The Effect of Curcumin Supplementation and Aerobic Training on Anthropometric Indices Serum Lipid Profiles, C-Reactive Protein and Insulin Resistance in Overweight Women: A Randomized, Double-Blind, Placebo-Controlled Trial

Sepideh Dolati¹, Khoosheh Namiranian², Reyhaneh Amerian³, Samane Mansouri⁴, Sajad Arshadi⁵, Mohammad Ali Azarbayjani²*¹

¹Department of Nutrition, Ministry of Health, Tehran; ²Department of Health Tehran University of Medical Sciences, Tehran; ³Department of Exercise Physiology, Faculty of Physical Education, Islamic Azad University of Tehran, Tehran; ⁴Nutrition Group, Abadan School of Medical Sciences, Abadan; ⁵Department of Exercise Physiology, Faculty of Physical Education and Sports Science, Islamic Azad University, Central Tehran Branch, Tehran, Iran

*Corresponding Author: Mohammad Ali Azarbayjani  https://orcid.org/0000-0002-3502-7487
Department of Exercise Physiology, Faculty of Physical Education and Sports Science, Islamic Azad University, Central Tehran Branch, Army Boulevard, Shahid Sohani St., Sohank Square, Tehran 1986755881, Iran
Tel: +98-9106759828, Fax: +98-81454357, E-mail: M_azarbayjani@iauctb.ac.ir

The first two authors contributed equally to this study.

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Background: This study aimed to investigate the effects of curcumin supplementation alone and in combination with aerobic training on body composition, glycemic variables, serum levels of C-reactive protein (CRP) and lipid profiles in overweight women.

Methods: In this randomized, double-blind, placebo-controlled trial, 40 healthy sedentary overweight females (aged 30–45 years with body mass [BMI] of 25–30 kg/m²) were sampled and randomly assigned to four groups of ten subjects each: curcumin supplementation (Cur), placebo (Pla), Cur+aerobic training (Tra), and Pla+Tra. Curcumin or placebo capsules (500 mg/day) were administered for 8 weeks.

Results: At the end of the intervention, the within-group analysis showed significant reductions in weight, BMI and fasting blood sugar in the Cur group and decreased waist circumference, waist-to-hip ratio, homeostatic model assessment for insulin resistance and serum insulin as well as low-density lipoprotein to high-density lipoprotein ratio (LDL/HDL) and total cholesterol to high-density lipoprotein ratio (TC/HDL) ratios and increased serum HDL cholesterol in the Cur+Tra group. Moreover, the between-groups analysis indicated increased HDL cholesterol in the Cur and Cur+Tra groups compared to the Pla group. The estimated marginal means of serum CRP were significantly higher in Pla+Tra group than in the Cur and Cur+Tra groups.

Conclusion: These findings suggest that the combination of curcumin supplementation with aerobic training more effectively improves glycemic and lipidemic statuses than curcumin supplementation or aerobic training alone.

Key words: Curcumin, Aerobic training, Overweight, C-reactive protein, Lipid profile, Insulin resistance
INTRODUCTION

Currently, overweight and obesity are problems around the world, especially for women.\(^1\,^2\) In developing countries, it seems that the prevalence of obesity among women is more than that among men.\(^3\) This condition has an important effect on health impairment, female reproduction\(^4\) and reduced quality of life.\(^5\) Overweight and obesity are associated with diseases such as cardiovascular disease, diabetes, various cancers, nervous system disorders and mortality.\(^6\,^7\) Studies have shown that overweight and obesity are associated with insulin resistance index. It seems these factors cause many complications, metabolic problems and some diseases.\(^3\,^8\,^9\,^10\)

Recent studies have focused on a variety of strategies such as physical activity, herbal therapy, dietary supplements, and pharmacological intervention for weight management as well as the effects on insulin resistance in overweight and obese patients.\(^8\,^11\) Various studies have indicated that physical activity is an important environmental factor associated with body weight regulation. Increasing physical activity has become an important aspect of nonpharmacological strategies to control obesity and blood glucose, as well as to prevent impaired lipid profile advancement and glucose intolerance progression.\(^12\) Furthermore, it has been reported that curcumin may have protective effects against obesity and the risk of chronic diseases such as cardiovascular diseases, diabetes, and several cancers.\(^13\,^14\)

