Effects of two-month physical-endurance and diet-restriction programmes on lipid profiles and insulin resistance in obese adolescent boys

O. Ben Ounis a,*, M. Elloumi a, I. Ben Chiekh a, A. Zbidi a, M. Amri c, G. Lac b, Z. Tabka a

a Laboratory of Cardio-Circulatory, Respiratory, Metabolic and Hormonal Adaptations to the Muscular Exercise, Faculty of Medicine Ibn El Jazzar, 4002 Sousse, Tunisia
b Department of biology, University Blaise-Pascal, 63177 Aubière, France
c Department of biology, University El Manar, 1002 Tunis, Tunisia

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Abstract

Aim. – The aim of this study was to assess the impact of a two-month programme of physical endurance and dietary restriction, alone and combined, on plasma lipids and insulin resistance in obese adolescents.

Methods. – A total of 24 obese adolescent boys participated in programmes of either dietary restriction (R), physical endurance at the point of maximum lipid oxidation (LIPOX max) (E) or diet combined with training (R + E). Anthropometric characteristics, metabolic measures and biochemical analyses were performed in all subjects before and after the interventions. An estimated insulin resistance was calculated using the homoeostasis model assessment (HOMA-IR) index.

Results. – At the end of the two-month programmes, adolescents in the R + E group showed greater reductions in body mass index (−3.9 ± 0.7 kg/m²) and waist circumference (−12.3 ± 4.8 cm) (P < 0.001) than either the R or E group. A significant decrease (P < 0.01) in HOMA-IR index (−2.13 ± 0.11), plasma triglycerides, LDL and total cholesterol was also seen in the R + E group. Moreover, at the end of the programme, the ratio of HDL cholesterol to triglycerides was significantly increased from baseline in the R + E group (0.93 ± 0.09 vs. 0.68 ± 0.11; P < 0.01).

Conclusion. – Compared with either moderate physical endurance or dietary restriction, a combination of both resulted in a significant decrease in cardiovascular risk factors and HOMA-IR index in obese adolescent boys.

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Résumé

Effet sur le profil lipidique et la résistance à l’insuline d’un programme comportant un entraînement en endurance, combiné ou non à un régime alimentaire, pendant deux mois chez des adolescents obèses.

Objet. – Évaluer les effets d’un régime alimentaire et d’un programme d’entraînement en endurance de deux mois sur la résistance à l’insuline et les lipides plasmatiques, indépendamment et combinés chez des adolescents obèses.

Méthodes. – Vingt-quatre garçons adolescents obèses ont participé au programme comparant les effets d’un régime alimentaire (R), d’un entraînement en endurance au point d’oxydation maximal des lipides (LIPOX max) (E) et d’un régime associé à l’entraînement (R + E). Les caractéristiques anthropométriques, les mesures métaboliques et les analyses biochimiques ont été enregistrées chez tous les sujets avant et après les programmes. L’estimation de la résistance à l’insuline a été calculée par l’index HOMA-R.

Résultats. – À l’issue de ce programme, R + E a montré une diminution plus importante de l’indice de masse corporelle (−3.9 ± 0.7 kg/m²) et du tour de taille (−12.3 ± 4.8 cm) (P < 0.001) que R et E. Une diminution significative (P < 0.01) du HOMA-R (−2.13 ± 0.11), des triglycérides, du LDL cholestérol et du cholestérol total a été observée chez R + E. Par ailleurs, le rapport du HDL cholestérol/triglycérides était significativement augmenté chez R + E (0.93 ± 0.09 vs. 0.68 ± 0.11 ; P < 0.01).

* Corresponding author.
E-mail address: omar_oda@yahoo.fr (O. Ben Ounis).

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Conclusion. – Compared to the alimentary diet alone or to endurance training alone, the combination of both programmes induced a reduction in serum factors of cardiovascular disease and of the index HOMA-R.

