Green tea polyphenols benefits body composition and improves bone quality in long-term high-fat diet–induced obese rats

Chwan-Li Shen a, b, *, Jay J. Cao c, Raul Y. Dagda a, Samuel Chanjaplammoottil d, Chuanwen Lu e, Ming-Chien Chyu d, Weimin Gao e, Jia-Sheng Wang f, James K. Yeh g

a Department of Pathology, Texas Tech University Health Sciences Center, Lubbock, TX 79430-8115, USA
b Laura W. Bush Institute for Women’s Health, Texas Tech University Health Sciences Center, Lubbock, TX 79430-8115, USA
c USDA ARS Grand Forks Human Nutrition Research Center, Grand Forks, ND 58201, USA
d Healthcare Engineering Graduate Program, Whitacre College of Engineering, Texas Tech University, Lubbock, TX, USA
e The Institute of Environmental and Human Health and Department of Environmental Toxicology, Texas Tech University, Lubbock, TX, USA
f Department of Environmental Health Science, University of Georgia, Athens, GA, USA
g Winthrop-University Hospital, Mineola, NY, USA

Article history:
Received 17 March 2012
revised 28 April 2012
accepted 2 May 2012

Keywords:
Tea
Obesity
Body composition
Bone strength
Anti-inflammation
Antioxidant
Rat

This study investigates the effects of green tea polyphenols (GTPs) on body composition and bone properties along with mechanisms in obese female rats. Thirty-six 3-month-old Sprague Dawley female rats were fed either a low-fat (LF) or a high-fat (HF) diet for 4 months. Animals in the LF diet group continued on an LF diet for additional 4 months, whereas those in the HF diet group were divided into 2 groups: with GTP (0.5%) or without in drinking water, in addition to an HF diet for another 4 months. Body composition, femur bone mass and strength, serum endocrine and proinflammatory cytokines, and liver glutathione peroxidase (GPX) protein expression were determined. We hypothesized that supplementation of GTP in drinking water would benefit body composition, enhance bone quality, and suppress obesity-related endocrines in HF diet–induced obese female rats and that such changes are related to an elevation of antioxidant capacity and a reduction of proinflammatory cytokine production. After 8 months, compared with the LF diet, the HF diet increased percentage of fat mass and serum insulin–like growth factor I and leptin levels; reduced percentage of fat-free mass, bone strength, and GPX protein expression; but had no effect on bone mineral density and serum adiponectin levels in the rats. Green tea polyphenol supplementation increased percentage of fat-free mass, bone mineral density and strength, and GPX protein expression and decreased percentage of fat mass, serum insulin–like growth factor I, leptin, adiponectin, and proinflammatory cytokines in the obese rats. This study shows that GTP...
supplementation benefited body composition and bone properties in obese rats possibly through enhancing antioxidant capacity and suppressing inflammation.

© 2012 Elsevier Inc. All rights reserved.

1. Introduction

Obesity and osteoporosis, 2 disorders of body composition, are growing in high proportion worldwide including the United States [1]. Evidence shows that obesity and osteoporosis share several common features including genetic predisposition and common progenitor cell [2]. Many epidemiology studies have highlighted the existence of the interrelation between obesity and osteoporosis as well as the impact of obesity on osteoporosis [1–7].

Greater adipose tissue mass, especially visceral adipose tissue, directly contributes to chronic systemic inflammation [8]. There is an increasing body of evidence suggesting the importance of chronic inflammation in the development of obesity, which can be detrimental to bone [9–11]. Animal studies have also shown that a relationship exists between obesity and poor bone quality, as determined by decreased microarchitectural and biomechanical properties, in diet-induced obese animals [12–17].

Green tea is one of the most popular beverages in the world. The impacts of green tea consumption on weight loss have been reported in clinical [18–24] and laboratory animal studies [25,26]. Such an antiobesity effect of green tea is probably due to its capacity in elevating thermogenesis and fat oxidation and lowering lipid peroxidation [27,28] as well as suppressing appetite and nutrient absorption [29]. On the other hand, our previous studies suggest the positive impacts of green tea polyphenols (GTPs) (extract of green tea) on bone health in various bone loss models [30–35]. Such an osteoprotective effect of green tea is probably due to its ability in suppressing chronic inflammation and oxidative stress damage or in increasing antioxidant capacities [30–35]. However, the effects of GTP on body composition, bone remodeling, and obesity-related endocrines along with related mechanism(s) in long-term high-fat (HF) diet-induced obese rats are still unclear.