Curcumin is a bioactive polyphenol found in turmeric rhizomes and is used in traditional Chinese medicine.\(^15\,^16\) There is evidence that in people with metabolic syndrome, curcumin can decrease body mass index (BMI), weight, waist circumference (WC) and leptin concentrations.\(^17\) In individuals with metabolic syndrome, the development of inflammatory mediators is the basis of biological disorders. Curcumin plays an inhibitory role in the development of inflammation in these patients. Curcumin decreased the release of cytokines and the permeability of the M1 family of macrophages and improved insulin sensitivity by activating SIRT1 in adipose tissue.\(^18\) Many studies have shown that curcumin has anti-inflammatory, anti-infectious, anti-oxidant, anti-arthritic, cardioprotective, anti-carcinogenic and anti-anxiety effects in obese individuals.\(^19\,^20\)
may help to improve conditions such as asthma, allergies, bronchial hyperactivity, sinusitis, anorexia, cough and hepatic disease and to inhibit cancer progression. The anti-inflammatory property of curcumin appears to be mediated through the inhibition of the induction of COX-2, LOX and iNOS and the production of cytokines such as tumor necrosis factor and C-reactive protein (CRP).

Most studies have explored the effects of training or curcumin supplementation separately on anthropometric indices, lipid profiles, CRP and insulin resistance. However, few studies have been done on the simultaneous effects of curcumin and physical activity on these factors. Therefore, we investigated the effects of curcumin supplement intake alone and in combination with aerobic training on body composition, glycemic variables, lipid profiles, and CRP in overweight women.

METHODS

Subjects

Forty healthy, sedentary (less than 30 minutes a day of moderate intensity physical activity for 3 days a week), overweight (24.9 <BMI <29.9 kg/m²) women aged 30–45 years were recruited from those referred to the comprehensive health center or health center located in the Yaftabad district of the Tehran University of Medical Sciences. In the random or accidental method used in this study, the choosing and investigation of subjects were completely random, such that each subject had the same chance of being chosen. In this method, a simple randomizing model like the drawing of lots was employed. In this case, the subjects were assigned to the control or intervention groups according to the lots results. The Phillips equation for sample volume estimation was used in this survey in order to approximate the volume of samples, in which the power of the experiment, the alpha of the equation, and the average alteration were 0.8, 0.05, and 5, respectively. According to the conducted estimation, the sample size was calculated to be 8.81. To be more conservative, among the overweight volunteer women, 10 people were chosen for the
experimental group.

Exclusion criteria for our study were allergy to curcumin, physical activity or aerobic exercises of any form and type in the past 6 months, pregnancy, underlying or infectious disease, following a special diet, intake of dietary supplements and herbal tea, smoking or other tobacco and hookah consumption, a history of high blood lipids without medication, cardiac failure, taking anti-inflammatory drugs, severe endocrine or metabolic disorders or hospitalization for any reason.

Study design
This study was designed as a double-blind, randomized, placebo-controlled clinical trial and performed between January 2018 and March 2018. A flowchart of the study protocol is shown in Fig. 1. The subjects (n=40) were randomly allocated using a list prepared with a random number generator into four groups of ten: curcumin supplementation (Cur), placebo (Pla), Cur+aerobic training (Tra), and Pla+Tra (Fig. 1). For 8 weeks, the Cur and Tra groups ingested two curcumin capsules per day (500 mg/day), and the Pla and Pla+Tra groups received a placebo every day.

The project was approved by the Ethical Committee at the Azad University, Tehran Branch, registered in the Iranian Registry of Clinical Trials (No. IR.SSRI.REC.1397.382), and written informed consent was obtained from all participants.

Supplementation
The turmeric powder was made by a reputable manufacturer, Golha Company, under supervision according to the standard processing procedure of pharmaceutical materials (Analysis Center of the Institute of Medicinal Plants). Then, 5,000 g of the powder was poured into 5,000 mL of alcohol at 80°C. The percolation method was used for the extraction by alcohol. After 24 hours, the contents were smoothed using a Buchner funnel and ordinary filter paper. The extraction efficiency was 10%. The powder was dispersed in a suitable solvent (80% ethanol) to prepare the drug form. Next, breadcrumbs were used as an expander and filler to achieve proper fluidity.
Based on previous clinical studies, an effective dose of 250 mg of the ethanolic extract is estimated to be 80%. Total curcuminoids have been estimated at 75% to 85% in previous studies. Therefore, 250-mg capsules (00 short stays; Iran Gelatin Company, Tehran, Iran) were prepared with a semiautomatic encapsulating machine. The curcumin extract concentration was analyzed by the high-performance liquid chromatography method (85% curcuminoids, including curcumin, demethoxycurcumin, and bisdemethoxycurcumin). Each capsule contained 250 mg of product. Subjects in the Cur and Cur+Tra groups were provided with two capsules of curcumin per day. Likewise, the Pla and Pla+Tra groups received two placebo capsules per day, which were similar in shape and color and made of an equivalent dose of starch. The study duration was 8 weeks, and all subjects were instructed not to alter their dietary habits during the intervention period.

