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Original article

A 6-week diet and exercise intervention alters metabolic syndrome risk factors in obese Chinese children aged 11−13 years

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Abstract

Purpose: A randomized, controlled trial was conducted to determine whether a 6-week low calorie diet and aerobic exercise intervention could alter metabolic syndrome (MetS) risk factors in pre-pubescent obese Chinese children.
Methods: The subjects were randomized into diet and exercise (DE) and control (C) groups. The DE group ingested 1600−2000 kcal/day adjusted to each participant's basal metabolic rate, and engaged in high-volume aerobic exercise (6 days/week, twice daily, for 3 h per session) for 6 weeks. A total of 215 obese children between the ages of 11 and 13 years were recruited into the study, with 167 subjects (DE, $n = 95$; C, $n = 72$) completing all phases. Pre- and post-study measures included body weight, body mass index, waist circumference, body fat percentage, blood pressure and other MetS-related markers from fasting blood samples (serum cholesterol, triglycerides, insulin, and glucose).
Results: Compared to controls, the DE subjects experienced significantly reduced levels for all outcome markers ($p < 0.05$), except for fasting blood glucose in boys ($p = 0.09$).
Conclusion: An intensive, 6-week diet and exercise intervention had favorable effects in altering MetS risk factors in obese Chinese children aged 11 to 13.

Keywords: BMI; Children; Insulin; Obesity; Triglycerides; Waist circumference

1. Introduction

China has experienced marked increases in the prevalence of childhood obesity over the last few decades. The consequences of childhood obesity include an increased incidence of metabolic syndrome (MetS), type 2 diabetes mellitus, and other chronic diseases in adulthood.[1] MetS is a common metabolic disorder that is caused by obesity.[2] Its pathophysiology is considered to be increased abdominal fat combined with dyslipidemia, insulin resistance and hyperinsulinemia.[3] The current epidemic of obesity with an increased risk for MetS constitutes a threat to the health of children in China.[4] Kong et al.[5] found that 1.2% of Chinese adolescents in Hong Kong, China suffered from MetS. Li et al.[1] reported a 3.3% prevalence of MetS in children aged 7 to 17, with more than 50% having at least one MetS risk factor.

Childhood obesity is the result of a prolonged imbalance between energy intake and expenditure. The decline in physical activity and the increased intake of high-calorie diets over the

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past decades are thought to be the primary causative factors for the development of obesity and MetS.[6] Increasing physical activity is associated with improved body fitness, weight control, and a lowered risk of MetS,[7] and combined diet and exercise interventions have great potential for improving the metabolic profile.[8] In a preliminary, non-randomized study, favorable changes in anthropometric and metabolic parameters were measured in 26 obese Chinese children following a 4-week exercise and low-calorie die intervention.[9]

Therefore, the purpose of this study was to further evaluate the efficacy of a short-duration diet and exercise intervention in altering MetS risk factors. The major outcome measures included changes in waist circumference (WC), blood pressure, body mass index (BMI), body composition, insulin sensitivity, lipid profiles, and other MetS risk factors defined by the International Diabetes Federation (IDF) in 2007[10] and utilized in previous epidemiologic studies.[11]

2. Methods

2.1. Participants

The subjects included 167 obese boys and girls, aged 11−13 years, who were recruited through the Shanghai Student Physical Fitness Monitoring Program and the Weight Loss Camp in the Shanghai University of Sport between 2009 and 2012. To enter the study, the subjects had to be: (1) at a pre-pubescent stage as determined from questionnaires and physical examinations performed by pediatricians; (2) have a BMI above 23.6 kg/m^2, 24.7 kg/m^2, and 25.7 kg/m^2 for ages 11, 12, and 13, respectively;[12] (3) have a WC above the 90th percentile of children in Shanghai (79.24 cm, 81.37 cm, 82.73 cm, for boys aged 11, 12, and 13, respectively; and 72.99 cm, 74.89 cm, 76.23 cm for girls aged 11, 12, and 13, respectively);[13] and (4) agree to be randomized into intervention or control groups, and be willing to adhere to all aspects of the research design. Written informed consent was obtained from the subjects and their parents, and the experimental procedures were approved by the institutional review board of the Shanghai University of Sport.

