/about/major/nhanes/growthcharts/datafiles.htm>) were used to generate Z scores of BMI values that were then applied to estimate sex-specific BMI-for-age percentiles for each subject and obesity risk classification for each subject. Body mass index percentile categories included <5th (underweight), ≥5th to 84th (normal weight), ≥85th to 94th (at risk for overweight), and ≥95th (overweight).

### 2.5. Blood pressure classification

Algorithms provided by the CDC were used to generate sex- and age-specific Z scores for height, which were combined with recently published standards for sex- and age-specific norms concerning systolic, and diastolic blood pressure to calculate systolic, and diastolic percentiles for each subject. Blood pressure classification was based on the National High Blood Pressure Education Program Working Group on High Blood Pressure in Children and Adolescent report [16] that incorporates the CDC age, height, and sex classification scheme as follows: “desirable blood pressure” requires both a systolic value below the 90th percentile and a diastolic value below the 90th percentile; “prehypertension” requires systolic value in the 90th to below the 95th percentile and/or diastolic value in the 90th to below the 95th percentile; “hypertension” requires systolic value in the 95th to below the 99th percentile and/or diastolic value in the 95th to below the 99th percentile; “severe hypertension” requires systolic value in the 99th percentile or above and/or diastolic value in the 99th percentile or above.

### 2.6. Classification of metabolic syndrome

Because there are no standardized criteria for diagnosis of the metabolic syndrome in children or adolescents, we

adapted guidelines from the National Cholesterol Education Program’s Adult Treatment Panel III [17] and the World Health Organization [18]. Age- and sex-specific algorithms provided by the CDC were also used for classification of hyperinsulinemia and lipids. The subjects in our study were classified as having the metabolic syndrome if 3 of more of the following criteria were met: (1) systolic or diastolic blood pressure greater than the 90th percentile; (2) BMI above the 95th percentile; (3) TG in excess of the 95th percentile; (4) HDL below the 5th percentile; and (5) fasting glucose ≥110 mg/dL or fasting insulin ≥75th percentile. These criteria have been used in previous studies of the metabolic syndrome [19–21].

### 2.7. Statistical analysis

Statistical analyses were performed with GraphPad Prism (GraphPad, San Diego, CA) and SAS software (version 8.2, SAS Institute, Cary, NC). Pre- and postintervention values were compared using matched-pair *t* tests. Correlations were tested by determining Pearson correlation coefficients. All data are expressed as mean ± SEM unless otherwise noted. A *P* value of less than .05 was considered statistically significant.

## 3. Results

### 3.1. Physical Characteristics, blood pressure, serum lipids, glucose, and insulin

Anthropometric and metabolic data are summarized in Table 1. The mean BMI of  $33.2 \pm 1.9$  kg/m<sup>2</sup> for the subjects at baseline indicates that, on average, these children were overweight (>95th percentile according to CDC BMI standards) at the commencement of the program. All subjects had a BMI above the 75th percentile and 11 of the 16 were at

Table 1  
Anthropometric and metabolic parameters in children undergoing a 14-day diet and exercise intervention

Parameter	Preintervention	Postintervention	% Decrease
Body weight (kg)	92.0 ± 7.0	88.0 ± 6.8	4.3**
BMI (kg/m <sup>2</sup> )	33.2 ± 1.9	31.8 ± 1.9	4.3**
Body fat (%)	37.5 ± 1.1	36.4 ± 1.2	3.0**
Waist circumference (cm)	103.3 ± 5.5	98.3 ± 3.3	4.8*
Systolic blood pressure (mm Hg)	130 ± 3.1	117 ± 1.8	10.4**
Diastolic blood pressure (mm Hg)	74.3 ± 3.0	67.2 ± 2.3	10.6*
Resting heart rate (beats per minute)	88 ± 2.9	78 ± 3.0	11.6*
Total cholesterol (mg/dL)	165 ± 7.8	127 ± 7.4	23.3**
HDL cholesterol (mg/dL)	42.3 ± 2.4	40.8 ± 3.0	3.4
LDL cholesterol (mg/dL)	94.1 ± 8.2	68.5 ± 6.7	25.3**
Total cholesterol/HDL cholesterol	4.16 ± 0.30	3.34 ± 0.30	19.8**
LDL cholesterol/HDL cholesterol	2.27 ± 0.29	1.78 ± 0.23	22.9**
Triglycerides (mg/dL)	146 ± 16.2	88.1 ± 8.1	39.5**
Blood glucose (mg/dL)	82.5 ± 2.3	88.3 ± 1.5	−7.1*
Insulin (μU/mL)	27.2 ± 3.4	18.3 ± 1.7	32.6**
HOMA-IR	5.79 ± 0.81	4.13 ± 0.38	28.6*
QUICKI	0.304 ± 0.006	0.313 ± 0.004	−3.04