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Keywords: Obese adolescents; Lipid; Insulin resistance; Physical exercise; Training programme; Low-calorie diet

Mots clés : Adolescents obèses ; Lipides ; Résistance à l’insuline ; Exercice physique ; Programme d’entraînement ; Régime hypocalorique

Abbreviations

<table>
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<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>R</td>
<td>Diet restriction</td>
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<tr>
<td>E</td>
<td>Exercise training</td>
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<tr>
<td>R+E</td>
<td>Diet restriction combined with exercise training</td>
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<tr>
<td>LIPOXmax</td>
<td>Maximal lipid oxidation point</td>
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<tr>
<td>LIPOXmax (mg/min)</td>
<td>Maximal rate of lipid oxidation</td>
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<tr>
<td>COP</td>
<td>Crossover point</td>
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<tr>
<td>W_max</td>
<td>Maximum aerobic power</td>
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<tr>
<td>VO2max</td>
<td>Maximum oxygen uptake rate</td>
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<td>HR</td>
<td>Heart rate</td>
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<tr>
<td>WC</td>
<td>Waist circumference</td>
</tr>
<tr>
<td>BF%</td>
<td>Body fat in percentage</td>
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<tr>
<td>FM</td>
<td>Fat mass</td>
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<tr>
<td>FFM</td>
<td>Fat free mass</td>
</tr>
<tr>
<td>PS</td>
<td>Pubertal status</td>
</tr>
<tr>
<td>VCO2</td>
<td>Dioxide of carbon rejected rate</td>
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</tbody>
</table>

1. Introduction

There is a global epidemic of obesity in children and adolescents in most of the developed countries today. This epidemic has been accompanied by a marked increase in the frequency of cardiovascular risk factors such as high blood pressure, dyslipidaemia and insulin resistance [1], the main component of the metabolic syndrome seen in a large number of overweight adolescents [2].

Waist circumference has been considered an acceptable surrogate marker of abdominal fat mass in adolescents [3], an increase in which is also associated with increased levels of cardiovascular risk factors [4]. An unbalanced diet and a lack of physical activity have been suggested to promote the development of excess fat storage in adipose tissue, which is an endocrine organ producing a variety of factors that can regulate energy metabolism and insulin sensitivity [5].

Skeletal muscle is the most important regulator of fat oxidation and can have a positive impact on fat-mass balance. Defects in muscle lipid metabolism have been observed in obese individuals both at rest and during exercise [6]. It is well accepted that prolonged aerobic exercise has beneficial effects on tissue sensitivity to insulin [7] and on the transport of blood lipids [8].

Weight loss has been shown to favourably affect several indicators of cardiovascular risk such as plasma lipids [9]. However, high-density lipoprotein cholesterol (HDL-C) levels are generally not improved [10]. As a low HDL-C is associated with increased cardiovascular risk [11], this may minimize the overall impact of diet on the risk of cardiovascular disease. On the other hand, exercise is associated with an increase in HDL-C [12]. For this reason, a combination of diet and exercise may be the optimal approach to controlling dyslipidaemia.

Brandou et al. [13] developed a model of maximum fat oxidation (LIPOXmax) based on the ‘crossover concept’ [14]. We used these two parameters to prescribe individualized exercise training for each of our study subjects.

The present study investigated the effects of diet and endurance training—alone or combined—on weight loss, insulin resistance and blood-lipid parameters in obese adolescent boys over a two-month period. We hypothesized that the combined diet and exercise regime would bring about improvements in insulin resistance and serum lipid profile via its effects on lipid oxidation during exercise.

2. Materials and methods

2.1. Subjects

We selected 24 obese adolescent boys, aged 12–14 years, whose body mass index (BMI) was greater than 97th percentile, as defined by French population curves [15]. None of the subjects were using drugs or other therapy for obesity, and none had prior histories of disease or injury that would prevent daily exercise. Consent to participate in the rehabilitation programme was obtained from each boy and his parents, and the project was approved by the Research Ethics Committee of the Faculty of Medicine, University of Sousse, in Tunisia.

The subjects were randomly assigned to one of three programme groups:

- diet (R);
- physical training at LIPOXmax (E);
- and diet plus training (R + E).

2.2. Anthropometry

Height, weight, and hip and waist circumferences were recorded. BMI was calculated as weight in kilograms divided by height in meters squared (kg/m²).

In all subjects, two skin-fold thicknesses (triceps and subscapular) were measured in triplicate by the same trained observer. Measurements were made on the right-hand side of the body using a Harpenden calliper.

Body-fat percentage (BF%) was calculated using the equations of Slaughter et al. [16] for boys with triceps and subscapular skin folds less than 35 mm as follows: \( \text{BF}% = 1.21 \times (\Sigma - 0.008 \times (\Sigma)^2 - 1.7) \), where \( \Sigma \) is the sum of two skin folds (triceps and subscapular) in millimetre.
Pubertal stage was evaluated according to the Tanner classification [17] by a trained paediatrician:

- prepubertal children were those in Tanner stage I;
- pubertal children were in Tanner stages II–III;
- and post-pubertal children were in Tanner stages IV–V.