Therefore, the present study was designed to investigate the effects of GTP supplementation on body composition (fat mass [FM], fat-free mass [FFM], total body water [TBW], intracellular fluid [ICF], and extracellular fluid [ECF]), bone quality (bone mineral density [BMD] and strength), and obesity-related endocrines (insulin-like growth factor 1 [IGF-I], leptin, and adiponectin) in HF diet-induced obese female rats. The possible anti-inflammatory and antioxidant mechanisms due to GTP supplementation were also evaluated. We hypothesized that (1) supplementation of GTP in drinking water would benefit body composition, enhance bone quality, and suppress obesity-related endocrines in HF diet-induced obese female rats and that (2) such changes in body composition, bone quality, and endocrine in GTP-supplemented group are related to an elevation of antioxidant capacity and a reduction of proinflammatory cytokine production. Studying the effects of GTP on body composition, bone quality, and obesity-related endocrines in obese female rats will potentially advance the understanding of their effects on musculoskeletal health involving adipose tissue, muscle mass, and bone in obese women.

2. Methods and materials

2.1. Animals and GTP treatments

Thirty-six virgin Sprague Dawley female rats (3-month-old; Harlan Laboratories, Indianapolis, Ind) were kept in an environmentally controlled animal care facility and allowed to acclimate for 5 days on an AIN-93M diet and distilled water ad libitum before the start of experiments. After acclimation, rats were randomized by weight and assigned to a low-fat (LF) (10% energy as fat) (n=12) or HF diet (45% energy as fat) (n=24) ad libitum for 4 months. The diets were based on a modification of the AIN-93M diet and supplied by Research Diets Inc (New Brunswick, NJ). Table 1 shows the composition of experimental diets with adequate protein, minerals, and vitamins.

After 4 months, animals in the LF diet group continued on an LF diet for additional 4 months (LF group, n=12), whereas those in the HF diet group were randomly divided into 2 groups: with (HF+GTP group, n=12) or without GTP (HF group, n=12) in drinking water, in addition to an HF diet for another 4 months. Food consumption was recorded daily. Rats were weighed twice a week and examined daily. Rats were housed in individual stainless steel cages under a controlled temperature of 21°C±2°C with a 12-hour light-dark cycle. All procedures were approved by the Texas Tech University Health Sciences Center Institutional Animal Care and Use Committee.

Rats in the HF+GTP group had free access to distilled water containing 0.5% (wt/vol) GTP. Distilled water mixed with GTP was prepared fresh daily, and the amount of water consumed was recorded for each rat. Green tea polyphenol was purchased from the same source as that used in our previous studies (Shili Natural Product Company, Inc, Guangxi, China) with purity higher than 98.5%. Every 1000-mg GTP contained 464-mg (-)-epigallocatechin gallate (EGCG), 112-mg (-)-epicatechin gallate, 100-mg (-)-epicatechin, 78-mg (-)-epigallocatechin, 96-mg (-)-gallocatechingallate, and 44-mg catechin according to the methods using high-performance liquid chromatography–electrochemical detector and high-performance liquid chromatography–ultraviolet detector.

2.2. Body composition measurement

Whole body composition was measured using the Imped-VET™ Bioimpedance Spectroscopy device (ImpediMed Limited, Brisbane, Australia) at baseline and every 2 months throughout the study. All animals were subjected to the following procedures from previous published studies for body composition determination [36,37]. At the end of measurement, acquired data were downloaded, processed, and generated including FM, FFM, TBW, ECF, and ICF using the
provided bioimpedance software (ImpediVet BISI v. 1.0.0.4; ImpediMed Limited). The reproducibility was 4.8%, 2.5%, and 2.5% for FM, FFM, and TBW, respectively [36].

2.3. Sample preparation

The final body weight was recorded. At the end of the experiment, after animals were anesthetized using isoflurane gas and euthanized by CO₂ inhalation, femora were harvested, cleaned of adhering soft tissues, and were kept in 70% ethanol at 4°C for later bone scans and bone strength test. The liver samples were collected and stored at −80°C for later analysis. Blood samples were collected and centrifuged at 1500g for 20 minutes at 4°C, and the serum was separated and stored at −80°C until analyzed.

