The purpose of this study is to compare the oxidative stress response to aerobic and anaerobic power testing, and to determine the impact of exercise training with or without glycine propionyl-L-carnitine (GPLC) in attenuating the oxidative stress response. Thirty-two subjects were assigned (double blind) to placebo, GPLC-1 (1g PLC/d), GPLC-3 (3g PLC/d) for 8 weeks, plus aerobic exercise. Aerobic (graded exercise test: GXT) and anaerobic (Wingate cycle) power tests were performed before and following the intervention. Blood was taken before and immediately following exercise tests and analyzed for malondialdehyde (MDA), hydrogen peroxide ($H_2O_2$), and xanthine oxidase activity (XO). No interaction effects were noted. MDA was minimally effected by exercise but lower at rest for both GPLC groups following the intervention ($p = 0.044$). A time main effect was noted for $H_2O_2$ ($p = 0.05$) and XO ($p = 0.003$), with values increasing from pre- to postexercise. Both aerobic and anaerobic power testing increase oxidative stress to a similar extent. Exercise training plus GPLC can decrease resting MDA, but it has little impact on exercise-induced oxidative stress biomarkers.

KEYWORDS malondialdehyde, hydrogen peroxide, reactive oxygen species, free radicals, exercise, nutritional supplements
INTRODUCTION

Exercise of sufficient intensity and duration increases the formation of reactive oxygen and nitrogen species (RONS), creating an imbalance between oxidant and antioxidant levels. Such a condition, referred to as oxidative stress, can lead to the oxidation of lipids, proteins, and other molecules (Halliwell and Gutteridge 1989). This has been demonstrated in multiple studies over the past 30 years since Dillard and colleagues first reported in 1978 that lipid peroxidation was increased following cycling exercise (Dillard et al. 1978). These findings are evident for both anaerobic (Bloomer and Goldfarb 2004) as well as aerobic exercise (Finaud et al. 2006; Vollaard et al. 2005). Little is known however, regarding the extent of oxidative stress when comparing aerobic and anaerobic exercise modes within the same subject population. In fact, few studies have investigated oxidative stress in response to both aerobic and anaerobic exercise bouts using a crossover design (Alessio et al. 2000; Bloomer et al. 2005; Magalhaes et al. 2007; Vincent et al. 2004). These studies have used either isometric handgrip (Alessio et al. 2000; Magalhaes et al. 2007) or resistance exercise (Bloomer et al. 2005; Vincent et al. 2005), and no study has included an anaerobic power test, as is commonly performed in several lab assessments, for comparison with the aerobic work. Of the comparison studies performed to date, anaerobic exercise has resulted in oxidative stress that equals or exceeds that of aerobic exercise. Hence, the initial purpose of this study was to compare the oxidative stress response with aerobic and anaerobic power tests within the same subjects.

Excessive oxidative stress has been implicated in a wide variety of disease processes (Dalle-Donne et al. 2006). Based on these observations, some concern exists related to increased oxidative stress commonly observed in response to acute exercise. As such, attempts to decrease oxidative stress in response to acute exercise are common. These include both regular exercise training (Ji et al. 2006; Powers et al. 1999) and antioxidant supplementation (Atalay et al. 2006; Powers et al. 2004; Urso and Clarkson 2003). Related to the former, although acute exercise increases oxidative stress transiently, this same exercise stimulus appears necessary to allow for an up-regulation in endogenous antioxidant defenses (Ji 2002; Ji et al. 2006). As for antioxidant supplementation, several isolated nutrients have been used in an attempt to attenuate the increase in oxidative stress biomarkers in response to acute exercise, as previously discussed in detail (Powers et al. 2004; Urso and Clarkson 2003).