2.3. Biochemical analysis

Total cholesterol (TC), triglycerides (TG), HDL-C and glucose levels were measured in all subjects before and after the interventional programmes using standardized techniques, as described by Wegge et al. [18]. LDL-C was calculated using the Friedewald formula [19], and plasma insulin was assayed using the IRMA kit (Immunotech, France). An estimate of insulin resistance was calculated by the homoeostasis model assessment (HOMA-IR) index as: [fasting insulin (µU/mL) × fasting glucose (mmol/L)]/22.5.

To distinguish normal from impaired insulin sensitivity, HOMA-IR greater than 2.5 and greater than 4.0 were the cut-off points used in children and adolescents, respectively [20]. We adapted guidelines from the World Health Organization (WHO) [21] to define the metabolic syndrome:

- raised arterial blood pressure defined as systolic blood pressure greater or equal to 140 mmHg and/or diastolic blood pressure greater or equal to 90 mmHg;
- raised plasma triglycerides greater or equal to 1.7 mmol/L and/or HDL cholesterol less than 0.9 mmol/L;
- waist-to-hip ratio greater than 0.9 and/or BMI greater than 30 kg/m².

2.4. Exercise testing

The subjects performed an exercise test on an electromagnetically braked cycle ergometer (Ergoline, Bitz, Germany) according to the protocol described by Brandou et al. [13]. Gas exchange was monitored on a breath-by-breath basis, using a metabolic cart (ZAN 600, ZAN Messgeräte, Oberthulba, Germany).

The maximum oxygen-uptake rate (VO₂max) and maximum aerobic power (W max) was calculated according to Wasserman’s equation for obese boys [22]:

\[
VO₂max = (28.5 \times \text{weight}) + 288.1.
\]

The following equation was used to calculate W max [22]:

\[
W_{max} = \left[VO₂max - 10 (\times \text{weight})\right] / 10.3.
\]

The test consisted of five consecutive six-minute steady-state workloads at 20, 30, 40, 50 and 60% of W max. Heart rate (HR) was monitored by electrocardiography during the exercise testing (ZAN ECG 800, ZAN Messgeräte). Calculation of cholesterol (CHO) and lipid-oxidation rates were assessed from gas-exchange measurements according to the non-protein respiratory quotient (R) technique [23] where: CHO (mg/min) = 4.585 VCO₂ – 3.2255 VO₂; lipids (mg/min) = 1.7012 VCO₂ + 1.6946 VO₂ (with VO₂ and VCO₂ in mL/min). VO₂ and VCO₂ were determined as the means of measurements taken during the fifth and sixth minutes of each state, according to MacRae et al. [24].

In addition, after smoothing the curves, we calculated two parameters to represent the balance between fat and CHO utilization induced by increasing exercise intensity:

- the crossover point (COP) of substrate utilization;
- and the maximum fat-oxidation (LIPOX max) point, as previously described [14,13].

2.5. Dietary programme

The subjects in the R and R+E groups recorded (four times/week), in a specially designed notebook, the quantity of and time at which food was eaten. A dietician then prescribed each individualized diet, including the quantity and type of foods recommended, after an initial dietary assessment to determine the total amount of calories to be consumed per day. The diet was set at 500 kcal per day below the initial dietary records, and comprised 15% proteins, 55% carbohydrates and 30% lipids. The foods were selected according to the subjects’ usual eating habits.

2.6. Training programme

Physical training (E and R+E) was carried out four days a week (90 min per day) for two months at a HR corresponding to LIPOX max, in a gymnasium supervised by physical-education professors. Exercises included a warm-up, running, jumping and playing with a ball. During each exercise session, HR was continuously monitored (Polar Electro, Kempele, Finland).

2.7. Statistical analysis

Data are presented as means plus or minus standard deviations (S.D.). Paired Student’s t test was used for comparisons among the three groups (R, E and R + E), and unpaired Student’s t test for group comparisons. Repeated-measures ANOVA compared the responses of each group at different times during the test, and before and after the interventions.

Tukey’s post-hoc test was used to compare means and, to evaluate the relationships between various parameters, Spearman’s correlation analysis was performed. P < 0.05 was considered statistically significant.

3. Results

3.1. Anthropometric characteristics

Anthropometric characteristics are summarized in Table 1. The three groups were closely matched by age, adiposity and pubertal stage (Table 1). Daily energy intake was significantly reduced during the two-month intervention in the R and R+E groups (P < 0.01), and did not differ between the two groups.