2.4. Assessment of femur bone mass

Total bone area, bone mineral content (BMC), and BMD of the whole left femur of each rat were determined by dual-energy x-ray absorptiometry (DXA) (HOLOGIC QDR-2000 plus DXA; Hologic, Waltham, Mass) according to our previously published study [32]. The coefficient of variation of these measurements at our laboratory was less than 1.0% [38].

2.5. Assessment of femur bone strength

Femoral quality (bone strength) was evaluated by a 3-point bending test using a custom-designed and custom-built apparatus according to the procedures of Nielsen [39]. Descriptions of the terms used for the assessment of bone strength have been described previously [40]. Maximum force (newton) and yield point force (newton) to break bones and modulus of elasticity were assessed.

2.6. Blood analysis

Serum IGF-I concentration was measured by enzyme-linked immunosorbent assay (ELISA) (Immunodiagnostic System, Inc, Fountain Hills, Ariz). Serum leptin (Lepton Mouse/Rat EIA; Alpcos Diagnostics, Salem, NH) and adiponectin (Adiponectin Rat ELISA; Alpcos Diagnostics, Salem, NH) were also analyzed by respective ELISA, following manufacturer’s instruction (Alpcos Diagnostics, Salem, NH). Serum proinflammatory cytokines including interleukin (IL)-1α, IL-2, IL-4, IL-10, granulocyte macrophage colony-stimulating factor (GM-CSF), interferon γ (IFN-γ), and tumor necrosis factor α (TNF-α) were analyzed by Bio-Plex™ Rat Cytokine Panel (Bio-Rad Laboratories, Inc, Hercules, Calif) with Luminex 100 Analyzer (Luminex Corporation, Austin, Tex) following the manufacturer’s instruction.

2.7. Analysis of liver glutathione peroxidase protein expression and activity

The individual rat liver tissue in the LF, HF, and HF+GTP groups (n=9 per group) was resuspended in a Radio Immuno Precipitation Assay lysis buffer (Santa Cruz Biotechnology, Santa Cruz, Calif). The samples were homogenized by sonication on ice with a sonic dismembrator (model 100; Fisher, Pittsburgh, Pa). Three pooled samples were obtained in each of the LF, HF, and HF+GTP groups in which an aliquot of 300 µg protein from 3 individual samples in each group was added together to form a pooled sample. Protein concentrations were measured using the Bradford protein assay (Bio-Rad Life Science, Hercules, Calif).

A total of 90 µg of protein from each of the pooled samples in the LF, HF, and HF+GTP groups were separated by 12% sodium dodecyl sulfate polyacrylamide gel electrophoresis. These were then transferred to polyvinylidene fluoride membranes and incubated overnight at 4°C in blocking buffer containing 3% nonfat dry milk in 1× phosphate-buffered saline and 0.1% Tween 20. After blocking, the membranes were probed with primary antibody glutathione peroxidase 1 (GPX) (1:50 dilution) (Santa Cruz Biotechnology) for 1 hour, and the antibody binding was detected with donkey anti-goat immunoglobulin G—horseradish peroxidase (Santa Cruz Biotechnology) at a dilution of 1:1000 for 1 hour at room temperature. After a brief incubation with enhanced chemiluminescence reagents (ECL; GE Healthcare, Cleveland, OH), the signals on membranes were exposed to x-ray films (Fujifilm Corporation, Tokyo, Japan). Relative densitometric digital analysis of protein bands were analyzed by Quantity One software (Bio-Rad) and normalized by the intensity of the housekeeping gene (α-Tubulin, 1:10000 dilution; Abcam, Cambridge, Mass) for each sample.

Liver samples were minced and homogenized (100 mg per 1 mL) at 4°C in 0.1 mol/L Tris-HCl buffer, pH 7.4, and centrifuged at 10000g for 15 minutes. The supernatant was collected and stored at −80°C for glutathione peroxidase (GPX) enzymatic activity assays. Glutathione peroxidase activity was coupled to nicotinamide adenine dinucleotide phosphate hydrogen use, and the production of nicotinamide adenine dinucleotide phosphate was measured spectrophotometrically at 340 nm [41].