One nutrient that has shown great promise as an antioxidant in both animals (Derin et al. 2004; Di Giacomo et al. 1993; Loster et al. 2001; Rauchova et al. 2002; Vanella et al. 2000) and humans (Corbucci et al. 1990; Sachan et al. 2005; Volek et al. 2002) is carnitine. The effects are believed to be mediated by a reduction in xanthine oxidase activity (Di Giacomo et al.
Exercise Induced Oxidative Stress and Carnitine

1993), a free-radical scavenging activity (Vanella et al. 2000), a regulation of fatty acid metabolism (Rauchova et al. 2002) or all of these. Propionyl-L-carnitine appears to have the highest affinity for carnitine acetyltransferase and possesses protective effects against RONS-induced oxidation (Rauchova et al. 2002). This form of carnitine recently has been combined with the amino acid glycine in a unique molecular bonded form called glycine propionyl-L-carnitine (GPLC). Previous reports indicate that glycine independently promotes positive effects on lipid peroxidation (Senthilkumar et al. 2004a, 2004b). To our knowledge, only one study to date has used carnitine to attenuate exercise-induced oxidative stress in humans, noting favorable results (Volek et al. 2002). Therefore, an additional purpose of the present study was to investigate the antioxidant effects of carnitine (in the form of GPLC), in conjunction with aerobic exercise training, on resting and exercise-induced oxidative stress in human subjects.

The oxidative stress response was compared using two common forms of exercise testing in a research/clinical lab: A Bruce treadmill protocol, representing a test of aerobic power (maximal oxygen consumption; VO$_{2\text{max}}$), and a Wingate cycle test, representing a test of anaerobic power. The potential attenuation in oxidative stress to both exercise tests was assessed by measuring oxidative stress biomarkers before and following an 8-week intervention of supervised aerobic exercise with or without GPLC supplementation. We hypothesized that both forms of exercise would induce oxidative stress and that oxidative stress would be lower following the intervention period as a result of exercise training, and to a greater extent with GPLC supplementation.

**MATERIALS AND METHODS**

Subjects and Screening

Thirty-two sedentary men and women between the ages of 20 and 40 years completed all aspects of this study (from an initial sample of 42 enrolled subjects). Subjects did not smoke, use nutritional supplements, or have any cardiovascular, metabolic, or orthopedic problems. Health history, drug and nutritional supplement usage, and physical activity questionnaires were completed to determine eligibility. Table 1 provides baseline descriptive characteristics of subjects. Subjects were informed of all procedures, potential risks, and benefits associated with the study and signed a consent form approved by the University Institutional Review Board for Human Subjects Research.

During the initial visit to the laboratory, stature, body mass, and body fat (seven site skinfolds) were measured (Jackson and Pollock 1978) in order to characterize subjects. Resting heart rate and blood pressure were measured, and subjects were familiarized to the graded exercise test (GXT;
TABLE 1 Subject Baseline Descriptive Characteristics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Placebo</th>
<th>GPLC-1</th>
<th>GPLC-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>27 ± 2</td>
<td>26 ± 2</td>
<td>27 ± 2</td>
</tr>
<tr>
<td>Stature (cm)</td>
<td>168 ± 3</td>
<td>169 ± 4</td>
<td>167 ± 2</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>78 ± 7</td>
<td>82 ± 8</td>
<td>69 ± 6</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>25 ± 2</td>
<td>26 ± 3</td>
<td>27 ± 2</td>
</tr>
<tr>
<td>Resting heart rate (bpm)</td>
<td>65 ± 2</td>
<td>70 ± 3</td>
<td>69 ± 3</td>
</tr>
<tr>
<td>VO2max (mL·kg⁻¹·min⁻¹)</td>
<td>32 ± 2</td>
<td>30 ± 3</td>
<td>28 ± 2</td>
</tr>
</tbody>
</table>

Data are mean ± SEM. No differences were noted between groups for any measured variable (p > 0.05).

by performing 2 minutes of each of the first two workloads) and the anaerobic power test (by performing a practice trial of this cycle test, as described below).

