The effect of eight-week walking program on plasma levels of amino acids in early/mid pubertal obese girls

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Abstract

Background: Altered circulating amino acids levels have been observed in metabolic disorders, like obesity, type-2 diabetes, and other insulin-resistant states. This study aimed to investigate the effect of 8-week walking on plasma amino acids (PAAs) in obese girls.

Methods: This clinical trial study (IRCT20180928041160N1) was conducted on 32 early/mid pubertal obese girls which they divided into interval-walking (IWG, n=12), continuous-walking (CWG, n=11) and control (CG, n=9) groups. The walking program (3-sessions/week for 8-weeks) consists of 30-min walking with 70-85%HRmax and 60-75%HRmax, respectively in the IWG (2-min walking and 1-min active rest) and CWG. The concentration of PAAs was measured at baseline and 72-hours after the last session in fasting state, using high-performance liquid chromatography. A repeated measures ANCOVA (group (3) * time (2)) with post hoc Bonferroni was used to analyze the data.

Results: More the PAAs were not affected by interval or continuous walking training. A significant increase in lysine (p=0.003, 95%CI 24.08, 108.97) was observed only in the CG, and there was a significant difference between the CG and CWG (p=0.032). Global arginine bioavailability (GABA) significantly decreased in the CG (P<0.001, 95%CI -0.65, -0.21) and the IWG (p=0.004, 95%CI -0.60, -0.21). A significant increase in weight (p=0.043, 95%CI 0.27, 1.46), insulin (p=0.046, 95%CI -0.91, 9.01), and HOMA-IR (p=0.007, 95%CI 0.26, 2.63) were found only in the CG, and both insulin and HOMA-IR tended to decline in the CWG.

Conclusion: Except for lysine and GABA, all groups roughly showed similar changes in more amino acids. Continuous-walking could improve the plasma level of lysine and GABA, which along with an improvement of fasting insulin levels and HOMA-IR.

Keywords: Obesity, Child, Puberty, Walking, Amino acids

Conflicts of Interest: None declared
Funding: University of Mazandaran

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Introduction

Today, childhood obesity has become a global public health crisis, and many developed and developing countries are struggling with this problem. Early-onset obesity in childhood is associated with an increased risk of obesity and increased obesity-related disorders such as insulin resistance (IR) and type-2 diabetes (T2D) in adulthood (1). In normal-weight children, a transient decrease in insulin sensitivity happens during puberty because of high circulating levels of growth hormone (2). Nevertheless, obese children are more prone to insulin resistance than normal-
weight children, and several studies demonstrated that in- 
sulin sensitivity (IS) does not recover in obese children at 
the end of puberty (2-4), which may have a negative effect 
on the function of beta cells (4).

Recently, metabolomics has provided insights into the 
mechanisms underlying the development of insulin re- 
sistance (5). Measurement of small-molecule metabolites, 
such as amino acids, leads to the identification of mech- 
anisms and biomarkers of many diseases. Recently, the role 
of plasma free amino acids (PAAs) in insulin resistance 
pathophysiology has been considered. Several studies 
demonstrated that PAAs profiles change in unfavorable 
conditions such as visceral fat accumulation and insulin re-
sistance (6-8). Wang and his colleagues showed that 12 
years before the onset of diabetes, fasting plasma levels of 
three branched-chain amino acids (BCAAs; valine, leucine, 
and isoleucine) and two aromatic amino acids (AAAs; ty- 
orine and phenylalanine) were elevated (9). In fact, in-
creasing levels of these amino acids occur before any 
changes in insulin action, suggesting these metabolites as 
biomarkers to predict the future development of diabetes, is 
superior to fasting levels of glucose and body mass index 
(BMI) (9). BCAAs and AAAs (tyrosine, tryptophan, and 
phenylalanine) levels are elevated in obese subjects and as-
associated with the risk of IR, and T2D (7, 10, 11). BCAAs 
dysmetabolism could lead to accumulation of toxic metab-
olites that can result in mitochondrial dysfunction in pan-
creatic islet beta cells, which are associated with IR and 
T2D (12). Increased BCAAs can activate the signaling 
pathway of mTORC1, S6 kinase, and phosphorylation of 
the subtype of insulin receptor-1, leading to IR and T2D 
(10). In addition to BCAAs and AAAs, other amino acids 
such as glutamate, serine, glycine, alanine, histidine, lysine, 
ornithine (7), methionine, proline, and glutamine (7, 13) 
also change in subjects with high visceral adiposity. The 
changes in the PAAs may be due to a combination of en-
hanced protein degradation due to IR in the muscle and 
changes in the regulatory point of liver gluconeogenesis 
(14).