2.2. Diet and exercise intervention

The subjects were randomized into diet and exercise (DE) (Weight Loss Camp) and control (C) groups (normal lifestyle patterns in the Shanghai Student Physical Fitness Monitoring Program) for 6 weeks. The DE intervention was similar to the regimen used in a previous study.[14] Participants in the 6-week intervention group (DE) received well-defined and balanced daily meals. The food intake energy level was individualized for each participant (1600−2000 kcal/day) based on their basal metabolic rate requirements as calculated using the Mifflin equation for overweight and obese subjects, and the China Food Composition tables.[15-17] Briefly, three well-balanced meals were provided each day with the following macronutrient allocations (percent of total energy intake): protein 30%, carbohydrate 50%, and fat 20%. Breakfast accounted for 35% of the total daily energy intake, lunch 40%, and supper 25%. The diet included important nutrients such as vitamins, minerals, essential amino acids, fiber, and poly-unsaturated fatty acids at adequate levels.

The intervention group engaged in high volumes of moderate exercise (6 days/week, twice daily, for 3 h per session) during the 6-week study period. The program began with 30 min warm up followed by 2 h of moderate aerobic exercise (heart rate 120−150 beats per minute), and included brisk walking, jogging, or swimming in morning, and table tennis or badminton in the afternoon, followed by 30 min relaxation. The heart rate was measured by palpation every 30 min. The emphasis of the exercise program was on enjoyment and safety, not competition or skill development.

2.3. Data collection

A standard questionnaire was administered to the participants and their parents by trained staff at the baseline examination to obtain information about personal and family medical history. Body weight, height, and waist circumference were measured twice with the participant wearing indoor clothing without shoes. The waist circumference was measured 1 cm above the participant's navel during light breathing. Percentage body fat was measured by bio-impedence analysis (TBF-215, Tanita, Tokyo, Japan). Blood pressure (BP) measurements were obtained in the morning with the participant in the sitting position after a 15-min rest by a sphygmomanometer (BP742, Omron Healthcare, Bannockburn, IL, USA) according to standard protocols.

Overnight fasting blood specimens were obtained for the measurement of insulin, glucose, and lipid concentrations. The blood samples were drawn at 7:00 am to 9:00 am, with all subjects having avoided food and beverage intake other than water for at least 8 h. The blood samples were drawn from an antecubital vein in overnight-fasted subjects in the seated position and rested for at least 15 min. The blood samples were centrifuged, and the plasma was aliquoted and stored at −80 °C until analysis. Fasting blood insulin (FBI) levels were measured with the use of an enzyme immunoassay method (AIA-PACK, Tosoh, Tokyo, Japan). The fasting blood glucose (FBG) concentration was measured with a modified hexokinase enzymatic method (7020 clinical analyzer, Hitachi, Tokyo, Japan). The homeostasis model assessment of insulin resistance (HOMA-IR) was used to measure the changes in insulin sensitivity, and was calculated using the following formula: fasting plasma insulin (μIU/mL) × fasting plasma glucose (mmol/L)/22.5.[18] A serum lipid panel was performed by our clinical hematology laboratory. The clinical laboratory staff were blinded to the treatment assignments, and the study coordinators were unaware of all outcome data until the end of the intervention.

2.4. Statistical analysis

The data were analyzed using a 2 × 2 (group × time) repeated-measures analysis of variance between subjects model for each gender separately. An independent t test was used to compare the baseline data between the DE and C groups, the data of changes between the DE and C groups, and the data between boys and girls. All data were presented as means ± SD (95% confidence intervals). All analyses were conducted with SPSS software (version 17.0, SPSS Inc., Chicago, IL, USA), and a $p < 0.05$ was considered statistically significant.