The HR corresponding to LIPOX max used to set the intensity of the training programme did not vary between individ-
Anthropometric characteristics and metabolic parameters of adolescents before and after the two-month dietary-restriction (R), exercise-training (E) and diet-plus-training (R+E) programmes.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>R group (n = 8) Before</th>
<th>After</th>
<th>E group (n = 8) Before</th>
<th>After</th>
<th>R + E group (n = 8) Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>163.3 ± 4.1</td>
<td>163.3 ± 5.1</td>
<td>163.8 ± 2.9</td>
<td>163.9 ± 3.1</td>
<td>164.2 ± 2.6</td>
<td>164.7 ± 1.3</td>
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<tr>
<td>Weight (kg)</td>
<td>81.4 ± 13.7</td>
<td>74.6 ± 12.8**</td>
<td>80.1 ± 15.8</td>
<td>78.2 ± 15.3</td>
<td>84.5 ± 13.5</td>
<td>73.0 ± 14.1***</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>30.7 ± 2.6</td>
<td>27.8 ± 2.6**</td>
<td>30.2 ± 4.2</td>
<td>29.4 ± 4.9</td>
<td>31.3 ± 4.0</td>
<td>27.4 ± 4.4***</td>
</tr>
<tr>
<td>FM (kg)</td>
<td>34.8 ± 5.3</td>
<td>29.2 ± 6.2**</td>
<td>34.3 ± 7.2</td>
<td>32.6 ± 6.3</td>
<td>35.4 ± 5.7</td>
<td>24.2 ± 6.3***</td>
</tr>
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<td>FFM (kg)</td>
<td>46.6 ± 6.2</td>
<td>45.4 ± 4.3*</td>
<td>45.8 ± 5.7</td>
<td>45.6 ± 4.8</td>
<td>49.1 ± 5.4</td>
<td>48.8 ± 6.2</td>
</tr>
<tr>
<td>Waist (cm)</td>
<td>97.3 ± 8.2</td>
<td>91.1 ± 9.7**</td>
<td>96.4 ± 11.2</td>
<td>94.6 ± 10.2</td>
<td>98.6 ± 6.7</td>
<td>86.3 ± 8.2***</td>
</tr>
<tr>
<td>Hip (cm)</td>
<td>101.7 ± 7.2</td>
<td>101.2 ± 5.5*</td>
<td>100.5 ± 8.8</td>
<td>99.9 ± 8.2</td>
<td>107.6 ± 9.1</td>
<td>98.7 ± 6.6***</td>
</tr>
<tr>
<td>Glucose (mmol/L)</td>
<td>4.61 ± 0.13</td>
<td>4.53 ± 0.18</td>
<td>4.58 ± 0.27</td>
<td>4.56 ± 0.17</td>
<td>4.64 ± 0.15</td>
<td>4.32 ± 0.22**</td>
</tr>
<tr>
<td>Insulin (µU/mL)</td>
<td>22.6 ± 6.2</td>
<td>21.8 ± 4.3</td>
<td>21.2 ± 5.7</td>
<td>16.1 ± 3.6*</td>
<td>23.2 ± 4.6</td>
<td>13.8 ± 3.3**</td>
</tr>
<tr>
<td>HOMA-IR</td>
<td>4.63 ± 1.7</td>
<td>4.39 ± 1.8</td>
<td>4.32 ± 1.3</td>
<td>3.26 ± 1.1*</td>
<td>4.78 ± 1.2</td>
<td>2.65 ± 1.5***</td>
</tr>
<tr>
<td>TG (mmol/L)</td>
<td>1.41 ± 0.16</td>
<td>1.39 ± 0.18</td>
<td>1.40 ± 0.12</td>
<td>1.27 ± 0.11*</td>
<td>1.45 ± 0.21</td>
<td>1.21 ± 0.19**</td>
</tr>
<tr>
<td>TC (mmol/L)</td>
<td>4.24 ± 0.31</td>
<td>3.93 ± 0.63*</td>
<td>4.22 ± 0.27</td>
<td>4.01 ± 0.42</td>
<td>4.29 ± 0.58</td>
<td>3.78 ± 0.52**</td>
</tr>
<tr>
<td>LDL-C (mmol/L)</td>
<td>1.02 ± 0.08</td>
<td>0.99 ± 0.11</td>
<td>1.03 ± 0.06</td>
<td>1.09 ± 0.1*</td>
<td>0.98 ± 0.08</td>
<td>1.13 ± 0.14**</td>
</tr>
<tr>
<td>HDL-C/LDL-C</td>
<td>2.57 ± 0.19</td>
<td>2.30 ± 0.26*</td>
<td>2.55 ± 0.11</td>
<td>2.34 ± 0.34</td>
<td>2.64 ± 0.13</td>
<td>2.09 ± 0.21**</td>
</tr>
<tr>
<td>LDL-C/HDL-C ratio</td>
<td>2.52 ± 0.29</td>
<td>2.32 ± 0.31</td>
<td>2.48 ± 0.18</td>
<td>2.15 ± 0.16*</td>
<td>2.69 ± 0.22</td>
<td>1.85 ± 0.13**</td>
</tr>
<tr>
<td>TC/HDL-C ratio</td>
<td>4.16 ± 0.25</td>
<td>3.97 ± 0.32</td>
<td>4.10 ± 0.28</td>
<td>3.68 ± 0.31*</td>
<td>4.38 ± 0.19</td>
<td>3.35 ± 0.20**</td>
</tr>
<tr>
<td>HDL-C/TG ratio</td>
<td>0.72 ± 0.07</td>
<td>0.71 ± 0.14</td>
<td>0.74 ± 0.06</td>
<td>0.86 ± 0.15*</td>
<td>0.68 ± 0.11</td>
<td>0.93 ± 0.09**</td>
</tr>
</tbody>
</table>