To prevent lifestyle-related diseases such as obesity, 
T2D, and other insulin-resistant modes, early diagnosis, 
and effective intervention is very important. Physical activ-
ity and exercise are at the forefront of both preventive 
and therapeutic strategy for obesity, which is a low-cost and 
non-pharmacologic intervention (15). Aerobic training (for 30-
minutes or more, 3-times per week or more, for 8-weeks or 
more) improves IS and other glycemic control markers, and 
regular aerobic exercise can be useful for improving IR in 
overweight and obese children without weight loss or cal-
oric restriction (16, 17). There is little known about the ef-
ectiveness of exercise interventions without diet restriction 
on PAAs profile, especially in the early/mid-puberty. A number of studies have shown that weight loss due to sur-
gery (18) or diet and exercise interventions (14, 19) can im-
prove the PAAs. In overweight and insulin-resistant adults, 
six months of combined exercise (aerobic and resistance) 
resulted in effective elimination of acyl groups derived 
from AAAs and BCAAs through the formation of glycine 
conjugates in the liver without significantly changing in cir-
culating levels of AAAs and BCAAs (20).

We assumed that an 8-week aerobic training period 
would improve the anthropometric and glycemic param-
ters, and these changes would be associated with the im-
provement of PAAs. Forasmuch as T2D often appears in 
the mid-stages of puberty and affects girls more than boys 
(21) and walking, a type of aerobic exercises can help to 
 improve abdominal obesity and IR markers in obese fe-
males and be considered as an effective and safe lifestyle 
strategy (22). Therefore, we conducted this study to inves-
tigate the effect of the eight-week interval and continuous-
walking on in early/mid pubertal obese girls.

Methods

Subjects

Thirty-two obese girls aged 9-11 years-old took part in 
the present research. Based on the recommendations of 
the International Obesity Task Force (IOTF) obesity was 
defined in the participants. All the girls had not experienced 
menarche and were checked to be within Tanner's stages of 
2-3. Breast budding and pubic hair growth in the girls were 
done using the visual inspection method of Marshall and 
Tanner (23). The health of these girls was checked by an 
experienced physician, and none of them had a history of 
cardiovascular disease, asthma, diabetes, etc., and they did 
not have any kind of injuries or physical problems. After a 
complete description of how the research was carried out, 
written consent was received from their parents. In this 
study, the inclusion criteria were as follows: age range be-
 tween 9-11 years old; BMI ≥22.81, BMI ≥24.11, BMI 
≥25.42 for ages 9, 10 and 11 year old respectively; Tanner's 
stages of 2-3; absence of diabetes mellitus; no history of 
neuromuscular, orthopedic, cardiovascular and respiratory 
diseases; not under any anti-fat, weight loss, and cortico-
steroid drugs; lack of regular physical activity during the 
previous 6 months. Exclusion criteria were participants’ 
unwillingness to continue the study; the incidence of dis-
eases during the study and drug use; orthopedic problems 
that prevented participation in a walking program and ir-
regular participation in training sessions, also, absence in 
exercises (consecutive or intermittent) for more than 3 ses-
sions in the training groups; participation in exercise ses-
sions more than twice a week in the control group.

To calculate the sample size, data from previous studies 
in overweight/obese youth were used. According to these 
studies, maximal effect size resulting from lifestyle inter-
ventions for the HOMA-IR was 2.4, and standard deviation 
range for the HOMA-IR was 1.8 to 2.5 (24, 25).

Thus, the sample size was calculated based on HOMA-
IR by considering an alpha of 0.05, a power of 80%, a 
standard deviation of 1.8, and an effect size of 2.4 using 
the formula "n = (Zα + Z [1-β])^2 × SD^2/d^2" (n = 9). We enrolled 
12 subjects per the groups to compensate for potential 
dropouts. After giving random numbers to the subjects, 
they were randomly divided into three groups (interval-
walking (IWG), continuous-walking (CWG) and control 
(CG) groups) using Random Allocation Software. At base-
line, 12 subjects were divided into each group, but some of 
them were excluded from this study, and eventually 12, 11 
and 9 subjects remained in the IWG, CWG and CG groups,
respectively (Fig. 1). This randomized clinical trial was approved by the ethics committee of the University of Mazandaran (IR.UMZ.REC.1397.015) and was registered in the Iranian Registry of Clinical Trials (IRCT 20180928041160N1).