Aerobic and Anaerobic Exercise Testing

A maximal GXT using the Bruce treadmill protocol was conducted while expired gases were collected via facemask and analyzed (SensorMedics Vmax 229 metabolic system; Viasys Healthcare, Yorba Linda, CA) for determination of VO2max. The maximal heart rate data (via electrocardiographic tracings) were used in prescribing the exercise intensity during the intervention period. The GXT was conducted in the morning following an overnight fast (minimum of 8 hr—necessary for blood collection purposes and analysis of oxidative stress biomarkers), and subjects were asked to avoid strenuous activity during the 2 days preceding the GXT. The test continued until exhaustion, and the highest mean 1-minute VO2 value was used to represent VO2max. Heart rate and rating of perceived exertion (RPE) were recorded at the end of each 3-minute stage of the test and at the conclusion of testing.

Two days following the GXT (in order to allow for adequate recovery), subjects completed a Wingate anaerobic power test (30-second cycle sprint test) on a Lode Excalibur Sport cycle ergometer (Lode B.V. Medical Technology Groningen-The Netherlands) interfaced with a computer. The force (N) that subjects pedaled against was determined based upon their lean body mass and equal to lean body mass (kg) × 0.7. Prior to performing the test, subjects received a 5-minute warm-up using a low intensity (75 watts), in which they performed a 3-to-5-second sprint at the top of each minute in order to familiarize subjects to the protocol. Heart rate and RPE were recorded at the end of the test. Total work performed also was recorded. These exact testing procedures were repeated following the 8-week intervention.

Supplementation

Following the completion of the above tests, subjects were randomized in a double-blind manner to one of following three groups, with the addition of
aerobic exercise: 1 g PLC + 348 mg glycine day$^{-1}$ (GPLC-1; $n = 11$, 5 men, 6 women); 3 g PLC + 1044 mg glycine day$^{-1}$ (GPLC-3; $n = 12$, 0 men, 12 women); 1 g cellulose placebo (PL; $n = 9$, 4 men, 5 women). Our dosing was based on previous studies using L-carnitine, which have provided dosages ranging from 2–4 grams per day (Heinonen 1996). In particular, a study by Volek et al. (2002) used 2 grams per day of L-carnitine, and measured similar dependent variables as we have included here. Hence, we chose to use dosing slightly less than and greater than this previous work.

The GPLC consisted of a molecularly bonded form of PLC and the amino acid glycine (GlycoCarn™, Sigma-tau HealthScience S.p.A., Rome, Italy). For ease of reporting throughout this article, we refer to the two dosages of GPLC as simply 1 and 3 g•day$^{-1}$ to reference the actual PLC content. Capsules were identical in appearance and were provided to subjects in unlabeled bottles every 2 weeks. Subjects were instructed to ingest three capsules twice daily (morning and evening) in conjunction with a carbohydrate-rich meal. Supplementation continued until all postintervention testing was completed. The 8-week treatment period was chosen based on previous studies using L-carnitine (Heinonen 1996), in addition to recommendations for improvements in functional capacity with aerobic training (American College of Sports Medicine [ACSM] 2005).

Aerobic Exercise Training
Following randomization all subjects began an 8-week supervised program of aerobic exercise consisting of a combination of walking, jogging, and stationary cycling, performed 3 days per week. The combination of these modes allowed for specificity to both of our chosen exercise tests (treadmill GXT and Wingate cycle). The training intensity and duration followed ACSM guidelines and began at a low level (55%–60% HR reserve for 30 min) and progressed to higher levels over the 8-week period (75%–85% HR reserve for 45 min; Week 1 = 55%–65%, Week 2 = 65%–75%, Week 3 = 70%–80%, and Week 4–8 = 75%–85%). Intensity was verified by use of heart rate monitors and RPE. Both heart rate and RPE were recorded at three equally spaced times during each exercise session by research assistants.