3. Results

3.1. Participants

Of the 270 children assessed for eligibility (Fig. 1), 25 had a waist circumference less than the 90th percentile, 22 had experienced the onset of puberty, and eight were unable to obtain approval from their physician. The remaining 215 participants were randomized 1:1 into the DE or C groups. The number of participants in each group is shown in Fig. 1. In view of the intensity of the program and the substantial commitment in time and effort by the participants, it is noteworthy that 87.96% of the intervention group completed all study requirements (dropout rate of 12.04%). Somewhat surprisingly, there was a greater dropout rate (32.71%) in the C group, even though the subject burden was low. The main reason given by the dropouts was a lack of interest. All final participants in the DE ($n = 95$) and C ($n = 72$) groups were included in the analysis. As shown in Table 1, the randomization protocol produced similar distributions of baseline characteristics in the two groups.

3.2. Effects of treatment

As shown in Table 2 and Fig. 2, the body weight, BMI, WC, and percent body fat were reduced in the DE group as compared to increases in the C group. The differences between the two groups for the changes in body weight (−12.40 kg in boys and −9.55 kg in girls), BMI (−4.85 in boys and −3.91 in girls), WC (−14.16 cm in boys and −12.48 cm in girls) and percentage body fat (−6.96% in boys and −5.98% in girls) after 6 weeks were all statistically significant ($p < 0.001$). Systolic and diastolic blood pressures decreased significantly in the DE group relative to no change in the C group ($p < 0.001$). The serum cholesterol concentrations decreased in the DE group relative to an increase in the controls ($p < 0.001$) with exception in girls' high-density lipoprotein-cholesterol (HDL-C) ($p = 0.01$) after 6 weeks. Only in the girls was a significant reduction in FBG observed ($p = 0.01$), whereas FBG was unchanged in the boys ($p = 0.09$). The mean FBI concentrations fell by 8.93 μIU/mL in the boys and 6.71 μIU/mL in the girls at 6 weeks in the DE group as compared to the increases in the C group ($p < 0.001$). The