The exercise protocol
Both continuous and interval-walking training was performed for eight weeks and three sessions per week. Each training session included 10-minutes of the warm-up (slow running and stretching), walking (15-25 minutes walking in sessions of 1-6 and 30 minutes walking in sessions of 7-24) and 5-minutes of cool-down (stretching). In the CWG, the subjects walked in the first four weeks with 60-75% maximum heart rate (HRmax) and with 70-75% HRmax in the other four weeks. In the IWG, the subjects walked the for first four weeks with 75-80% HRmax and with 80-85% HRmax in the other four weeks. The interval-walking included a 2-minute walking (the first four weeks with 75-80% HRmax and with 80-85% HRmax in the other four weeks) and the 1-minute active rest (walking with 50-60% HRmax). To calculate the maximum heart rate of the subjects, the Tanaka et al. (26) formula "208 – (0.7×age)" was used. The heart rate was controlled by a polar (AXN500, Finland). The CG subjects were not included in any training program.

Outcome measurement
Glycemic parameters: Blood sampling was done at 8 o'clock in two phases, before exercise and 72 hours after the last exercise session on the night fasting state. The 5 cc of blood samples were taken from the brachial vein in the sitting position and then centrifuged at 3000 rpm for 10 minutes. Aliquots of plasma were stored at −80 °C until required. Insulin levels were determined by an electrochemical luminescence immunosassay (Cobas e 411, Hitachi, Tokyo, Japan). The quantitative estimation of fasting plasma glucose was done by the glucose oxidase method using enzymatic kit GOD-POD, glucose oxidase-peroxidase (Bionik Company, Tehran, Iran). IR was evaluated using the homeostatic model assessment (HOMA). HOMA-IR was calculated according to the formula: fasting insulin (μIU/mL) × fasting glucose (mg/dL)/405 (27).

Plasma amino acids profile: The plasma concentrations of amino acids were measured using high-performance liquid chromatography (HPLC) (28-30). Briefly, 25 μL of plasma was mixed for a few seconds with 250 μL of internal standard (norvaline with the concentration of 50 μM/L). Then, 350 μL of methanol was added to it and vortexed for 30 seconds. The mixture centrifuged for 6 minutes at 10,000 rpm. 200 μl of the supernatant was added to 200 μl of the derivative solution (ortho-phthalaldehyde/2-mercaptoethanol) and vortexed for 30 seconds. The mixed solution was maintained for 30 minutes. Then, 10 μl of it was injected into the HPLC system. HPLC system (Agilent 1200 infinity) was equipped with a fluorescence detector (excitation wavelength of 340 nm with detection at 450 nm); column, Inertsil (5 μm, 25 x 4.6 mm); column temperature, 37 °C; run length, 45 min. Mobile phase A was 0.1 M Sodium acetate, adjusted to pH 6.96 with glacial acetic acid, tetrahydrofuran, and methanol (65/5/30 v/v/v) while mobile phase B was methanol.

Anthropometric parameters: Height and weight of the participants were measured with light clothing and without shoes using a stadiometer and a calibrated scale (recorded to the nearest 0.001 meters and 0.1 kilograms). BMI was calculated by divided weight (in kilogram) by height.
Effect of walking on plasma amino acids

Using a repeated measures ANCOVA (group (3) * time (2)) revealed significant group by time effect for weight (F=4.126, p=0.027, η2=0.228), BFP (F=8.199, p=0.002, η2=0.369), WHR (F=8.310, p=0.001, η2=0.372), insulin (F=3.654, p=0.039, η2=0.207), and HOMA-IR (F=5.028, p=0.014, η2=0.264). The simple effects test revealed a significant increase of weight (p=0.043, Cohen’s d=−0.17), insulin (p=0.046, Cohen’s d=−0.67), and HOMA-IR (p=0.007, Cohen’s d=−1.36) only in the CG and observed a significant decrease of BFP (p<0.001, Cohen’s d=−0.99; p=0.006, Cohen’s d=0.25), WHR (p<0.001, Cohen’s d=1.89; p<0.001, Cohen’s d=0.50) in IWG and CWG respectively, without significant differences between the groups in the pre- and post-test (Fig. 2). The interaction effects of height and BMI were not significant (p>0.05).