Blood Collection and Biochemistry
Both pre-and postintervention, venous blood samples (~20mL) were taken from subjects’ forearm via needle and vacutainer before (following a 10-minute rest period) and within 1 minute following both exercise tests. We chose to collect samples at the immediate postexercise time point because in most (but not all) studies, this time has been associated with the greatest magnitude of postexercise increase in our chosen markers. Lactate was measured in whole blood (Accutrend; Roche Diagnostics, Mannheim,
Germany). The remainder of blood was immediately processed, and plasma and serum was stored in multiple aliquots at −80°C until analyzed. All assays were performed in duplicate on first thaw.

Antioxidant capacity was measured in serum using the Trolox-equivalent antioxidant capacity (TEAC) assay using procedures outlined by the reagent provided (Sigma Chemical, St. Louis, MO), and as previously described (Rice-Evans 2000). The TEAC was measured only at rest (prior to the GXT), pre- and postintervention. Malondialdehyde (MDA) was analyzed in plasma using the method described by Jentzsch et al. (1996). Hydrogen peroxide and xanthine oxidase activity were measured in plasma using the Amplex Red reagent method as described by the manufacturer (Molecular Probes, Invitrogen Detection Technologies, Eugene, OR).

Dietary Records

All subjects were instructed to maintain their normal diet during the intervention period. Subjects completed 7-day food records during weeks 1 and 8 of the intervention. Records were analyzed for total kilocalories, protein, carbohydrate, fat, vitamin C, vitamin E, and vitamin A using Diet Analysis Plus (ESHA Research, Salem, OR).

Statistical Analysis

Malondialdehyde, hydrogen peroxide, xanthine oxidase activity, and lactate were analyzed using a 3 (group) × 2 (exercise type) × 2 (time: pre/postexercise) × 2 (pre/postintervention) ANOVA. Where appropriate, significant interactions and main effects were further analyzed using Tukey’s post hoc tests. Dietary and descriptive data (e.g., weight, body fat percentage), as well as TEAC and exercise test variables (e.g., heart rate) were analyzed using a 3 (group) × 2 (pre/postintervention) ANOVA. Data are presented as mean ± SEM. The level of significance was set at $p \leq 0.05$. All analyses were performed using JMP statistical software version 4.0 (SAS Institute, Cary, NC).

RESULTS

Compliance to supplementation was measured every 2 weeks via capsule counts upon bottle return and was greater than 95% in all three groups, with no statistical difference between groups ($p > 0.05$). Exercise attendance (85%–91%) and ability to maintain the appropriate exercise intensity (90%–94%) was not different between groups ($p > 0.05$). Although only 32 subjects successfully completed all aspects of this study, a total of 42 subjects initially were enrolled and equally randomized to the three groups ($n = 14$ per group). Ten subjects were dropped, either due to their request or their
inability to maintain compliance above 80% for both supplementation and exercise training. No interactions or main effects were noted for any descriptive characteristic (e.g., age, body mass, body fat percentage; \( p > 0.05 \)). In addition, no interactions or main effects were noted for dietary variables \( (p > 0.05) \), with normal intake of total kilocalories, macro- and micronutrient intake noted (Table 2). Maximal heart rate or RPE were not different between groups or from pre- to postintervention for either the GXT or Wingate \( (p > 0.05) \). All subjects achieved a heart rate that exceeded 93% of maximum on the GXT and 90% for the Wingate, and reported an RPE \( \geq 17 \) for both tests (both pre- and postintervention, with no differences noted between groups or from pre- to postintervention; \( p > 0.05 \)). Total work performed during the Wingate test did not differ between the placebo \( (202 \pm 21 \text{ kJ}) \), GPLC-1 \( (178 \pm 19 \text{ kJ}) \), and GPLC-3 \( (168 \pm 18 \text{ kJ}) \) groups \( (p > 0.05) \), and increased 8%-12% from pre- to postintervention, with no difference detected between groups or across time \( (p > 0.05) \). Exercise test data are included in Table 3.