Aerobic training

Subjects in the Cur+Tra and Pla+Tra groups underwent aerobic training (3 days per week for 8 weeks) in a gym. The aerobic capacity of each subject was examined by a 6-minute Rockport test. The maximum heart rate for each person was estimated as equal to $208 - 0.7 \times \text{age}$\textsuperscript{30}. In the training session, subjects were first warmed up for 6 minutes with stretching exercises and then ran continuously on the treadmill at a speed of 7 km/hr, at a heart rate of 50% to 80% of maximum, for twenty minutes. Their heart rate was monitored by a polarimeter (Polar, Finland; within a 5% error rate of a heartbeat) during running to maintain the specified intensity. This intensity was individualized. Every person had a certain intensity. The younger subjects ran with higher intensity and the older ones ran with lower intensity. In each of the next sessions, 90 seconds were added to the running time. The training intensity was controlled using a belt heart rate sensor (Polar beat). Subjects in the Cur and Pla groups were instructed not to change their level of physical activity.
Anthropometric measurements

Anthropometric indexes were measured by one observer. Bodyweight was measured by electronic digital scales, which were accurate to 0.1 kg with subjects in light clothing and no shoes. Height was measured in the standing position to the nearest 0.1 cm using a flexible stadiometer. BMI was calculated by dividing body weight (kg) by height squared (m). The waist and hip circumferences (HC; to the nearest 0.5 cm) were collected in the standing position according to standardized methodologies. The waist circumference was measured from the front at the narrowest point between the rib cage and iliac crest after full expiration, while the HC was measured from the side at the maximal extension of the buttocks using an ordinary measuring tape. Waist-to-hip ratio (WHR) was calculated based on the WC (cm) divided by HC (cm).

Laboratory tests

Ten milliliters of blood were obtained from the left vein in the sitting position from each patient in the early morning after overnight fasting. Then, samples were centrifuged and analyzed. Fasting blood sugar (FBS) was assessed using an enzymatic (glucose oxidase-peroxide) in vitro test (Autoanalyzer; Echo Plus Corp., Rome, Italy). Fasting serum insulin concentration was also assessed using ELISA kits (Diametra Corp., Milan, Italy) with a sensitivity of 2 IU/mL. The concentrations of serum triglyceride (TG), serum cholesterol, high-density lipoprotein (HDL), and low-density lipoprotein (LDL) were measured by enzymatic colorimetric techniques (Pars Test Iran kit, with a sensitivity of 1 mg/dL for TG, serum LDL and HDL, and 3 mg/dL for serum cholesterol). Also, the coefficients of variation for the measurements were 1.4% for TG and cholesterol and 1.5% for LDL and HDL. The serum CRP level was measured by enzyme immunometric assay using a commercial kit (Diagnostic Biochem Canada Co., Ontario, Canada). The insulin resistance index and quantitative insulin sensitivity check index (QUIKI) were calculated by the following formulas:

\[
\text{HOMA-IR} = \frac{\text{fasting insulin} \times \text{fasting blood glucose}}{22.5}
\]
and QUICKI = 1/(log [insulin, mIU/L] + log [glucose, mg/dL]).

Statistical analysis
The statistical analyses were performed using IBM SPSS version 19.0 (IBM Corp., Armonk, NY, USA). All data are presented as mean±standard deviation. The Kolmogorov-Smirnov test was used to check the normal distributions of continuous variables. Between-group comparisons were performed using the analysis of covariance followed by the least significant difference post-hoc test (Bonferroni test). Within-group comparisons were performed using paired sample t-tests. A P-value less than 0.05 was considered statistically significant.

RESULTS
All forty women in the study performed the intervention for 8 weeks. No one reported any adverse side effects of curcumin ingestion.