2.8. Statistical analyses

Data are expressed as means±SEM. All data were analyzed with SigmaStat software, version 2.03 (Systat Software, Inc, San Jose, Calif). Data of body weight and body composition (%FM, %FFM, %TBW, and ECF/ICF ratio) were analyzed (1) by 1-way analysis of variance (ANOVA) with repeated measures followed by Fisher protected least significant difference (Fisher LSD) post hoc tests to evaluate the effect of time among the same treatment animals and (2) by 1-way ANOVA followed by Fisher LSD post hoc tests at the same collection time (0, 2, 4, 6, and 8 months) to evaluate the treatment’s effect. Data of bone parameters, serum biomarkers, and GPX protein expression and activity were analyzed by 1-way ANOVA followed by Fisher LSD post hoc tests to evaluate the treatment effects. A significance level of P<.05 was used for all statistical tests.

3. Results

3.1. Food intake, body weight, and body composition

Throughout the study, the average feed consumption was similar among 3 groups (13.9±1.6, 12.8±0.6, and 12.2±1.1 g/d for the LF, HF, and HF+GTP groups, respectively). There was no difference in initial body weight among all treatment...
groups (Fig. 1A). Over the course of the 8-month study, all animals gained body weight regardless of treatment groups. At 4 months, compared with the LF-treated group, the HF-treated group had significantly greater body weight. At the end of study, supplementation of GTP into drinking water (the HF+GTP group) significantly prevented weight gain compared with the HF-only diet (the HF group) (Fig. 1A). At the end of study, the order of body weight was the HF group > the HF+GTP group = the LF group (P = .002).

At the baseline, there was no difference in any parameters of body composition among all treatment groups (Fig. 1B, C, D, and E for %FM, %FFM, %TBW, and ECF/ICF ratio, respectively). At 4 months, compared with the LF-treated group (the LF group), the HF-treated groups (the HF group and the HF+GTP group) had significantly greater %FM and ECF/ICF ratio and less %FFM and %TBW. After 4-month GTP supplementation, the rats in the HF+GTP group had less %FM and ECF/ICF ratio and greater %FFM and %TBW relative to those in the HF group.

3.2. Bone mass and strength

There was no difference in total bone area among all treatment groups (Table 2). Compared with the LF and HF groups, the HF+GTP group had significantly higher values for BMC and BMD (Table 2). In terms of bone strength at femur, as assessed by 3-point bending test, the order was the LF group > the HF+GTP group > the HF group for both maximal force and yield point force (Table 2).

3.3. Liver GPX protein expression and activity

Relative to the LF group, the HF group had a decrease in GPX1 protein expression intensity (Fig. 2A and B). Green tea polyphenol supplementation resulted in an increase in GPX1 protein expression intensity in the HF+GTP group when compared with those in the HF group. The order of GPX1 intensity was the LF group > the HF+GTP group > the HF group, respectively (Fig. 2B). Similar to the results of GPX protein expression, GTP supplementation led to an increase in the activity of GPX in liver of the HF+GTP rats when compared with the HF group (1415±72 mU/mg protein for the HF group vs 1622±50 mU/mg protein for the HF+GTP group).

3.4. Serum IGF-I, leptin, adiponectin, and proinflammatory cytokines

Relative to the LF group, the HF group had higher serum IGF-I and leptin concentrations. The rats in the HF+GTP group had lower serum IGF-I, leptin, and adiponectin concentrations when compared with those in the HF group (Table 3). In terms of serum proinflammatory cytokines, there was no statistical difference in the production of serum proinflammatory cytokines between the LF and the HF groups. Compared with the HF group, 4-month GTP supplementation to the HF diet (the HF+GTP group) caused a significant decrease in all serum proinflammatory cytokines including IL-1α, IL-2, IL-4, IL-10, GM-CSF, IFN-γ, and TNF-α (Table 3).