The changes of PAAs after 2-month walking interventions are shown in Table 2. The pattern of changes in more PAAs was roughly similar in the three groups. No significant group by time effect was observed for more PAAs except lysine (F=3.588, p=0.041, η2=0.204) and the global arginine bioavailability (GABA) (arginine/citrulline + ornithine) (F=3.323, p=0.050, η2=0.186). The simple effects test revealed a significant increase of lysine (p=0.003, Cohen’s d=−1.12) only in the CG and a significant decrease of GABA in the CG (p=0.001, Cohen’s d=−3.89) and the IWG (p=0.004, Cohen’s d=2.48) (Fig. 3). Pairwise comparisons by Bonferroni for lysine at pre- and post-test revealed a significant difference between the CG and CWG (p=0.032) at post-test. Time and group main effects were not observed for any of the PAAs (p>0.05).

After adjusting for the change in WHR and BFP, the time and group main effects on lysine concentration lost statistical significance (p=0.114, p=0.107 receptively), but it remained statistically significant after adjusting for the change in body weight, Insulin, and HOMA-IR (p=0.041, p=0.027, p=0.011 receptively). Also, after adjusting for the change in body weight, WHR, BFP, Insulin, and HOMA-IR, the time and group main effects on GABA and arginine remained statistically significant (p=0.027, p=0.011 receptively). The effect size was interpreted as follows: small effect (η2: 0.01–0.058, Cohen's d: 0.2-0.49), medium effect (η 2: 0.06–0.14, Cohen's d: 0.5-0.79), and large effect (η2=0.138, Cohen’s d=0.8) (32). The correlation between variables was evaluated using the Pearson correlation coefficient. Statistical analysis was performed with SPSS software (version 25). The level of statistical significance was set at p<0.05. All data are reported as the mean and standard deviation.

Results

The changes in anthropometric and metabolic variables after 2-month walking interventions are shown in Table 1.

Table 1. Anthropometric and metabolic variables at baseline and post walking interventions in early/mid pubertal obese girls

<table>
<thead>
<tr>
<th>Control (n=9)</th>
<th>Change, 95% CI</th>
<th>Interval-walking (n=12)</th>
<th>Change, 95% CI</th>
<th>continuous-walking (n=11)</th>
<th>Change, 95% CI</th>
<th>Interacti on Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
<td>Pre</td>
<td>Post</td>
</tr>
<tr>
<td>Age (year)</td>
<td>9.66±0.56</td>
<td>9.86±0.95</td>
<td>9.66±0.56</td>
<td>9.86±0.95</td>
<td>9.33±0.57</td>
<td>9.53±0.77</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>46.9±4.98</td>
<td>47.8±5.13</td>
<td>53.5±10.4</td>
<td>53.0±10.1</td>
<td>47.7±9.8</td>
<td>48.0±9.92</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>139.5±5.9</td>
<td>140.6±5.1</td>
<td>142.7±8.6</td>
<td>144.6±8.8</td>
<td>137.6±7.1</td>
<td>139.4±7.5</td>
</tr>
<tr>
<td>BMI (kg/m2)</td>
<td>24.0±3.7</td>
<td>24.0±3.8</td>
<td>25.8±2.1</td>
<td>25.0±2.2</td>
<td>26.9±6.3</td>
<td>26.4±6.44</td>
</tr>
<tr>
<td>BFP (%)</td>
<td>31.5±1.8</td>
<td>32.1±1.8</td>
<td>31.6±1.9</td>
<td>29.7±1.8</td>
<td>31.8±4.2</td>
<td>30.3±4.45</td>
</tr>
<tr>
<td>WHtR</td>
<td>0.52±0.02</td>
<td>0.51±0.02</td>
<td>0.53±0.02</td>
<td>0.50±0.01</td>
<td>0.51±0.00</td>
<td>0.52±0.05</td>
</tr>
<tr>
<td>Glucose (mg/dL)</td>
<td>90.5±3.3</td>
<td>95.8±7.57</td>
<td>81.8±6.15</td>
<td>90.2±8.59</td>
<td>80.7±7.5</td>
<td>83.9±8.74</td>
</tr>
<tr>
<td>Insulin (µU/mL)</td>
<td>14.1±4.7</td>
<td>18.6±6.88</td>
<td>17.4±8.50</td>
<td>19.1±6.65</td>
<td>18.4±6.5</td>
<td>14.9±5.08</td>
</tr>
<tr>
<td>HOMA-IR</td>
<td>3.15±1.0</td>
<td>4.6±1.05</td>
<td>3.5±1.81</td>
<td>4.3±1.18</td>
<td>3.7±1.57</td>
<td>3.07±1.10</td>
</tr>
</tbody>
</table>

Abbreviations: BMI, body mass index; BFP, body fat percentage; WHR, waist to height ratio; HOMA-IR, homeostatic model assessment for insulin-resistance. Data were statistically evaluated by repeated measures ANCOVA (covariate baseline level of glucose) post hoc Bonferroni.
IR, the time and group main effects on GABA attenuated or remained statistically significant (p=0.053, p=0.092, p=0.044, p=0.047, p=0.033 receptively).