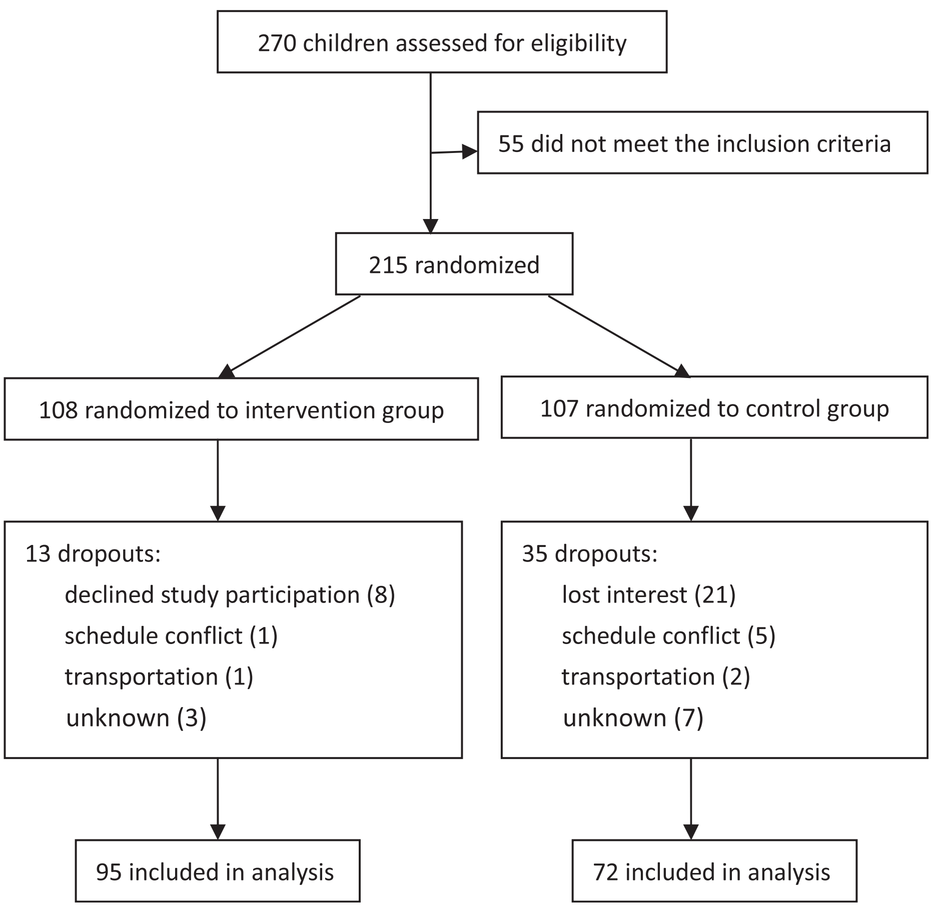

Fig. 1. Enrollment, randomization, and dropout of the study participants.

Table 1
Baseline characteristics of children randomized into intervention and control groups (mean ± SD).

Characteristic	Girl			Boy		
	DE (n = 43)	C (n = 34)	p	DE (n = 52)	C (n = 38)	p
Age (year)	12.02 ± 0.91	12.56 ± 0.70	0.05	12.04 ± 0.74	11.95 ± 0.73	0.56
Weight (kg)	73.64 ± 10.85	74.58 ± 7.48	0.67	80.34 ± 16.07	79.04 ± 9.86	0.64
BMI	29.38 ± 3.35	29.77 ± 1.50	0.51	30.78 ± 3.56	30.09 ± 1.57	0.22
WC (cm)	94.60 ± 8.29	95.20 ± 5.61	0.70	98.26 ± 9.95	97.83 ± 8.15	0.82
Body fat (%)	38.07 ± 5.51	37.94 ± 3.82	0.91	36.38 ± 5.91	35.88 ± 5.12	0.67
Blood pressure (mm Hg)						
Systolic	112.79 ± 9.38	111.97 ± 7.91	0.68	111.67 ± 9.98	107.68 ± 8.89	0.05
Diastolic	64.67 ± 8.67	63.74 ± 5.73	0.57	61.79 ± 7.39	60.24 ± 7.05	0.32
Cholesterol (mmol/L)						
Total	4.38 ± 0.80	4.32 ± 0.56	0.74	4.52 ± 0.80	4.46 ± 0.54	0.63
HDL	1.22 ± 0.21	1.18 ± 0.16	0.43	1.24 ± 0.23	1.22 ± 0.15	0.62
LDL	2.47 ± 0.54	2.52 ± 0.33	0.58	2.68 ± 0.56	2.61 ± 0.32	0.46
Triglycerides (mmol/L)	1.46 ± 0.61	1.50 ± 0.39	0.74	1.55 ± 0.92	1.58 ± 0.41	0.83
Fasting glucose (mmol/L)	4.05 ± 0.98	4.08 ± 0.54	0.87	4.30 ± 0.87	4.21 ± 0.56	0.58
Fasting insulin (μIU/mL)	12.93 ± 5.15	12.67 ± 5.06	0.82	17.66 ± 8.52	16.16 ± 5.24	0.31
HOMA-IR	2.38 ± 1.28	2.42 ± 1.35	0.90	3.38 ± 1.75	3.15 ± 1.50	0.52

Abbreviations: DE = intervention group; C = control group; BMI = body mass index, calculated as weight in kilograms divided by height in meters squared; WC = waist circumference; HDL = high-density lipoprotein; LDL = low-density lipoprotein; HOMA-IR = homeostasis model assessment of insulin resistance.