Antioxidant capacity as measured by TEAC was not different between placebo \( (0.61 \pm 0.07 \text{ to } 0.66 \pm 0.08 \text{ mmol}\cdot\text{L}^{-1}) \), GPLC-1 \( (0.58 \pm 0.06 \text{ to } 0.61 \pm 0.06 \text{ mmol}\cdot\text{L}^{-1}) \), and GPLC-3 \( (0.61 \pm 0.05 \text{ to } 0.65 \pm 0.04 \text{ mmol}\cdot\text{L}^{-1}) \), nor was TEAC different from pre- to postintervention \( (p > 0.05) \), with an average increase of 5%-8%. A time main effect was noted for blood lactate \( (p < 0.00001) \), with values increasing from 1.45 \pm 0.30 to 8.89 \pm 0.51 \text{ mmol}\cdot\text{L}^{-1} \) from pre- to postexercise, with almost identical values from pre- to postexercise for the GXT \( (1.44 \pm 0.32 \text{ to } 9.00 \pm 0.48 \text{ mmol}\cdot\text{L}^{-1}) \) and Wingate test \( (1.45 \pm 0.28 \text{ to } 8.70 \pm 0.51 \text{ mmol}\cdot\text{L}^{-1}) \). No other interactions or main effects were noted for blood lactate \( (p > 0.05; \text{ Table 3}) \).

Regarding the oxidative stress biomarkers, a group by pre/postintervention interaction was noted \( (p = 0.044) \) for MDA, as well as a group main effect \( (p = 0.040) \). Values were lower for both GPLC groups following the intervention compared with preintervention. No other interaction or main effects were noted for MDA \( (p > 0.05; \text{ Figure 1}) \). A time main effect was noted for

### Table 2: Subject Dietary Data During Weeks 1 and 8 of an 8-Week Intervention of Aerobic Exercise with or without GPLC Supplementation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Placebo pre</th>
<th>Placebo post</th>
<th>GPLC-1 pre</th>
<th>GPLC-1 post</th>
<th>GPLC-3 pre</th>
<th>GPLC-3 post</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kilocalorie</td>
<td>1800 ± 120</td>
<td>2159 ± 174</td>
<td>2059 ± 168</td>
<td>1988 ± 210</td>
<td>1800 ± 174</td>
<td>1643 ± 120</td>
</tr>
<tr>
<td>Protein (g)</td>
<td>74 ± 8</td>
<td>85 ± 11</td>
<td>83 ± 10</td>
<td>81 ± 11</td>
<td>76 ± 9</td>
<td>69 ± 6</td>
</tr>
<tr>
<td>CHO (g)</td>
<td>223 ± 20</td>
<td>253 ± 24</td>
<td>241 ± 21</td>
<td>243 ± 32</td>
<td>233 ± 22</td>
<td>203 ± 21</td>
</tr>
<tr>
<td>Fat (g)</td>
<td>67 ± 7</td>
<td>80 ± 6</td>
<td>75 ± 5</td>
<td>67 ± 9</td>
<td>75 ± 8</td>
<td>62 ± 7</td>
</tr>
<tr>
<td>Vit C (mg)</td>
<td>85 ± 27</td>
<td>61 ± 18</td>
<td>56 ± 12</td>
<td>52 ± 15</td>
<td>68 ± 15</td>
<td>81 ± 20</td>
</tr>
<tr>
<td>Vit E (mg)</td>
<td>4 ± 2</td>
<td>5 ± 1</td>
<td>6 ± 2</td>
<td>5 ± 2</td>
<td>6 ± 2</td>
<td>5 ± 1</td>
</tr>
<tr>
<td>Vit A(RE)</td>
<td>866 ± 111</td>
<td>872 ± 157</td>
<td>864 ± 138</td>
<td>812 ± 115</td>
<td>921 ± 101</td>
<td>615 ± 87</td>
</tr>
</tbody>
</table>