4. Discussion

In the present study, obese rats were used to demonstrate beneficial impacts of GTP supplementation in drinking water on HF diet–induced unfavorable body composition (increased %FM and decreased %FFM) and to elucidate GTP’s osteoprotective role simultaneously. A recent in vitro study provided the first laboratory evidence on the antifat and probone effects of the green tea extract and epigallocatechin, as shown by suppression of adipocyte formation and promotion of bone formation in pluripotent rat mesenchymal stem cells [42]. These rat mesenchymal stem cells were isolated from the bone marrow of the tibiae and femora and give rise to adipocytes, osteoblasts, chondrocytes, and monocytes. To our knowledge, our study is the first in vivo study to investigate the efficacy of the concentrated form of green tea (ie, GTP) on antiobesity and osteoprotection in the same animal model and the first to address the effects of GTP on 3 organs (adipose tissue, muscle, and bone) associated with musculoskeletal health with possible molecular mechanisms in 1 animal model.

The present finding that GTP supplementation in drinking water inhibited weight gain and favored a healthier body composition in HF diet–induced obese rats supports our stated hypotheses as shown in decreased %FM and increased %FFM measured by bioimpedance spectroscopy. The present result of GTP inhibiting obesity, in terms of body weight and %FM (or adipose tissue), is similar to previous studies using various obesity animal models supplemented with GTP [43–48] or EGCG (the most abundant component in green tea extract) [49–51] in drinking water or diet for different study periods. On the other hand, the observation that GTP supplementation significantly increased %FFM in obese rats measured by bioimpedance spectroscopy is consistent with those reported by Chen et al [52] using DXA as well as by Klaus et al [53] using quantitative magnetic resonance. The findings that 4 months of GTP administration only affected FM weight but did not change FFM weight agrees with the result of Klaus et al [53] in drinking water or diet for different study periods. On the other hand, the observation that GTP supplementation significantly increased %FFM in obese rats measured by bioimpedance spectroscopy.

Besides FM and FFM, we measured TBW, ICF, and ECF in animals using bioimpedance spectroscopy. Muscle tissue

| Table 1 – Ingredient composition (gram per kilogram) of the diets fed to rats |
|------------------------|----------------|----------------|
| Ingredient             | LF diet       | HF diet       |
| Casein                 | 200           | 200           |
| L-cystine              | 3             | 3             |
| Cornstarch             | 315           | 72.8          |
| Maltodextrin 10        | 35            | 100           |
| Sucrose                | 350           | 172.8         |
| Cellulose              | 50            | 50            |
| Soybean oil            | 10            | 10            |
| Lard                   | 35            | 192.5         |
| AIN-76 minerals        | 10            | 10            |
| Dicalcium phosphate    | 13            | 13            |
| Calcium carbonate      | 5.5           | 5.5           |
| Potassium citrate, 1 H2O | 16.5       | 16.5          |
| AIN-76 vitamins        | 10            | 10            |
| Choline bitartrate     | 2             | 2             |
| Protein (%, wt/wt)     | 19.2          | 23.7          |
| Carbohydrate (%, wt/wt)| 67.3          | 41.4          |
| Fat (%, wt/wt)         | 4.3           | 23.6          |
| Energy (Kcal/g diet)   | 0.92          | 1.13          |
holds a large amount of water, which consists of ECF and ICF [54]. Yamada et al. [55] demonstrated that (1) ICF/TBW ratio decreased and the ECF/TBW ratio increased significantly in the lower leg with age and that (2) ICF/TBW ratio was significantly correlated with muscle strength and power in the lower extremities in humans. The present result shows that 4 months of GTP supplementation led to a higher ratio of ICF/TBW in the HF+GTP group (0.599) relative to those in the HF group (0.584) (*P < .05 between the LF and HF groups; #P < .05 between the HF and HF+GTP groups; ^P < .01 between the LF and HF+GTP groups). The higher ICF/TBW ratio because of GTP supplementation may contribute to the skeletal muscle physiology in the HF+GTP animals, an issue to be further investigated in the future research.

Previous studies have demonstrated that (1) a significantly elevated fat-to-muscle ratio in subjects with myogenic atrophy and both functional activity scales and strength correlated closely with percentage of lean body mass as determined by DXA [56,57] and that (2) an increase in ECF/ICF ratio was observed in subjects with Duchenne muscular dystrophy compared with the control [58]. Our findings that...
long-term GTP administration lowered the FM/FFM ratio (0.347, 0.449, and 0.392 for the LF, HF, and HF+GTP groups, respectively) and ECF/ICF ratio (Fig. 1D) in the HF diet–induced obese rats further suggest that green tea consumption may benefit skeletal muscle integrity.