Table 2
Changes in MetS risk factors for intervention and control groups at 6 weeks.*

Measure	Girl				Boy			
	DE (n = 43)	C (n = 34)	Between group difference	p	DE (n = 52)	C (n = 38)	Between group difference	p
Weight (kg)	−6.70 (−7.56 to −5.84)	2.85 (2.28−3.42)	−9.55 (−10.57 to −8.53)	<0.001	−8.60 (−9.32 to −7.88)	3.80 (3.11−4.49)	−12.40 (−13.42 to −11.39)	<0.001
BMI	−2.86 (−3.22 to −2.50)	1.05 (0.83−1.28)	−3.91 (−4.33 to −3.50)	<0.001	−3.51 (−3.77 to −3.26)	1.34 (1.11−1.56)	−4.85 (−5.20 to −4.49)	<0.001
WC (cm)	−12.31 (−13.84 to −10.79)	0.17 (−0.09 to 0.43)	−12.48 (−14.02 to −10.94)	<0.001	−13.92 (−16.01 to −11.82)	0.24 (0.05−0.43)	−14.16 (−16.26 to −12.06)	<0.001
Body fat (%)	−5.83 (−6.60 to −5.07)	0.14 (0.06−0.22)	−5.98 (−6.75 to −5.21)	<0.001	−6.92 (−7.65 to −6.18)	0.04 (−0.04 to 0.13)	−6.96 (−7.69 to −6.22)	<0.001
Blood pressure (mm Hg)								
Systolic	−12.07 (−14.48 to −9.66)	0.24 (0.06−0.41)	−12.31 (−14.72 to −9.89)	<0.001	−14.17 (−16.60 to −11.74)	0.21 (−0.03 to 0.45)	−14.38 (−16.83 to −11.94)	<0.001
Diastolic	−7.37 (−9.86 to −4.88)	0.35 (−0.25 to 0.96)	−7.73 (−10.28 to −5.17)	<0.001	−4.79 (−6.36 to −3.22)	0.24 (0.06−0.41)	−5.03 (−6.60 to −3.45)	<0.001
Cholesterol (mmol/L)								
Total	−0.80 (−0.95 to −0.65)	0.01 (0.01−0.01)	−0.95 (−1.10 to −0.80)	<0.001	−0.88 (−1.10 to −0.66)	0.01 (0.01−0.01)	−1.08 (−1.25 to −0.91)	<0.001
HDL	−0.07 (−0.10 to −0.03)	−0.01 (−0.02 to −0.01)	−0.05 (−0.09 to −0.01)	0.01	−0.15 (−0.19 to −0.10)	−0.02 (−0.02 to −0.01)	−0.13 (−0.18 to −0.08)	<0.001
LDL	−0.54 (−0.64 to −0.43)	0.02 (0.02−0.02)	−0.55 (−0.66 to −0.45)	<0.001	−0.71 (−0.84 to −0.59)	0.02 (0.01−0.03)	−0.73 (−0.86 to −0.61)	<0.001
TG (mmol/L)	−0.93 (−1.08 to −0.78)	0.02 (0.01−0.03)	−0.81 (−0.95 to −0.66)	<0.001	−1.06 (−1.23 to −0.89)	0.02 (0.01−0.02)	−0.89 (−1.11 to −0.67)	<0.001
FBG (mmol/L)	−0.29 (−0.51 to −0.07)	0.00 (−0.03 to 0.04)	−0.29 (−0.52 to −0.07)	0.01	−0.11 (−0.27 to 0.06)	0.04 (0.00−0.07)	−0.14 (−0.31 to 0.02)	0.09
FBI (μIU/mL)	−6.71 (−8.72 to −4.69)	0.16 (0.10−0.22)	−6.87 (−8.89 to −4.85)	<0.001	−8.93 (−11.23 to −6.63)	0.11 (0.02−0.09)	−9.03 (−11.33 to −6.73)	<0.001
HOMA-IR	−1.34 (−1.75 to −0.94)	0.04 (0.01−0.06)	−1.38 (−1.79 to −0.97)	<0.001	−1.80 (−2.28 to −1.33)	0.06 (0.02−0.10)	−1.86 (−2.34 to −1.39)	<0.001

Abbreviations: DE = intervention group; C = control group; BMI = body mass index; WC = waist circumference; HDL = high-density lipoprotein; LDL = low-density lipoprotein; HOMA-IR = homeostasis model assessment of insulin resistance; TG = triglyceride; FBG = fasting blood glucose; FBI = fasting blood insulin.