Baseline characteristics of the participants in different groups of the present study
The baseline characteristics of the participants are presented in Table 1. Regarding age, height, BMI, and HC, there were no significant differences in the baselines between groups (Table 1). The baseline waist circumference (WC) in the Cur+Tra group was significantly higher than those in the Cur and placebo groups (Table 1). Also, the baseline WHRs in the Cur+Tra and Pla+Tra groups were significantly higher than that of the placebo group (Table 1).

The effects of aerobic training, curcumin, and their interaction on anthropometric variables
As shown in Table 2, no significant differences were observed between groups regarding weight and BMI. However, weight and BMI were significantly reduced (1.4%) in the Cur group versus the baseline measurements. Regarding WC, no significant difference was observed between groups. The post-test WCs in the placebo, Pla+Tra, and Cur+Tra groups were reduced significantly compared to the baselines by 2.22%, 6.8%, and 6.95%, respectively. HC was not
significantly changed between or within groups. Regarding WHR, no significant difference was observed between groups. A significant reduction of WHR was observed in the post-test Pla+Tra and Cur+Tra groups compared to their pre-test values (Table 2).

The effects of aerobic training, curcumin, and their interaction on glycemic variables

Glycemic variables are presented in Table 3. Regarding insulin, no significant difference was observed between groups. However, insulin was significantly reduced compared to the baseline in the Cur+Tra group. Regarding FBS, no significant difference was observed between groups. However, FBS decreased significantly by 7.5% in the Cur group compared to the baseline. Homoeostatic model assessment for insulin resistance (HOMA-IR) showed no significant changes between or within groups. However, a trend to decrease was observed in the Pla+Tra group compared to the baseline and was near statistical significance ($P=0.053$). Regarding QUIKI, no significant difference was observed between groups. Serum QUIKI increased significantly in the Cur+Tra group compared to the baseline (Table 3).

The effects of aerobic training, curcumin, and their interaction on serum lipids and lipoproteins

Regarding the serum levels of TG and TC, no significant changes were observed between or within groups (Table 4). However, there were significant differences between groups and changes within groups regarding serum HDL level. Serum HDL levels were significantly higher in the Cur, Pla+Tra, and Cur+Tra groups compared to that of the placebo group. The serum HDL level was significantly lower in the post-test than the pre-test in the Pla group. In contrast, the serum HDL level was significantly higher in post-tests than pre-tests in the Pla+Tra and Cur+Tra groups (Table 4).

Regarding serum LDL level, there were significant changes between groups (Table 4). Serum LDL levels were significantly lower in the Cur and placebo groups compared to the Cur+Tra
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group. In addition, the post-test LDL was significantly lower in the Pla+Tra group compared to the baseline. Also, post-test LDL was on trend to decrease in the Cur+Tra group compared to the baseline \((P=0.058)\).

TC/HDL and LDL/HDL showed the same pattern of differences (Table 4). There were significant differences between groups; the Pla+Tra and Cur+Tra groups showed lower TC/HDL and LDL/HDL ratios compared to the placebo group. TC/HDL and LDL/HDL were lower in the Pla+Tra and Cur+Tra groups compared to the Cur group. Post-test TC/HDL and LDL/HDL in the Cur+Tra and Pla+Tra groups were significantly lower than their baselines (Table 4). As shown in Fig. 2, the results of covariance analysis after adjustment for baseline values showed that the estimated marginal means of serum CRP were significantly higher in the Pla+Tra group than in the Cur and Cur+Tra groups. No within-group change was found for CRP compared to baseline values.

**DISCUSSION**

This study was conducted to investigate the effects of curcumin supplementation alone and in combination with aerobic training on body composition, CRP, glycemic variables, and lipid profiles in overweight women. The results of the present study indicated that 500 mg per day of curcumin for 8 weeks significantly decreased weight, BMI, and FBS in overweight women. Curcumin intake with aerobic training significantly decreased serum insulin, TC/HDL, and LDL/HDL ratios, WC and WHR, and increased QUIKI and HDL indices. Aerobic training, with curcumin or placebo, had a positive effect on WC and WHR. Curcumin supplementation alone did not have any effect on WC, HC, WHR, serum insulin, HOMA-IR, or QUICKI, but this study showed that curcumin supplementation had an effect on HDL compared with the placebo group and on LDL compared with the Cur+Tra group. It seems that the only effective factor in reducing WC, WHR, serum insulin, and QUICKI was aerobic training. However, there were no significant changes between these four groups in weight, BMI, or glycemic variables before the intervention.
or after it. Consistent with our results, Rahimi et al.\textsuperscript{32} also reported that nano-curcumin (80 mg/day) treatment for 3 months in 70 subjects with type 2 diabetes mellitus significantly reduced fasting blood glucose. In some previous studies, improvements in glycemic variables have been reported.\textsuperscript{33} The possible mechanism of this effect may be due to curcumin's role in insulin secretion by activating phosphoinositide 3 kinase and insulin signaling improvement.\textsuperscript{34} Also, aerobic training increases insulin’s ability to stimulate muscle glucose uptake.\textsuperscript{35}