Biomechanical loading of body weight has been shown to stimulate bone formation, decrease apoptosis, and increase proliferation and differentiation of osteoblasts and osteocytes [59], probably through Wnt/β-catenin signaling pathway [60,61]. Because marrow adipocytes and osteoblasts are derived from common multipotential mesenchymal stem cells [62], marrow adipogenesis may be inversely related to osteoblastogenesis [63,64]. Thus, excessive FM can be detrimental to the bone [65,66]. In the present study, relative to the LF group, the current HF group with a greater body weight had poor bone quality, as shown in maximal force and yield point force, whereas there was no statistically significant difference in bone mass probably because of a large SEM (Table 2). Our results of poor bone quality because of an HF diet in the obese rats are supported by others [14,67-69]. For example, Ionova-Martin et al [14] stated that, in HF fed mice, all geometric parameters of the femoral bone (ie, bone size), except bone length, were larger, but size-independent mechanical properties of cortical bone (ie, strength, bending stiffness, and fracture toughness) were reduced probably because of a compensatory mechanism.

The findings that GTP supplementation in drinking water enhanced bone mass (ie, BMD and BMC) and bone strength in obese rats support our proposed hypothesis that long-term GTP supplementation improves bone quality as determined by DXA and 3-point bending test. Such a beneficial effect of GTP on bone properties is in agreement with our previous studies using various bone loss models due to aging [31,32], estrogen deficiency [31,32], testosterone deficiency [25], and chronic inflammation [33,34]. In addition to the dietary fat and GTP supplementation presented in this study, some other known factors, such as antiresorptive agents, parathyroid hormone, [70] or exercise [71], have also shown to affect bone quality.

Obesity is associated with significant increase in serum leptin that can suppress bone formation [72,73]. Leptin has pleiotropic effects on modulating energy expenditure, appetite, and neuroendocrine functions. In addition, leptin has been shown to stimulate inflammatory responses in obese humans [74,75]. In contrast to leptin, adiponectin acts as an anti-inflammatory cytokine that suppresses TNF-α–induced nuclear factor-kappaB activation [76]. Both leptin and adiponectin have been used as mediators to show the effects of FM on the skeleton [77-79]. The observation that relative to the LF group, the HF group increased FM and leptin and decreased adiponectin, and bone strength seems to support the relationships among leptin, adiponectin, FM, and skeleton health. In human studies, the parallel changes in body fat and BMD, at least partially, are mediated via circuiting leptin [80-82] and adiponectin [83] in overweight/obese postmenopausal women.

In the current study, we also found that GTP reduces various obesity-related endocrine parameters, such as IGF-I, leptin, and adiponectin. The observation that GTP supplementation to the obese rats resulted in an inhibition of serum IGF-I is consistent with the study of Kao et al [84] showing EGCG’s inhibitory impact on IGF-I concentration in Sprague-Dawley, lean Zucker, and obese Zucker rats. Our finding that GTP supplementation suppressed the leptin concentration agrees with previous studies using green tea extract [85] and EGCG and obese male rats [84]. Furthermore, adiponectin plays an important role in regulating insulin function and energy homeostasis, and it was negatively associated with risk factors for cardiovascular disease [86]. Lower rate of weight gain was correlated with lower concentrations of plasma adiponectin [86]. Our study shows an inhibitory effect of GTP on serum adiponectin levels in HF diet–induced obese rats, and such findings agree with previous studies [44,87].

Recent studies have suggested that, in the development of obesity, greater adipose tissue mass, especially visceral adipose tissue, directly contributes to chronic systemic inflammation.

### Table 2 – Bone mass and strength

<table>
<thead>
<tr>
<th>Parameters</th>
<th>LF</th>
<th>HF</th>
<th>HF+GTP</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone mass by DXA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total bone area (cm²)</td>
<td>1.848±0.017</td>
<td>1.892±0.014</td>
<td>1.905±0.017</td>
<td>0.56</td>
</tr>
<tr>
<td>BMC (mg)</td>
<td>435.6±5.4</td>
<td>449.5±5.0</td>
<td>476.6±4.7</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>BMD (mg/cm³)</td>
<td>236.7±1.3</td>
<td>236.4±1.1</td>
<td>248.9±0.9</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Bone strength by 3-point bending test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximal force (N)</td>
<td>143.1±11.4</td>
<td>111.1±8.7</td>
<td>138.3±7.1</td>
<td>.04</td>
</tr>
<tr>
<td>Yield point force (N)</td>
<td>128.4±13.6</td>
<td>95.5±8.4</td>
<td>122.0±6.3</td>
<td>.049</td>
</tr>
</tbody>
</table>

Values are expressed as means±SEM (n=10-12).