Data are means ± S.D.
PS: pubertal status; BMI: body mass index; FM: fat mass; FFM: fat-free mass; HOMA-IR: homeostasis model assessment index for insulin resistance; TG: triglycerides; TC: total cholesterol; HDL-C: high-density lipoprotein cholesterol; LDL-C: low-density lipoprotein cholesterol.

* P < 0.05, ** P < 0.01, *** P < 0.001.

...trials in the E (HR = 127.2 ± 4.1 bpm; P < 0.05) and R + E (HR = 124.5 ± 3.6 bpm; P < 0.05) groups.

After the two-month programme, BMI, waist circumference and fat mass decreased significantly in both the R (−2.9 ± 0.2 kg/m², −6.2 ± 2.4 cm and −5.6 ± 0.8 kg, respectively; P < 0.01) and R + E (−3.9 ± 0.7 kg/m², −12.3 ± 4.8 cm and −11.2 ± 3.7 kg, respectively; P < 0.001) groups (Table 1). There were no significant changes in these parameters in the E group.

### 3.2. Substrate oxidation

Parameters of substrate utilization changed (Fig. 1), with increases in COP and LIPOX<sub>max</sub> points in the E (+12.8 ± 3.2 of W<sub>max</sub> and +66.0 ± 12.3 µmol/min, respectively; P < 0.05) and R + E (+20.4% ± 4.6 of W<sub>max</sub> and +108.4 ± 23.6 µmol/min, respectively; P < 0.001) groups. No changes were observed in the R group (Fig. 1).

### 3.3. Biochemical analysis

Neither the plasma concentrations of glucose and insulin nor the lipid profile differed across the three groups before the programme (Table 1). However, after the two-month intervention, fasting insulin levels decreased significantly in the E and R + E groups: −5.1 ± 1.3 µU/mL (P < 0.05) and −9.4 ± 3.6 µU/mL (P < 0.01), respectively. In addition, the post-interventional HOMA-IR (insulin resistance) was significantly improved in the E (P < 0.05) and R + E (P < 0.01) groups, whereas the R group showed no significant reduction. The R + E group also showed...
significant decreases in plasma TG, LDL-C and TC concentrations, and in LDL-C/HDL-C and TC/HDL-C ratios ($P < 0.01$), while the R group achieved significant decreases in plasma TC and LDL-C ($P < 0.05$) (Table 1).

However, in the E group, reductions were less marked for all measures ($P < 0.05$), with no changes in either TC or LDL-C. Also, after the intervention, the E group’s HDL-C/TG ratio was higher ($0.86 \pm 0.15 \text{ vs. } 0.74 \pm 0.06; P < 0.05$), as was that of the R+E group ($0.93 \pm 0.09 \text{ vs. } 0.68 \pm 0.11; P < 0.01$). No changes were observed in the R group in HDL-C/TG ratio (Table 1).