Data are mean ± SEM. No interaction effects, time main effect, or treatment main effects were noted for any dietary variable \( (p > 0.05) \).
TABLE 3 Peak Exercise Test Variables Before and After an 8-Week Intervention of Aerobic Exercise with or without GPLC Supplementation

<table>
<thead>
<tr>
<th>Variable</th>
<th>Placebo pre</th>
<th>Placebo post</th>
<th>GPLC-1 pre</th>
<th>GPLC-1 post</th>
<th>GPLC-3 pre</th>
<th>GPLC-3 post</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR (bpm)</td>
<td>189 ± 4</td>
<td>186 ± 4</td>
<td>187 ± 3</td>
<td>185 ± 5</td>
<td>188 ± 4</td>
<td>187 ± 5</td>
</tr>
<tr>
<td>RPE</td>
<td>18 ± 1</td>
<td>17 ± 1</td>
<td>17 ± 2</td>
<td>18 ± 1</td>
<td>17 ± 2</td>
<td>17 ± 1</td>
</tr>
<tr>
<td>Lactate (mmol L⁻¹)</td>
<td>8.7 ± 0.32</td>
<td>9.0 ± .48</td>
<td>8.9 ± 0.42</td>
<td>8.7 ± 0.49</td>
<td>9.1 ± 0.38</td>
<td>8.9 ± 0.41</td>
</tr>
<tr>
<td>RER</td>
<td>1.22 ± 0.08</td>
<td>1.19 ± 0.10</td>
<td>1.20 ± 0.10</td>
<td>1.15 ± 0.11</td>
<td>1.22 ± 0.13</td>
<td>1.18 ± 0.11</td>
</tr>
<tr>
<td>Exercise time (sec)</td>
<td>624 ± 16</td>
<td>629 ± 18</td>
<td>607 ± 40</td>
<td>630 ± 41</td>
<td>572 ± 21</td>
<td>578 ± 28</td>
</tr>
<tr>
<td>Exercise time (sec)</td>
<td>181 ± 3</td>
<td>182 ± 4</td>
<td>182 ± 3</td>
<td>180 ± 5</td>
<td>184 ± 4</td>
<td>182 ± 3</td>
</tr>
<tr>
<td>Lactate (mmol·L⁻¹)</td>
<td>8.2 ± 0.30</td>
<td>8.6 ± .37</td>
<td>8.1 ± 0.42</td>
<td>8.0 ± 0.51</td>
<td>8.4 ± 0.41</td>
<td>8.6 ± 0.49</td>
</tr>
</tbody>
</table>

Data are mean±SEM. No interaction effects, exercise type effects, pre/post-intervention effects, or group main effects were noted for any variable (p > 0.05).

1Represents data obtained for the GXT.
2Represents data obtained for the Wingate test.

Exercise time for the Wingate test was equal to 30 seconds for all subjects pre- and postintervention. Respiratory exchange ratio (RER) data were not collected during the Wingate test.
FIGURE 1 Plasma malondialdehyde (μmol·L⁻¹) before and following a GXT (A) and Wingate cycle test (B), before and following an 8-week intervention of aerobic exercise with or without GPLC supplementation.

Pre Ex 1 = Preexercise, preintervention; Post Ex 1 = Postexercise, preintervention.
Pre Ex 2 = Preexercise, postintervention; Post Ex 2 = Postexercise, postintervention.
*Group by pre/postintervention interaction (p = 0.044); group main effect (p = 0.040). No other interaction or main effects were noted for malondialdehyde (p > 0.05). Percent change values from pre- to postexercise are included above. Data are mean ± SEM.

hydrogen peroxide (p = 0.05), with values increasing from pre- to postexercise (Figure 2). No other interaction or main effects were noted for hydrogen peroxide (p > 0.05), although the group main effect approached statistical significance (p = 0.11). Both a time (p = 0.003) and group (p < 0.0001) main
FIGURE 2 Plasma hydrogen peroxide (μmol·L⁻¹) before and following a GXT (A) and Wingate cycle test (B), before and following an 8-week intervention of aerobic exercise with or without GPLC supplementation.