* All data are presented as means (95% confidence intervals).

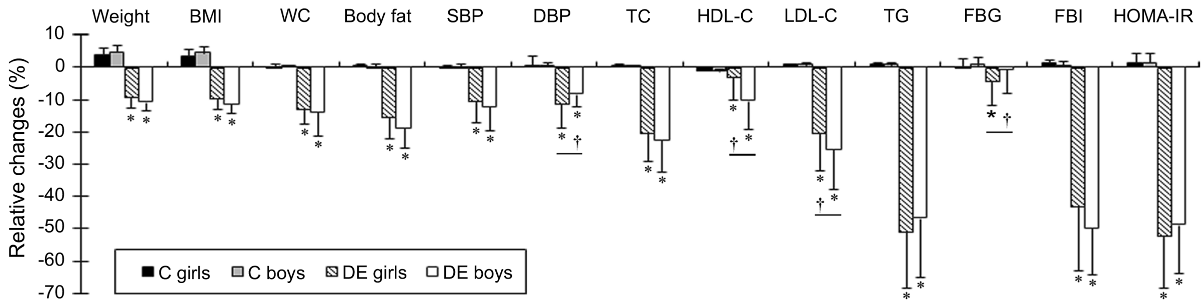

Fig. 2. Changes in metabolic risk factors: weight, body mass index (BMI), waist circumference (WC), body fat percentage, systolic blood pressure (SBP), diastolic blood pressure (DBP), total cholesterol (TC), high-density lipoprotein-cholesterol (HDL-C), low-density lipoprotein-cholesterol (LDL-C), triglyceride (TG), fasting blood glucose (FBG) and insulin (FBI), and homeostasis model assessment of insulin resistance (HOMA-IR) for control (C) and diet and exercise intervention groups (DE). All data are shown as the percentage changes in relation to the baseline value. *$p < 0.05$, ED *vs.* C; $^{\dagger}p < 0.05$, girls *vs.* boys.

differences in the changes in the HOMA-IR between the DE and C groups at 6 weeks (−1.80 *vs.* 0.06 in boys and −1.34 *vs.* 0.04 in girls) were statistically significant ($p < 0.001$). Additionally, DBP, FBG, HDL-C, and low-density lipoprotein-cholesterol (LDL-C) were changed differently in the boys and girls after a 6-week diet and exercise intervention. The DBP and FBG were reduced greater in the girls, while the decrease in the HDL-C and LDL-C level were more prominent in the boys ($p < 0.05$, Fig. 2).

3.3. The prevalence of MetS in the DE group

Before the intervention, 10 children in the DE group were diagnosed as MetS patients according to the 2007 IDF criteria.[10] All children in the DE group had at least one MetS risk factor: WC ≥ 90th percentile for ages 11−13 (95/95, 100%), systolic blood pressure (SBP) ≥ 130 mmHg (4/95, 4.21%), diastolic blood pressure (DBP) ≥ 85 mmHg (1/95, 1.05%), triglyceride (TG) ≥ 1.7 mmol/L (29/95, 30.53%), HDL-C < 1.03 mmol/L (19/95, 20%), or fasting blood glucose (FBG) ≥ 5.6 mmol/L (1/95, 1.05%). After the intervention, none of the children in the DE group were classified as having MetS. The number of children having MetS risk factors also dropped: SBP ≥ 130 mmHg (decrease 100%), DBP ≥ 85 mmHg (decrease 100%), FBG ≥ 5.6 mmol/L (decrease 100%), TG ≥ 1.7 mmol/L (1/95, 1.05%, decrease 96.55%), and WC ≥ 90th percentile for ages 11−13 (68/95, 71.58%, decrease 28.42%).