Mean anthropometric and metabolic measures of overweight youth undergoing a 14-day diet and exercise intervention. All data are expressed as mean ± SEM.

\* *P* < .05.

\*\* *P* < .01.

risk (>85th percentile) or overweight (>95th percentile) according to CDC BMI standards. The mean baseline percentage body fat of  $37.5\% \pm 1.1\%$  combined with a mean  $103.3 \pm 5.5$  cm waist circumference suggests central adiposity, with excessive total body fat at the beginning of the program. After the 2-week intervention, body weight

(Fig. 1A), BMI, waist circumference, and percentage body fat were all reduced significantly ( $P \leq .01$ ), although the subjects remained overweight because of the brevity of the intervention. Correlation analyses indicated no significant correlation between change in BMI or body weight and any of the parameters measured (all  $R^2 < 0.1$ ).

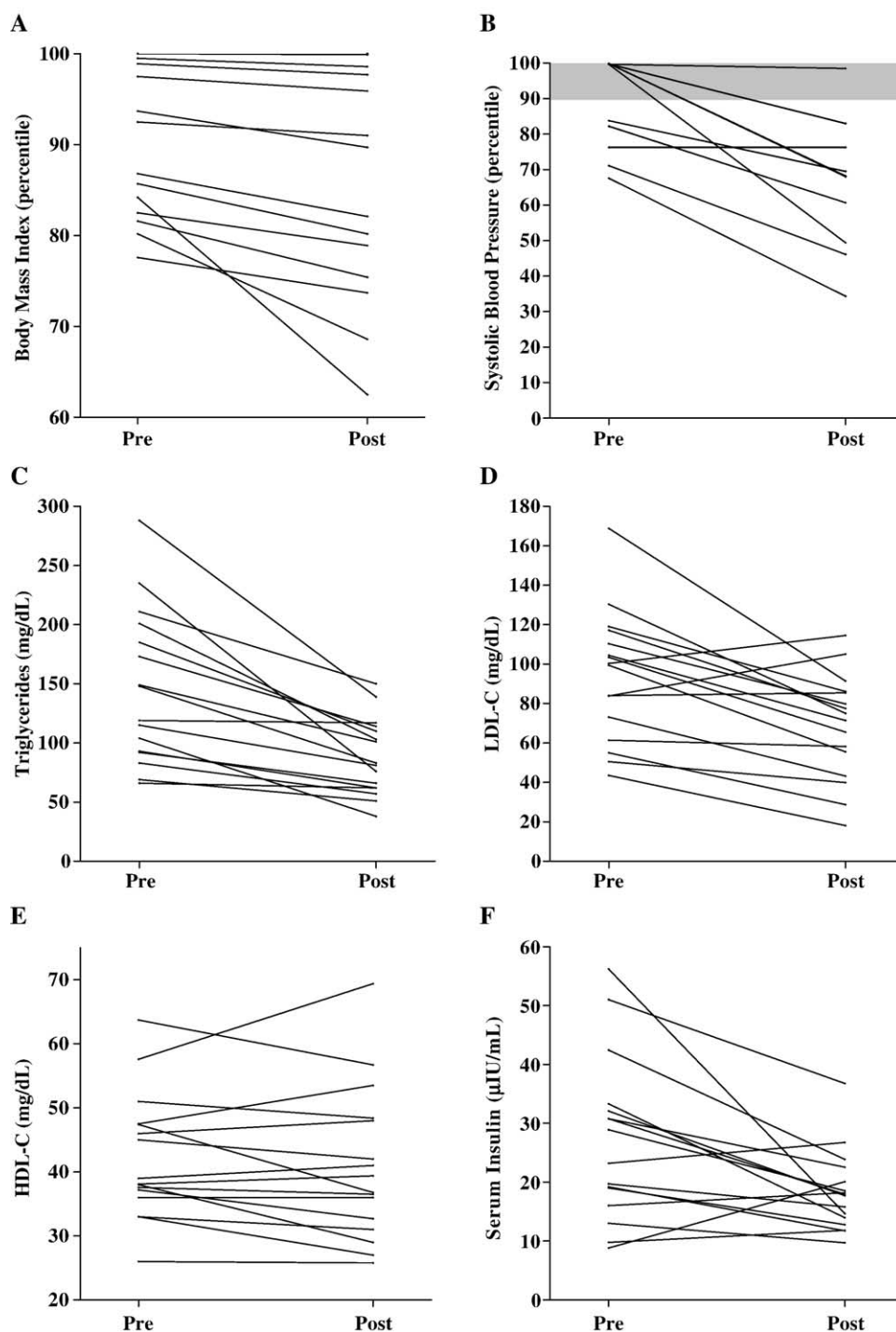


Fig. 1. A, Before-and-after plot of bodyweight in overweight youth ( $n = 16$ ) undergoing a 14-day diet and exercise intervention. B, Before-and-after plot of systolic blood pressure percentiles adjusted for age, sex, and race. Shaded portion indicates 90th percentile and above. C, Before-and-after plot of serum triglycerides. D, Before-and-after plot of LDL cholesterol. E, Before-and-after plot of HDL cholesterol. F, Before-and-after plot of serum insulin.



Table 2  
Prevalence of metabolic syndrome pre- and postintervention

Parameter	Preintervention	Postintervention
Elevated blood pressure (SBP or DBP >90th percentile)	9	1
BMI >95th percentile	7	7
Triglycerides >95th percentile	7	0
HDL <5th percentile	1	4
Fasting glucose $\geq$ 110 mg/dL or insulin $\geq$ 75th percentile	9	3
Subjects with the metabolic syndrome ( $\geq$ 3 risk factors)	7	0

Number of overweight children and adolescents possessing risk factors for the metabolic syndrome before and after the 14-day diet and exercise intervention.