Pre Ex 1 = Preexercise, preintervention; Post Ex 1 = Postexercise, preintervention.
Pre Ex 2 = Preexercise, postintervention; Post Ex 2 = Postexercise, postintervention.
Time main effect (p = 0.05). No other interaction or main effects were noted for hydrogen peroxide (p > 0.05). Percent change values from pre- to postexercise are included above. Data are mean ± SEM.

effect were noted for xanthine oxidase activity, with values increasing from pre- to postexercise, and collectively lower for GPLC-3 compared with GPLC-1 and placebo. No other interaction or main effects were noted for xanthine oxidase activity (p > 0.05; Figure 3).
FIGURE 3 Plasma xanthine oxidase activity (µM/L) before and following a GXT (A) and Wingate cycle test (B), before and following an 8-week intervention of aerobic exercise with or without GPLC supplementation.

Pre Ex 1 = Preexercise, preintervention; Post Ex 1 = Postexercise, preintervention.
Pre Ex 2 = Preexercise, postintervention; Post Ex 2 = Postexercise, postintervention.
*Group main effect (p < 0.0001); time main effect (p = 0.003). No other interaction or main effects were noted for xanthine oxidase activity (p > 0.05). Percent change values from pre to postexercise are included above. Data are mean ± SEM.

DISCUSSION

Findings from this investigation indicate the following: (1) markers of oxidative stress are increased in response to both aerobic and anaerobic power testing, (2) the response does not differ between exercise modes, (3) an 8-week
intervention of aerobic exercise combined with GPLC supplementation decreases resting MDA, and (4) exercise training alone (at the intensity and duration performed here) or in combination with GPLC does not attenuate the increase in oxidative stress following aerobic or anaerobic power testing. Based on these findings, we accept our hypotheses that both forms of exercise would induce oxidative stress and that oxidative stress (with regards to MDA) would be lower following the intervention period as a result of GPLC supplementation. We must reject, however, our hypothesis that oxidative stress would be lower following the intervention of exercise training (with regards to all oxidative stress variables).

Although we noted small increases in TEAC (5%-8%) for all groups, these failed to reach statistical significance. It is possible that a greater increase in TEAC would have been related to more robust decreases in our oxidative stress biomarkers. These insignificant increases in TEAC partly could be due to our relatively short exercise intervention, coupled with the use of a moderate intensity exercise protocol. In relation to GPLC supplementation, while evidence exists for an antioxidant effect of this nutrient (DiGiacomo et al. 1993; Vanella et al. 2000), it may not be related specifically to TEAC, which is influenced primarily by albumin and uric acid (Rice-Evans 2000). The GPLC may exhibit antioxidant properties via other mechanisms, such as a free-radical scavenging activity (Vanella et al. 2000) and/or a regulation of fatty acid metabolism (Rauchova et al. 2002), which were not measured in the present study.

With the exception of the decrease in resting MDA in both GPLC groups and the insignificant decrease in resting MDA in the placebo group (7%; $p > 0.05$), minimal changes were observed in all groups with regards to resting hydrogen peroxide or xanthine oxidase activity. Moreover, the percent change values from pre- to postexercise were not different between exercise modes, between groups, or from pre- to postintervention (Figures 1-3). These findings indicate that in our population of previously untrained subjects, the oxidative stress response to aerobic and anaerobic power testing is similar, and does not appear affected by an 8-week intervention of aerobic exercise alone or in conjunction with GPLC supplementation. It is possible that the rise in oxidative stress following an acute exercise stress is necessary to promote adaptations related to upregulation of endogenous antioxidant defenses (Ji 2002; Ji et al. 2006). Additionally, because RONS play important roles in cell signaling (Haddad 2002), redox regulation of gene transcription (Liu et al. 2005), cellular immunity (Fialkow et al. 2007), and apoptosis (Lee and Wei 2007), it is probable that transient increases in oxidative stress following exercise serve useful purposes. Thus, RONS appear essential for normal physiological function, and minor increases in response to strenuous exercise in otherwise healthy individuals are likely not problematic.