The results of Pearson’s correlation coefficients showed that, at baseline, none of the PAAs were significantly correlated with weight and BMI (p>0.05). The levels of tryptophan, methionine, and GABA were negatively correlated with weight and BMI (r=-0.417, p=0.018; r=-0.447, p=0.010; r=-0.450, p=0.010; r=-0.476, p=0.006; r=-0.486, p=0.005; r=-0.450, p=0.010; r=-0.350, p=0.049; receptively). In addition, the levels of isoleucine, leucine, valine, sum of BCAAs, methionine, tryptophan, and sum of isoleucine, phenylalanine, and tyrosine significantly correlated with WHtR (r=-0.460, p=0.010; r=-0.468, p=0.005; r=-0.450, p=0.010; r=-0.350, p=0.049; receptively). The levels of asparagine, serine, glutamine, glycine, p=0.046; receptively).

### Table 2. Plasma free amino acid profiles at baseline and post walking interventions in early/mid pubertal obese girls

<table>
<thead>
<tr>
<th>Amino Acid</th>
<th>Control (n=9)</th>
<th>Change, 95% CI</th>
<th>Interval-walking (n=12)</th>
<th>Change, 95% CI</th>
<th>Continuous-walking (n=11)</th>
<th>Change, 95% CI</th>
<th>Interaction Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valine</td>
<td>249.77±7</td>
<td>14.19</td>
<td>-22.66±5</td>
<td>295.81±8</td>
<td>33.13</td>
<td>-45.65±2</td>
<td>-14.46, 88.76</td>
</tr>
<tr>
<td>Isoleucine</td>
<td>40.44±14</td>
<td>7.31</td>
<td>44.16±10</td>
<td>54.41±18</td>
<td>10.25</td>
<td>40.64±4</td>
<td>7.15</td>
</tr>
<tr>
<td>Leucine</td>
<td>133.33±3</td>
<td>9.75</td>
<td>141.66±2</td>
<td>154.78±4</td>
<td>13.12</td>
<td>126.45±4</td>
<td>7.02</td>
</tr>
<tr>
<td>BCAAs</td>
<td>243.56±11</td>
<td>31.25</td>
<td>448.50±9</td>
<td>505.02±21</td>
<td>56.52</td>
<td>397.45±4</td>
<td>61.92</td>
</tr>
<tr>
<td>Phenylalanine</td>
<td>58.11±19</td>
<td>8.50</td>
<td>60.25±12</td>
<td>64.88±15</td>
<td>4.63</td>
<td>56.36±5</td>
<td>-26.68, 149.32</td>
</tr>
<tr>
<td>Tyrosine</td>
<td>74.88±21</td>
<td>12.00</td>
<td>81.16±10</td>
<td>89.81±23</td>
<td>8.65</td>
<td>71.09±2</td>
<td>-3.74, 22.07</td>
</tr>
<tr>
<td>IPT</td>
<td>173.44±5</td>
<td>15±4</td>
<td>185.58±2</td>
<td>209.11±4</td>
<td>23.53</td>
<td>168.09±4</td>
<td>17.90</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>58.88±19</td>
<td>2.64</td>
<td>56.16±10</td>
<td>65.13±17</td>
<td>8.97</td>
<td>56.91±5</td>
<td>-3.42</td>
</tr>
<tr>
<td>Methionine</td>
<td>31.77±10</td>
<td>-0.38</td>
<td>30.75±6</td>
<td>33.06±9</td>
<td>2.25</td>
<td>28.27±2</td>
<td>-4.91</td>
</tr>
<tr>
<td>Alanine</td>
<td>496.55±1</td>
<td>7.94±7</td>
<td>469.58±1</td>
<td>444.87±8</td>
<td>-24.71</td>
<td>40.57±5</td>
<td>-16.25, 9.40</td>
</tr>
<tr>
<td>Glutamic acid</td>
<td>219.22±29</td>
<td>0.84</td>
<td>236.25±1</td>
<td>265.67±9</td>
<td>20.43</td>
<td>269.36±4</td>
<td>45.61</td>
</tr>
<tr>
<td>Glutamine</td>
<td>421.33±1</td>
<td>-11.54±16.82</td>
<td>56.6±1</td>
<td>0.51</td>
<td>-3.13, 21.25</td>
<td>6.86±8</td>
<td>0.773</td>
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<tr>
<td>Histidine</td>
<td>38.8±11</td>
<td>-186.84±16.14</td>
<td>11.6±0.9</td>
<td>1.95</td>
<td>-24.2, 8.80</td>
<td>5.38±0</td>
<td>-7.74, 5.93</td>
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<tr>
<td>Aspartic acid</td>
<td>20.3±10</td>
<td>-84.04±8.92</td>
<td>34.32±2</td>
<td>9.41</td>
<td>-39.59, 52.73</td>
<td>45.94±0</td>
<td>0.36</td>
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<tr>
<td>Serine</td>
<td>211.77±5</td>
<td>-0.39</td>
<td>216.66±5</td>
<td>118.78±4</td>
<td>-97.89</td>
<td>204.27±5</td>
<td>9.41, 6.66</td>
</tr>
</tbody>
</table>