Using the 90th percentile standard set by the National Heart, Lung, and Blood Institute [16] for either systolic or diastolic blood pressure as the definition for prehypertension, 9 of 16 subjects were prehypertensive or hypertensive before intervention. After intervention, decreases in systolic (10.4%,  $P < .001$ ) and diastolic (10.6%,  $P = .01$ ) blood pressure were observed, with 8 of the 9 subjects with elevated blood pressure exhibiting blood pressures in the normotensive range (Fig. 1B). In addition, resting heart rate decreased by 11.6% postintervention.

All serum lipids improved significantly ( $>20\%$  decreases,  $P < .01$ , Table 1, Fig. 1C and D), with the exception of HDL, which showed no significant change (Fig. 1E). Fasting insulin level decreased significantly (32.6%,  $P < .01$ , Fig. 1F) after the program. Although blood glucose increased significantly ( $P = .01$ ) postintervention, HOMA-IR, a surrogate of insulin resistance, improved significantly postintervention ( $P < .01$ ). The QUICKI improved after treatment, although it did not reach statistical significance ( $P = .08$ ).

Table 2 indicates the number of children in the study classified as having elevated risk factors and the metabolic syndrome, according to criteria modified from the National Cholesterol Education Program's Adult Treatment Panel III [17] and the World Health Organization [18]. Before the intervention, 7 of the 16 children were classified as having the metabolic syndrome, and at departure, none were classified as having the metabolic syndrome.

#### 4. Discussion

Westernized societies have seen a rapid rise in obesity rates in recent years, with a concomitant increase of children exhibiting characteristics of the metabolic syndrome [7–9]. Previous studies in adult populations using similar diet and exercise protocols resulted in significant improvements in body weight, BMI, serum lipids, glucose, insulin, inflammatory markers, oxidative stress, and adhesion molecule expression [12,22,23]. Accordingly, the present study was designed to investigate the effects of a structured diet and exercise program on the metabolic syndrome in young

subjects. The major new finding is the rapid reversal of metabolic syndrome with a short, residential diet and activity intervention.