3.4. Correlations among improvements due to the three programmes

Waist circumference and the HOMA-IR ($r = 0.69; P < 0.01$) were significantly correlated in the R+E subjects. In those in the E and R+E groups, significant correlations were observed between changes in LIPOX$_{\text{max}}$ and LDL-C/HDL-C ratio ($r = -0.52; P < 0.05$ and $r = -0.53; P < 0.01$, respectively), and between changes in LIPOX$_{\text{max}}$ and TC/HDL-C ratio ($r = -0.37; P < 0.05$ and $r = -0.62; P < 0.01$, respectively).

4. Discussion

The present study compared the effects of physical-endurance training and dietary restriction, alone and combined, on insulin resistance and lipid profile in obese Tunisian boys. We found that dietary intervention on its own promoted fat loss, and improved TC and LDL-C levels, whereas training intervention alone increased lipid oxidation during exercise, improved the usual index of insulin resistance and plasma triglycerides, and increased HDL-C. The combined diet plus training resulted in further improvements in body composition, insulin resistance and serum lipid profile, and also offered further benefits to HDL-C, LDL-C/HDL-C ratio and measures of LIPOX$_{\text{max}}$.

Obesity is a major independent risk factor for cardiovascular disease [1]. In humans, a higher risk of atherosclerosis has been found with high concentrations of TC and LDL-C, and low concentrations of HDL-C [25]. Moreover, low HDL-C levels are often a reflection of insulin resistance [26].

In addition, it has been suggested that ratios of TC/HDL and LDL/HDL are better predictors of cardiovascular disease (CVD) risk reduction than HDL, LDL or TC values on their own [27]. Evidence to support this idea comes from the reduced cardiovascular disease risk in subjects after following the R+E programme. In the present study, TC and LDL-C, along with the ratios of TC/HDL-C and LDL-C/HDL-C, were significantly reduced after a programme of diet combined with physical training.

Although exercise alone did not change TC or LDL-C, it had a positive influence on HDL-C and the TC/HDL-C ratio. Dietary restriction has led to either a decrease or no change in HDL-C [10]. In the present study, exercise significantly increased HDL-C ($P < 0.05$ and $P < 0.01$ with E and R+E, respectively), whereas the diet group experienced a decline in HDL-C ($P = 0.8$).

These findings are in agreement with a previous study showing that eight weeks of endurance exercise three times a week increased HDL-C by approximately 10% [28]. Thus, adding exercise training at LIPOX$_{\text{max}}$ to a restricted diet appears to be an important factor in improving blood-lipid profiles in obese adolescents.

As for insulin sensitivity, we observed a small reduction in fasting glucose accompanied by a much larger decrease in insulin after the diet plus exercise intervention. Nevertheless, HOMA-IR decreased significantly ($P < 0.01$) with R+E, suggesting a decrease in insulin resistance.

In this study, insulin resistance status was assessed by the HOMA-IR index. However, in children, the validity of this surrogate has been challenged. Indeed, Brandou et al. have reported a poor correlation between insulin sensitivity and HOMA-IR index in children aged six to 18 years, suggesting a limited accuracy of this surrogate as a predictor of insulin sensitivity in this population [29].

Previous studies in overweight children after regular exercise programmes have reported improvements in fasting insulin [7], whereas diet plus aerobic exercise (three days per week) improved HOMA-IR in overweight subjects [30]. Exercise is known to increase insulin-receptor autophosphorylation, GLUT4 expression and glucose transport [31]. In addition, a third major cause of insulin resistance is a sedentary lifestyle. An immediate effect of exercise is an increase in glucose transporters in muscle, which secondarily improves insulin-mediated glucose disposal [32].

In the present study, changes in body composition did not correlate significantly with metabolic changes after a two-month dietary programme. However, the reduced risk of cardiovascular disease was associated with an increase in fat oxidation in the E and R+E subjects.

Our study further demonstrates that low-intensity (at LIPOX$_{\text{max}}$) training should be routinely recommended for obese adolescents. Indeed, it is useful to propose to such a population several options of exercise of variable intensity, according to their level of sedentarity, to optimize lipid utilization during exercise [33].

5. Conclusion

The main findings of this study are that two months of individualized exercise training at LIPOX$_{\text{max}}$ combined with a restricted diet can result in improvements in plasma lipoproteins, lipid profile and insulin resistance. In addition, such an intervention can reduce fat mass, waist circumference and improve ‘fat-burning’ during submaximum exercise. For this reason, this intervention may be the optimal approach for the prevention and management of adolescent obesity and the cardiovascular risk factors present in this population.

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