Fig. 2. Estimated marginal means (± standard error) of weight (A), BFP (B), WHrR (C), Insulin (D), and HOMA-IR (E) at pre- and post test. * = P<0.05: versus pre-test; † = P<0.01: versus pre-test, ‡ = P<0.001: versus pre-test. Abbreviations: BFP, body fat percentage; WHrR, waist to height ratio; HOMA-IR, homeostatic model assessment for insulin-resistance.
**Effect of walking on plasma amino acids**

### Table 2

<table>
<thead>
<tr>
<th>µmol/L</th>
<th>Control (n=9)</th>
<th>Change, 95% CI</th>
<th>Interval-walking (n=12)</th>
<th>Change, 95% CI</th>
<th>continuous-walking (n=11)</th>
<th>Change, 95% CI</th>
<th>Interaction Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre</td>
<td>Post</td>
<td></td>
<td>Pre</td>
<td>Post</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Glycine</td>
<td>310.44±41</td>
<td>215.61±67</td>
<td>-94.83</td>
<td>293.83±39</td>
<td>230.39±5</td>
<td>-63.44</td>
<td>-79.13</td>
</tr>
<tr>
<td></td>
<td>0.75</td>
<td>0.46</td>
<td>(0-161.46, 28.19)</td>
<td>5.59</td>
<td>8.22</td>
<td>(-121.15, -5.74)</td>
<td>9.49</td>
</tr>
<tr>
<td>Asparagine</td>
<td>40.44±11</td>
<td>42.85±14</td>
<td>2.41</td>
<td>40.41±10</td>
<td>40.99±12</td>
<td>0.58</td>
<td>33.91±11</td>
</tr>
<tr>
<td></td>
<td>0.89</td>
<td>0.52</td>
<td>(-7.80, 12.62)</td>
<td>0.42</td>
<td>0.58</td>
<td>(-8.26, 9.43)</td>
<td>10.18±11</td>
</tr>
<tr>
<td>Lysine</td>
<td>165.11±4</td>
<td>229.63±72</td>
<td>66.53</td>
<td>147.75±1</td>
<td>167.09±5</td>
<td>19.35</td>
<td>162.91±11</td>
</tr>
<tr>
<td></td>
<td>2.84</td>
<td>2.22</td>
<td>(24.08, 108.97)</td>
<td>7.74</td>
<td>3.61</td>
<td>(-17.41, 56.11)</td>
<td>136.73±3</td>
</tr>
<tr>
<td>Threonine</td>
<td>137.88±3</td>
<td>131.01±20</td>
<td>-6.87</td>
<td>177.58±3</td>
<td>158.96±4</td>
<td>-18.62</td>
<td>159.45±12</td>
</tr>
<tr>
<td></td>
<td>4.90</td>
<td>3.33</td>
<td>(-46.59, 32.85)</td>
<td>7.87</td>
<td>3.88</td>
<td>(-50.01, 15.78)</td>
<td>45.65±5</td>
</tr>
<tr>
<td>Arginine</td>
<td>81.77±38</td>
<td>40.66±14</td>
<td>-41.09</td>
<td>79.41±21</td>
<td>55.59±22</td>
<td>-23.82</td>
<td>66.09±17</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>78</td>
<td>(-62.87, -19.31)</td>
<td>66</td>
<td>70</td>
<td>(-42.69, -4.96)</td>
<td>28.14±3</td>
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<tr>
<td>Citrulline</td>
<td>41.00±16</td>
<td>34.48±6.5</td>
<td>-6.51</td>
<td>46.66±13</td>
<td>47.52±24</td>
<td>0.86</td>
<td>38.64±20</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>17</td>
<td>(-8.35, 21.37)</td>
<td>36</td>
<td>02</td>
<td>(-6.41, 19.72)</td>
<td>11.54±6</td>
</tr>
<tr>
<td>Ornithine</td>
<td>66.33±28</td>
<td>86.65±15</td>
<td>20.32</td>
<td>61.67±25</td>
<td>78.37±17</td>
<td>-16.70</td>
<td>52.09±11</td>
</tr>
<tr>
<td></td>
<td>73</td>
<td>27</td>
<td>(-5.54, 46.19)</td>
<td>96</td>
<td>55</td>
<td>(-5.70, 39.11)</td>
<td>36.15±9</td>
</tr>
<tr>
<td>GABA</td>
<td>0.77±0.12</td>
<td>0.34±0.10</td>
<td>-0.43</td>
<td>0.86±0.1</td>
<td>0.45±0.2</td>
<td>-0.41</td>
<td>0.56±0.1</td>
</tr>
</tbody>
</table>