The serum lipid profile improved significantly for all measures with the exception of HDL, which did not change. These reductions in lipids are in accordance with studies of adults attending this residential program, except that HDL decreases in adults [12,22,23]. The low saturated fat, *trans* fat, and cholesterol content of the diet and high fiber intake are likely responsible for the decrease in total cholesterol and LDL. The high levels of physical activity and relatively low baseline levels of HDL likely played a role in the maintenance of their HDL levels. In addition, it has been suggested that ratios of total cholesterol/HDL and LDL/HDL are better predictors of CAD risk reduction than HDL, LDL, or total cholesterol values alone [24–26]. Evidence supporting this idea comes from data in populations after very low-fat diets with reduced cardiovascular disease risk, despite low HDL concentrations [27].

The marked improvement observed in serum TG is primarily due to the combination of the high-fiber, unrefined-carbohydrate diet and the regular physical activity. Because consumption of processed carbohydrates is generally high in obese children [28], the transition to a diet largely devoid of refined carbohydrates, along with a daily exercise regimen [29], facilitated the reduction of TG. In addition, the decrease in serum insulin may also play a role in reducing TG.

Insulin resistance, thought to be at least partially modulated by visceral and intramuscular lipid accumulation [30–32], is hypothesized to be an underlying cause for the other risk factors of the metabolic syndrome [33]. In the present study, we noted a small rise in fasting glucose (7.1%) accompanied by a much larger decrease in insulin (32.6%) after the diet and exercise intervention. Because our subjects began treatment with normal baseline glucose concentrations, decreases were not expected. Nevertheless, HOMA-IR decreased significantly, suggestive of an increase in insulin sensitivity (Table 1). Previous studies in overweight children after regular exercise programs report improvements in fasting insulin [34,35], whereas a combined diet (nutritionist visits) and 3 d/wk of aerobic exercise improved HOMA-IR in overweight subjects [36]. The factors responsible for the changes in insulin in our subjects are likely because of improved insulin sensitivity from increased physical activity and the low-glycemic load of the diet. For example, low glycemic-load diets are associated with improvements in postprandial glucose, insulin, and lipids [37,38]. Exercise is known to increase insulin receptor autophosphorylation, glucose transporter 4 expression, and glucose transport [39–41].

Elevated blood pressure is well recognized as a risk factor for coronary events in adults [42]. Overweight in children is associated with arterial endothelial dysfunction, which is a hallmark of elevated blood pressure [43]. Of the 16 subjects, 9 had elevated blood pressure before the diet

and exercise intervention, and all but 1 became normotensive after the program. Both systolic and diastolic blood pressures changed significantly postintervention, with ~10% reductions in each measure. Because the postintervention blood pressure was taken after more than 12 hours after the last exercise bout and after an overnight fast, this reduction is likely independent of the acute hypotensive effect of exercise [44]. Potential mechanisms responsible for this change may include increased endothelial nitric oxide synthase activity, decreased sympathetic nervous system activation, decreased renin activity, and increased insulin sensitivity [22,45–47]. Our findings are supported by Woo et al [48] who noted significant improvements in arterial endothelial function after a 1-year diet and exercise program in overweight children. Although the diet and exercise regimen was less stringent compared with that of our study, it illustrates the efficacy and sustainability of such a program in young individuals.

The subjects were not engaging in regular physical activity on a regular basis before the intervention and, thus, the high baseline resting heart rate and 11% reduction in resting heart rate in 2 weeks reflects low initial fitness coupled with adaptations to the exercise activities. This reduction was noted despite the lack of monitoring intensity during exercise. Resting heart rate is a reliable indicator of cardiovascular fitness, is positively correlated with cardiovascular mortality in adults [49–51], and is strongly associated with hypertension [51,52].