* P < .05 between the LF and HF groups.

** P < .05 between the HF and HF+GTP groups.

*** P < .05 between the LF and HF+GTP groups.
Table 3 - Serum hormone and proinflammatory cytokines

<table>
<thead>
<tr>
<th>Parameters</th>
<th>LF</th>
<th>HF</th>
<th>HF + GTP</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hormone</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGF-1 (ng/mL)</td>
<td>784.2±20.8*</td>
<td>875.5±37.1**,**</td>
<td>764.3±29.7**</td>
<td>.034</td>
</tr>
<tr>
<td>Leptin (pg/mL)</td>
<td>279.5±55.2*</td>
<td>775.2±75.1**,**</td>
<td>482.5±97.7**</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Adiponectin (µg/mL)</td>
<td>15.7±0.7***</td>
<td>11.4±0.8*</td>
<td>10.3±1.0**</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Proinflammatory cytokines</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IL-1α (pg/mL)</td>
<td>348.4±32.3</td>
<td>439.8±49.9**</td>
<td>267.1±33.2**</td>
<td>.019</td>
</tr>
<tr>
<td>IL-2 (pg/mL)</td>
<td>11180.5±675.3</td>
<td>12369.7±709.1**</td>
<td>9741.0±496.2**</td>
<td>.013</td>
</tr>
<tr>
<td>IL-4 (pg/mL)</td>
<td>1002.9±68.2</td>
<td>1088.6±66.9**,**</td>
<td>846.4±49.7**</td>
<td>.048</td>
</tr>
<tr>
<td>IL-10 (pg/mL)</td>
<td>3621.8±382.2</td>
<td>4638.2±558.9**</td>
<td>2716.6±386.7**</td>
<td>.021</td>
</tr>
<tr>
<td>GM-CSF (pg/mL)</td>
<td>763.5±60.1</td>
<td>908.4±84.2**</td>
<td>616.1±61.7**</td>
<td>.021</td>
</tr>
<tr>
<td>IFN-γ (pg/mL)</td>
<td>543.0±39.3</td>
<td>615.6±79.3**</td>
<td>386.3±40.1**</td>
<td>.030</td>
</tr>
<tr>
<td>TNF-α (pg/mL)</td>
<td>2314.1±176.9</td>
<td>2635.3±250.1**</td>
<td>1692.1±152.9**</td>
<td>.010</td>
</tr>
</tbody>
</table>

Values are expressed as means±SEM (n=10-12).
* P<.05 between the LF and HF groups.
** P<.05 between the HF and HF+GTP groups.
*** P<.05 between the LF and HF+GTP groups.

This study is limited in lacking an LF+GTP group (and absence of a 2×2 study design). Although we have demonstrated GTP’s osteoprotective effects on various bone loss models of rats and that the amount of fat intake in our previous rat studies was comparable with that in the current study [31,33–35], the potential difference in study design (ie, sex, age, and study duration) should be noted.

In the present study, GTP was evaluated as an alternative treatment option for musculoskeletal health due to obesity. Our data show GTP’s beneficial effects on body composition and bone health parameters in obese middle-aged female rats. Although there may be differences between obese middle-aged female rats and obese middle-aged women in terms of the effects of GTP supplementation on musculoskeletal health, along with a clinical study result showing the beneficial effects of catechin-rich green tea and insulin on the body composition of overweight adults [101], our study presents a critical first step toward evaluating the effects of green tea on musculoskeletal health in obese middle-aged women. Further translational research should be conducted based on findings from the current animal study to investigate possible clinical efficacy of GTP on musculoskeletal health involving fat, bone, and muscle organs in obese women.

Acknowledgment

This study was supported by Laura W. Bush Institute for Women’s Health and Winthrop-University Hospital (CLS) and partially supported by the USDA Agricultural Research Service (ARS) CRIS program 5450-51000-046-00D and 5450-51000-039-00D (JJC).

References