**Abbreviations:** BCAAs, sum of branched-chain amino acids; GABA, global arginine bioavailability; IPT, sum of isoleucine, phenylalanine, and tyrosine. Data were statistically evaluated by repeated measures ANCOVA (covariate baseline level of glucose) post hoc Bonferroni.

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citrulline, alanine, methionine, leucine, and isoleucine significantly correlated with insulin and HOMA-IR (for insulin, respectively, r=0.436, p=0.013; r=0.521, p=0.002; r=0.431, p=0.014; r=0.404, p=0.022; r=0.495, p=0.004; r=0.461, p=0.008; r=0.494, p=0.004; r=0.395, p=0.025; r=0.379, p=0.033; for HOMA-IR, respectively, r=0.412, p=0.019; r=0.506, p=0.003; r=0.341, p=0.027; r=0.352, p=0.048; r=0.449, p=0.010; r=0.443, p=0.011; r=0.474, p=0.006; r=0.386, p=0.029; r=0.372, p=0.036). Also, the sum of BCAAs was negatively correlated with HOMA-IR (r=-0.351, p=0.049). Only the plasma levels of lysine showed a significant correlation with glucose (r=0.510, P=0.003).

The changes in serum levels of serine, asparagine, and arginine were associated with the changes in insulin levels (r=0.388, p=0.028; r=0.373, p=0.035; r=0.415, p=0.018; respectively) and HOMA-IR (r=0.387, r=0.387, p=0.032; r=0.390, p=0.021; respectively). Also, the changes of lysine and histidine levels were associated with the changes in glucose levels (r=0.657, p=0.020; r=0.536, p=0.002) respectively. The changes in lysine levels significantly correlated with WHR changes (r=-0.356, p=0.046). The changes of other amino acids did not have any significant correlation with the changes in other variables (p>0.05).

**Discussion**

The purpose of this study was to evaluate the changes in the PAAs after two-month of walking interventions in early/mid pubertal obese girls. More the PAAs were not affected by interval or continuous walking training. We observed that lysine levels significantly increased in the CG and continuous-walking could prevent the increase of it. Also, GABA significantly decreased in the CG and IWG, however no significant changes were observed in the CWG.

The pattern of changes in more PAAs in the three groups was somewhat similar, indicating that the walking interventions did not alter the mean of more PAAs. In our study, however no significant changes were observed in the CWG. Moreover, GABA significantly decreased in the CG and IWG, and continuous-walking could prevent the increase of it. Also, the PAAs after two-month of walking interventions in early/mid pubertal obese girls. More the PAAs were not affected by interval or continuous walking training. We observed that lysine levels significantly increased in the CG and continuous-walking could prevent the increase of it. Also, GABA significantly decreased in the CG and IWG, however no significant changes were observed in the CWG.

The pattern of changes in more PAAs in the three groups was somewhat similar, indicating that the walking interventions did not alter the mean of more PAAs. In our study, there was no significant decrease in subjects' weight after eight weeks of walking interventions. However, those studies that reported significant changes in PAAs have been significant weight loss (14, 18-20). In line, Reimehr et al. (19) demonstrated that BMI-standard deviation score reduction > 0.5 in children can cause significant changes in levels of PAAs due to dietary and exercise habits. In addition, Tochikubo et al. showed that weight loss more than 3% in children can cause significant changes in levels of PAAs due to dietary and exercise habits. In addition, Tochikubo et al. showed that weight loss more than 3% in children can cause significant changes in levels of PAAs due to dietary and exercise habits. In addition, Tochikubo et al. showed that weight loss more than 3% in children can cause significant changes in levels of PAAs due to dietary and exercise habits.