The major finding of this investigation is that all 7 subjects classified with the metabolic syndrome at baseline were no longer classified as such after treatment, despite remaining overweight. The improvements in TG, blood pressure, and insulin were primarily responsible for the amelioration of the syndrome. Because pediatric obesity has increased since 1994 [53], the prevalence of the metabolic syndrome in the youth is likely to be greater than current estimates. Furthermore, Weiss et al [19] reported that the greater the degree of overweight in children, the greater the prevalence of the metabolic syndrome, whereas Brage et al [54] noted that cardiovascular fitness varied inversely with metabolic syndrome risk. This information, combined with reports that the metabolic syndrome phenotype tends to persist and worsen over time if no preventive actions are taken [19], highlights the value of diet and exercise intervention to mitigate the increase in the population at risk. In addition, Sudi et al [55], using a restrictive diet (~4.602 kJ/d [~1100 kcal/d]) and substantially more physical activity (4.5 h/d), documented reduced total cholesterol, TG, body weight, and insulin in overweight children over a 3-week span. We suggest that the ad libitum diet and lower amount of physical activity may be more sustainable in this population and thus suggest that energy restriction and large volumes of exercise are not required to achieve significant metabolic benefits. In addition, Kelly et al [56] noted modest improvements in blood pressure, HDL, insulin, and flow-mediated dilation in overweight children and adolescents

with exercise alone, suggesting that superior results are achieved for many variables, that is, lipid reductions and C-reactive protein reductions (Roberts et al, unpublished data) when a combined intervention is used.

The current study has important strengths and limitations to consider. The major strength of the study is the monitoring permitted by the study. Monitoring food intake and physical activity reduces the need to query subjects about their compliance or to rely on food and activity questionnaires. Furthermore, all exercise sessions were supervised, and adherence to the diet and activities was essentially 100%. On the other hand, further studies must assess the ability of these changes to be durable in children in a home environment, as has been shown in adults previously [23]. Furthermore, we do not know the degree of dietary change, given that baseline dietary intake was not assessed. In addition, the study was not a randomized, controlled trial, and the results support the need for larger, randomized, controlled investigations. The present study was not designed to investigate the independent effects of diet and physical activity and, thus, cannot discern which aspect(s) of the intervention were responsible for the changes noted, nor can we assess whether the weight loss or the diet and activity per se induced the changes noted. However, changes in body composition did not correlate significantly with metabolic changes. Because we did not assess dietary intake before the study, we can only comment on the dietary components that the average American consumes. For example, the subjects consumed a minimum of 4 vegetables and 3 fruit servings per day, which is significantly greater than the average reported in 1 study in normal-weight children (BMI = 20) of approximately 2.3 vegetables and 0.85 fruit servings per day. In this report, only 5% and 20% of children met the former US Department of Agriculture Food Guide Pyramid recommendations for fruits and vegetables, respectively [57]. In addition, data from the Continuing Survey of Food Intakes by Individuals suggests that fruits are the most commonly omitted food group, intakes of specific types of vegetables (ie, dark green, deep yellow) and of whole grains are well below that recommended, whereas intakes of total fat and added sugars exceed current recommendations. Data suggest that diets of most of the population require improvement [58].

In summary, the results of this study document that dramatic reductions in the incidence of metabolic syndrome and its associated factors in children can be achieved in a very short period through changes in diet and exercise alone. Our data are the first to document significant improvement in the metabolic syndrome in less than 3 weeks. Not only are obesity and physical inactivity associated with each other [7,59], they are important factors that carry over into adulthood and increase the risk for CAD and future chronic diseases. It is important to note that these improvements were achieved, in part, with a diet that limited only refined-carbohydrate, fat, sodium, and animal-derived products. The low energy density and high-fiber content of the diet provided sufficient bulk to ensure satiety and a net

negative energy balance, when combined with daily exercise. If sustained, lifestyle modification can help mitigate chronic disease-related complications in the future. Given the challenge of implementing lifestyle changes in children and adolescents, future studies should investigate how youth and their families can incorporate and sustain these changes into their lives.

## Acknowledgment

This study was supported by a grant from the L-B Research/ Education Foundation and funding from UCLA. Christian Roberts was supported by a National Research Scholarship Award postdoctoral fellowship, NIH F32 HL68406-01, during this project. This study was not funded by the Pritikin Longevity Center.

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