Only a few studies have compared aerobic and anaerobic exercise modes in regards to the oxidative stress response using a crossover design.
Bloomer and colleagues (2005) noted a similar immediate postexercise increase in oxidative stress biomarkers following aerobic (cycling) compared with anaerobic (squatting) exercise when matched for exercise time. A recent investigation matched aerobic exercise (treadmill running) with climbing (intermittent isometric exercise) performed at the same percentage of VO₂max and noted greater oxidative stress following climbing exercise (Magalhaes et al. 2007). Alessio and coworkers (2000) noted higher lipid peroxidation following anaerobic (isometric handgrip) exercise and higher protein oxidation following aerobic exercise to exhaustion (treadmill test), when matched for total time. One additional investigation matched treadmill walking and resistance exercise with respect to heart rate and noted similar increases in lipid peroxidation (Vincent et al. 2004). Other studies have compared aerobic and anaerobic exercise in subjects performing one mode or the other, noting similar changes in oxidative stress biomarkers (Inal et al. 2001; Marzatico et al. 1997). Although the protocols have differed greatly across studies, data from prior studies agree with the findings presented here, in that both acute aerobic and anaerobic exercise induce oxidative stress to a similar extent. Although our percent change values in oxidative stress biomarkers were generally higher for the GXT compared with the Wingate test (Figures 1–3), these differences were not of statistical significance.

The generation of RONS may be associated with a variety of factors including increased oxygen flux through the mitochondrial electron transport chain, mechanical stresses, ischemia-reperfusion conditions (in particular in inactive skeletal muscle and organ tissue, which are deprived of blood flow during strenuous exercise), changes in blood borne variables, in addition to other factors as previously described (Jackson et al. 2007). Indeed, aerobic and anaerobic exercise modes rely on different metabolic pathways for ATP production, and have the ability to induce multiple distinct changes within biological systems. In the present study, as well as in most other human studies presented in the literature, only blood oxidative stress was measured. Therefore, it is unknown whether or not differing changes in skeletal muscle or organ tissue oxidative stress may have occurred. Moreover, we measured oxidative stress only before and within the 1 minute following exercise. It is possible that differences between exercise modes may have been present at times distant to our postexercise collection period. This is a limitation of the present study. Moreover, because we did not include non-exercise control groups (with and without GPLC supplementation) in our design, we cannot truly assess the independent contribution of GPLC in relation to the decreases observed in resting MDA.

Previous animal (Derin et al. 2004; DiGiacomo et al. 1993; Loster et al. 2001; Rauchova et al. 2002; Vanella et al. 2000) and human (Corbucci et al. 1990; Sachan et al. 2005) studies have reported a decrease in oxidative stress following supplementation with carnitine. To our knowledge, only one study has measured oxidative stress following carnitine supplementation in
response to acute exercise (Volek et al. 2002). Findings from the Volek et al. (2002) study oppose those of the present investigation, in that subjects consuming L-carnitine L-tartrate (2 grams per day for 3 weeks before performing a bout of resistance exercise) experienced a significant attenuation in xanthine oxidase activity. Despite this finding, the immediate postexercise response for MDA was similar between carnitine and placebo groups. It is possible that differences in the protocols used between the Volek et al. (2002) study and the present study could be responsible for the mixed results, as well as differences in the type of carnitine supplement used.

In summary, oxidative stress is increased to a similar extent in response to both aerobic and anaerobic power testing. Eight weeks of aerobic exercise combined with GPLC supplementation decrease resting MDA, but have little impact on hydrogen peroxide or xanthine oxidase activity either at rest or in response to acute exercise. It is probable that transient changes in oxidative stress in response to acute exercise are necessary for normal biological functioning.

REFERENCES