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reduction in IR by ~27%. These researchers did not find any significant change in most of amino acids except for glycine and citrulline. Although the PAAs, especially the BCAAs, did not alter with walking interventions, we found that insulin and HOMA-IR levels increased significantly in the CG, while the walking groups did not show significant changes, especially in the CWG which tended to decline in both insulin and HOMA-IR. Lee et al. (33) demonstrated that the exercise intervention increased IS by 29%, lowered liver fat by 25% and increased BCAA catabolism in liver, skeletal muscle, and adipose tissue, whereas no significant change was observed in plasma level of BCAAs and changes did not correlate to changes in IS. They suggested that elevated plasma level of BCAAs may not play a direct role causing IR (33).

We observed that lysine levels in the CG were significantly increased, while the levels in the CWG tended to decrease. Lysine is an essential amino acid, but a significant contribution of microbial-derived lysine to the free plasma lysine and the body protein pools were observed in humans (34). In addition, gut microbiota composition of obese humans is significantly different from normal-weight individuals (35). In a study of children, it was shown that changes in the gut microbiota composition preceded weight changes (36). Interesting, exercise can induce modifications in the gut microbiota composition (37). One of the limitations of this study is the lack of control of the subjects’ diet and the evaluation of gut microbiota, and there is the ambiguity that the walking protocols in this study have affected the gut microbiota composition. Furthermore, neutrophils are also one of the secretive sources of arginine, ornithine, lysine, hydroxylysine, histidine (38). Galkina et al. (38) found that insulin significantly stimulated the amount of secreted hydroxylysine, a metabolite of lysine, in neutrophils. In addition, it has been reported that plasma concentrations of lysine positively associated with gestational diabetes mellitus through modifying IR and secretion (39). We also observed that increase of lysine in the CG and the reduction of lysine in the CWG was along with an increase and tended to decrease in insulin and HOMA-IR, respectively. However lysine changes only had a significant correlation with glucose and WHtR changes.

Moreover, we found that GABA (arginine/citrulline + ornithine) significantly increased in the CG, and the continuous-walking could somewhat prevent the further reduction of GABA. In patients with diabetes or cardiovascular disease, the reduction of GABA commonly observed (40, 41). Galkina et al. (38) demonstrated that neutrophils secrete more ornithine than arginine, and this can contribute to the alteration of the PAAs content in patients with metabolic disorders. It is clear that there is a connection between obesity and neutrophils. Blood levels of neutrophils increased in obese adults (42) and youth (43), which is related to waist circumference, WHtR, and BMI in obese youth (44). In addition, it has been shown that obesity inhibits plasma arginine concentration and GABA (45). Another limitation of this study was the lack of evaluation of neutrophils and arginase. Serum levels of arginase, a key enzyme in the urea cycle, were evaluated in various diseases such as T2D (46) that involved in indirect regulation of nitric oxide by the consumption of arginine, which is a common substrate for nitric oxide synthase. Consumption of arginine by arginase may lead to the reduction of nitric oxide, resulting in vascular damage (47). It has been demonstrated that arginine inhibition prevents the development of hypertension and improves IS in obese rats (48). In the present study, GABA reduction was along with increased levels of insulin and HOMA-IR, but no significant correlation was found between GABA and insulin or HOMA-IR changes. However the changes in arginine had a significant correlation with changes in both insulin and HOMA-IR.

For future studies, it is recommended that subjects’ diet monitored. In addition, the role of gut microbiota composition and neutrophil circulation levels in altering the plasma profile of amino acids should be considered and evaluated. These may help to understand the mechanisms involved in improving exercise-induced glucose homeostasis.

Conclusion

In summary, except for lysine and GABA, all three groups showed a roughly similar pattern in more amino acids in early/mid pubertal obese girls. Only the continuous-walking could improve the plasma level of lysine and GABA, which along with improvement of fasting insulin levels and HOMA-IR. There was a correlation between changes in serum lysine levels with changes in glucose and changes in arginine level with the changes in levels of insulin and HOMA-IR. Future studies should be done to understand the mechanisms related to exercise involved in the regulation of lysine levels and GABA.

Acknowledgments

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Conflict of Interests

The authors declare that they have no competing interests.

References

Effect of walking on plasma amino acids


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