In the Panahi et al.\textsuperscript{36} study that used 1,000 mg curcumin supplementation over 3 months, weight and BMI in diabetic patients decreased significantly, similar to the results of this study. In 2018, several dose-response meta-analyses have shown the lowering effect of 8 weeks or more of curcumin supplementation on the WC variable in overweight subjects.\textsuperscript{33} The mechanism of the curcumin effect on the anthropometric indices is unclear. However, curcumin down-regulates the kinase enzyme, which has been suggested to have an important role in obesity pathogenesis.\textsuperscript{37} A high dose of curcumin also reduces obesity by the inhibition of adipocyte differentiation through suppression of the transcription factor peroxisome proliferator-activated receptor-c.\textsuperscript{38}

Our results showed that the FBS was decreased significantly in the Cur group at the end of the study. Also, curcumin supplementation with aerobic training for 8 weeks reduced serum insulin level significantly and improved the QUICKI index. Various studies have shown the separate effects of curcumin and aerobic training on lipid profiles.\textsuperscript{39} Our results showed that aerobic training decreased the LDL level. The anti-hyperlipidemia effect of aerobic training is a possible reason. It can be stated that aerobic training leads to an increase in lipoprotein lipase activity. As a result, the catabolism of cholesterol-rich lipoprotein increases, and thus the amount of LDL is reduced.\textsuperscript{40} The results of the between-group analyses showed a beneficial effect of curcumin supplementation with aerobic training on HDL cholesterol levels. This finding is consistent with the study by Panahi et al.\textsuperscript{14} It is clear that Apo-A1 mediates the cholesterol transfer from cells to HDL particles, and curcumin can induce Apo-A1 expression.\textsuperscript{41} Also, curcumin was found to modulate the removal of HDL by hepatocytes.\textsuperscript{42}
The other interesting finding of the present study was the lower serum CRP levels in the Cur and the Cur+Tra groups compared to the Pla+Tra group. Although CRP was not statistically significant in this study, its difference in the Tra group (23.86%) indicated that exercise was physiologically very effective. According to the previous findings, the influence of physical activity on inflammation is complex. Inflammatory markers can be affected by exercise type, intensity, duration, and consistency of the exercise sessions. As shown in Fig. 1, daily curcumin supplements in those who engaged in aerobic training moderated circulatory CRP. It has been shown that CRP production is controlled by the nuclear factor kappa B (NF-κB) transcription signaling pathway. A study by Shishodia et al. has suggested that curcumin is a well-known suppressor of the NF-κB pathway, as dietary composition is one of the considerable factors involved in the development of inflammatory-related diseases. Therefore, the anti-inflammatory properties of curcumin might provide a therapeutic window.

The limitations of our study were as follows. First, this was a short-term trial, and it is unknown if longer durations of supplementation could cause further improvements. Second, the impact of different dose levels was not investigated in the current research. In addition, recent studies have shown that the bioavailability of curcumin is low because of its poor absorption and rapid metabolism. Consequently, any dose-response relationship for the metabolic effects of curcumin remains unknown. Finally, our study did not consider dietary changes during the trial to monitor and normalize the dietary intakes between the experimental and control groups. The strengths of our study were the successful blinding of subjects (only two subjects claimed to know whether they were on curcumin or not), and the high rate of compliance (all subjects reported that they had taken capsules on all days).
CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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AUTHOR CONTRIBUTIONS

Study concept and design: ***; acquisition of data: ***; analysis and interpretation of data: ***; drafting of the manuscript: ***; critical revision of the manuscript: ***; statistical analysis: ***; administrative, technical, or material support: ***; and study supervision: ***.