4. Discussion

In this randomized, controlled 6-week study of a group of 167 obese children, a low-calorie diet in combination with high volumes of moderate exercise significantly lowered MetS risk factors such as BMI, WC, BP, serum cholesterol and TGs, and FBI. In a previous study, we showed that supervised exercise improved the neutrophil-to-lymphocyte ratio.[13] In another study, a 12-week diet and physical activity intervention reduced MetS risk factors without changes in systemic inflammation in obese children from the United States.[19] The major strengths in our study included the use of a randomized design, the enrollment of both males and females, careful monitoring of the diet, and supervised exercise sessions for all DE subjects. We found some gender-specific differences in MetS risk factor changes, suggesting that pre-pubescent girls and boys may not respond in the same way to diet and exercise interventions.

Anthropometric outcome measures showed positive changes in the obese children following the lifestyle intervention, with 6%−8% decreases in body weight, BMI, and WC. The percentage change in the WC was greater than for the BMI and weight in the DE subjects, suggesting that diet and exercise intervention may preferentially reduce abdominal fat in obese children and thus lower the risk of MetS.[20]

The systolic and diastolic blood pressures have increased substantially among children and adolescents in China, and is likely to increase the incidence of early hypertension.[21] Both acute and chronic moderate exercise have an effect in reducing BP. Sharman et al.[22] reported that an acute 10-min bout of moderate aerobic exercise reduced the brachial SBP and DBP in healthy adults. Roberts et al.[23] found that a short-term, rigorous diet and exercise intervention reduced both SBP and DBP by 10% in overweight children. In our study, we found similar decreases in blood pressure after the 6-week, low-calorie diet and high volume moderate exercise intervention.

The prevalence of insulin resistance is increasing, and is considered to be a major pathophysiological factor responsible for many clinical complications of childhood obesity.[11] Therefore, we measured the changes in HOMA-IR in the two groups as a surrogate risk factor. Similar to the anthropometric parameters, the HOMA-IR decreased in the DE group as compared to an increase in the controls, with substantial changes in both boys and girls (−1.80 and −1.34, respectively). Exercise is known to increase insulin receptor auto-phosphorylation, glucose transporter-4 expression, and glucose transport.[24] The factors responsible for the changes in the insulin profile in our subjects are likely due to improved insulin sensitivity from increased physical activity and the low-calorie diet.[25] Despite improvements in both HOMA-IR and insulin levels, no changes in FBG levels were measured in the boys, as reported by others.[26]

Obese compared to non-obese children often consume larger amounts of processed carbohydrates.[27] The diet used in this intervention program was largely devoid of refined carbohydrates. The improvement in TG experienced by the DE subjects was primarily due to the combination of the low-calorie, unrefined-high fiber carbohydrate diet and the large volumes of moderate physical activity. The decrease in insulin also played a role in reducing TG levels. A 3-month study utilizing a low-carbohydrate diet also found a 20%−25% decrease in TG levels in obese adults.[28] In our 6-week study of obese children, the TC also decreased 0.65−1.10 mmol/L. Nieman et al.[29] reported a 0.6−0.8 mmol/L decrease in TC in overweight women following 12-week of energy restriction and exercise training. The LDL-C decreased 0.54 mmol/L in the girls and 0.71 mmol/L in the boys, similar to what has been reported in previous studies using diet and exercise interventions.[23,29] The HDL-C decreased in the DE group as compared to the controls, which has been reported in other studies when subjects are experiencing strong decreases in body weight.[26]

Our study has several limitations. The duration of our intervention program was 6 weeks, and the follow-up was limited due to the summer vacation period. We combined data from 2009 to 2012, with a focus on MetS risk factors, but not other important clinical end points. Future studies may focus on the long-term benefits to MetS risk factors after 6-week diet and exercise interventions in children, and a cost-benefit analysis.

In conclusion, an intensive low-calorie diet and exercise program was associated with substantial improvements in MetS risk factors such as BMI, WC, BP, insulin sensitivity, and serum TC and TG levels. These data support the value of short-term lifestyle interventions in reducing disease risk factors in obese Chinese children.

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