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Table 1. Demographic and baseline values of anthropometric variables

| Variable       | Cur (n=10)       | Pla (n=10)       | Pla+Tra (n=10) | Cur+Tra (n=10) | P     |
|----------------|------------------|------------------|----------------|----------------|-------|
| Age (yr)       | 38.9±5.40        | 40.80±3.55       | 38.20±5.67     | 35.80±3.22     | 0.128 |
| Height (cm)    | 159.09±4.64      | 161.83±5.36      | 159.58±6.98    | 162.44±4.36    | 0.441 |
| Weight (kg)    | 68.31±6.54       | 71.31±5.73       | 70.37±9.23     | 74.45±6.63     | 0.298 |
| BMI (kg/m²)    | 26.96±1.90       | 27.21±1.43       | 27.52±1.70     | 28.18±1.70     | 0.425 |
| WC (cm)        | 103.85±6.63      | 106.55±4.59      | 103.00±6.42    | 108.80±6.19    | 0.142 |
| WHR            | 0.83±0.05        | 0.78±0.02        | 0.87±0.04†     | 0.88±0.07†     | <0.001|

Values are presented as mean±standard deviation. Data analysis was done by analysis of variance and least significant difference post-hoc tests.

*P<0.05 vs. supplement group; †P<0.05 vs. placebo group.

Cur, Curcumin supplement; Pla, placebo; Pla+Tra, placebo+training; Cur+Tra, curcumin supplement+training; BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist to hip ratio.
Table 2. Anthropometric variables across the study period categorized by group

| Group            | Weight (kg) | BMI (kg/m²) | WC (cm) | HC (cm) | WHR |
|------------------|-------------|-------------|---------|---------|-----|
|                  | Before      | After       | P       | Before  | After | P     | Before  | After       | P     | Before  | After       | P    |
| Cur* (n=10)      | 68.31±6.54  | 67.39±7.08  | 0.033   | 26.96±1.90 | 26.59±2.06 | 0.035 | 86.40±4.94 | 85.35±5.56 | 0.173 | 103.85±6.63 | 104.00±6.81 | 0.866 |
| Pla† (n=10)      | 71.31±5.73  | 70.47±5.98  | 0.138   | 27.21±1.43 | 26.89±1.56 | 0.148 | 83.50±3.53 | 81.85±4.00 | 0.045 | 106.55±4.59 | 105.90±4.88 | 0.301 |
| Pla+Tra‡ (n=10)  | 70.37±9.23  | 69.24±9.73  | 0.053   | 27.52±1.70 | 27.05±1.85 | 0.056 | 90.20±4.94 | 84.1±6.60 | 0.001 | 102.30±5.37 | 108.40±5.60 | 0.343 |
| Cur+Tra§ (n=10)  | 74.45±6.63  | 73.84±6.18  | 0.070   | 28.18±1.70 | 27.95±1.63 | 0.073 | 96.60±11.18 | 89.90±9.53 | 0.026 | 108.80±6.19 | 108.40±5.60 | 0.479 |

Values are presented as mean±standard deviation.

*Data analysis was done by analysis of covariance and least significant difference post-hoc test after adjustment for baseline values; †Statistical analysis was done by paired sample t-test.

BMI, body mass index; WC, waist circumference; HC, hip circumference; WHR, waist-to-hip ratio; PC, percent change; Cur, curcumin supplement; Pla, placebo; Pla+Tra, placebo+training; Cur+Tra, curcumin supplement+training.
Table 3. Glycemic variables across the study period categorized by group

| Group         | Insulin (μU/mL) | FBS (mg/dL) | HOMA-IR | QUICKI |
|---------------|----------------|-------------|---------|--------|
|               | Before         | After       | P       | PC     | Before | After | P       | PC     | Before | After | P       | PC     | Before | After | P       | PC     |
| Cur (n=10)    | 8.07±3.79     | 7.83±2.99   | 0.844   | 0.041  | -7.57±10.37 | 2.00±1.22 | 0.414  | 4.84±64.27 | 0.35±0.03 | 0.36±0.02 | 0.673 | 1.58±8.10 |
| Pla (n=10)    | 7.25±3.12     | 8.38±3.64   | 0.181   | 1.00   | -0.48±11.19 | 1.72±0.91 | 0.245  | 18.00±33.58 | 0.36±0.02 | 0.35±0.02 | 0.258 | -1.72±5.03 |
| Pla+Tra (n=10)| 7.85±2.85     | 7.92±2.15   | 0.942   | 0.108  | -3.38±6.33 | 1.78±0.64 | 0.800  | 4.19±36.03 | 0.35±0.17 | 0.35±0.01 | 0.988 | 0.12±4.58 |
| Cur+Tra (n=10)| 9.17±3.32     | 7.27±2.29   | 0.039   | 0.389  | -2.59±11.12 | 2.12±0.62 | 0.053  | -18.72±25.34 | 0.34±0.17 | 0.36±0.02 | 0.044 | 4.10±5.52 |

$P^*$: 0.353 0.388 0.289 0.452

Values are presented as mean±standard deviation.

*Data analysis was done by analysis of covariance and least significant difference post-hoc tests after adjustment for baseline values; †Statistical analysis was done by paired sample t-test.

PC, percent change; FBS, fasting blood sugar; HOMA-IR, homeostatic model assessment for insulin resistance; QUICKI, quantitative insulin sensitivity check index; Cur, curcumin supplement; Pla, placebo; Pla+Tra, placebo+training; Cur+Tra, curcumin supplement+training.
### Table 4. Lipid profiles across the study period categorized by group

| Group          | TC Before (n=10) | TC After (n=10) | PC | TC Before (n=10) | TC After (n=10) | PC | TG Before (n=10) | TG After (n=10) | PC | HDL Before (n=10) | HDL After (n=10) | PC | LDL Before (n=10) | LDL After (n=10) | PC | TC/HDL Before (n=10) | TC/HDL After (n=10) | PC | LDL/HDL Before (n=10) | LDL/HDL After (n=10) | PC |
|----------------|------------------|-----------------|----|------------------|-----------------|----|-----------------|-----------------|----|------------------|-----------------|----|------------------|-----------------|----|-----------------|-----------------|----|------------------|-----------------|----|
| Cur (n=10)     | 182.20±26.02     | 174.70±26.91    | 0.178 | 1.55±39.22      | 1.53±39.22      | 0.879 | 8.42±20.26      | 7.54±18.25      | 0.979 | 1.34±20.26      | 1.34±20.26      | 0.979 | 3.24±18.37      | 3.24±18.37      | 0.979 | 2.11±18.37      | 2.11±18.37      | 0.979 |
| Pla (n=10)     | 175.20±25.71     | 164.30±25.25    | 0.120 | 6.77±14.23      | 6.77±14.23      | 1.000 | 2.89±10.77      | 2.89±10.77      | 1.000 | 9.40±16.80      | 9.40±16.80      | 1.000 | 14.79±17.77     | 14.79±17.77     | 1.000 | 1.81±18.37      | 1.81±18.37      | 1.000 |
| Pla+Tra (n=10) | 164.5±38.31      | 152.80±32.17    | 0.311 | 5.58±18.18      | 5.58±18.18      | 0.973 | 2.30±10.54      | 2.30±10.54      | 0.973 | 7.30±20.65      | 7.30±20.65      | 0.973 | 16.79±21.93     | 16.79±21.93     | 0.973 | 2.11±18.37      | 2.11±18.37      | 0.973 |
| Cur+Tra (n=10) | 188.00±33.62     | 158.10±34.24    | 0.088 | 5.29±22.92      | 5.29±22.92      | 0.979 | 4.19±29.12      | 4.19±29.12      | 0.979 | 7.20±21.09      | 7.20±21.09      | 0.979 | 19.65±24.48     | 19.65±24.48     | 0.979 | 2.11±18.37      | 2.11±18.37      | 0.979 |

Values are presented as mean±standard deviation.

*Statistical analysis was done by paired sample t-test; †P<0.05 vs. Pla group; ‡P<0.05 vs. Pla+Tra group; ¶P<0.05 vs. Cur+Tra group; ‖Data analysis was done by analysis of covariance (ANCOVA) and least significant difference (LSD) post hoc test after adjustment for baseline values; ¶Data analysis was done by ANCOVA and LSD post-hoc test after adjustment for baseline values and baseline WC.

TC, total cholesterol; TG, triglyceride; HDL, high-density lipoprotein; LDL, low-density lipoprotein; PC: percent change; Cur, curcumin supplement; Pla, placebo; Pla+Tra, placebo+training; Cur+Tra, curcumin supplement+training.
Figure 1. A flowchart of the study protocol.
Figure 2. Marginal means of serum C-reactive protein (CRP) in the study groups after adjustment for baseline values. Data analysis was done by analysis of covariance.