Abstract: Lower body fat percentage is positively associated with climbing performance. This may lead climbers to practice unhealthy diet restriction when no sport-specific nutrition information exists. This study examined whether prolonged diet restriction affects body composition, oxidative stress, or other potential health risks in outdoor rock climbers. Two healthy male climbers conducted a 5 week rock climbing trip with a limited food budget ($1 each per day). Subjects underwent an energy restriction of approximately 40%. Loss of body weight and fat mass at week 5 were 5.8% and 16.1%, respectively, and were accompanied by significant subcutaneous fat loss in the iliac crest and abdomen. Triacylglycerols (TG), free fatty acids and C-reactive protein (CRP) dramatically decreased from baseline to week 2, and then maintained the lower level until week 5. Plasma vitamin C was below the normal range, and F2-isoprostanes, a marker of oxidative stress, continuously increased to week 5. Superoxide dismutase and glutathione peroxidase increased to week 2, but had returned to baseline levels at week 5. These results indicate that prolonged reduced energy intake while climbing may have an impact on weight loss and fat mass loss, which may contribute to low circulating TG and CRP, indicating improvements in markers of cardiovascular risk, and may lead to increased oxidative stress and reduced circulating antioxidants. Further studies are warranted to determine whether antioxidant supplementation or increased energy intake reduce oxidative stress.

Key words: rock climbing, body composition, energy restriction, oxidative stress, antioxidants, C-reactive protein.

Résumé : Un pourcentage de gras corporel inférieur est associé à une meilleure performance en escalade. Puisqu’il n’y a pas encore des informations nutritionnelles spécifiques pour ces athlètes, ils sont à risque de pratiquer des régimes alimentaires restrictifs. Cette étude a évalué les effets d’un régime alimentaire restrictif sur la composition corporelle, le stress oxydatif et d’autres paramètres affectant la santé des escaladeurs à plein air. On a suivi deux escaladeurs masculins qui participaient à un voyage d’une durée de cinq semaines et qui avaient un budget d’un dollar par jour chacun. Leur régime alimentaire restrictif imposait une restriction calorique de 40 %. Des pertes de poids corporels de 5,8 % et de gras corporel de 16,1 % ont été observées après la cinquième semaine. La perte du gras sous-cutané était plus importante aux niveaux de l’abdomen et de l’iliaque. Une diminution drastique de triacylglycérols (TG), d’acides gras libres (FFA) et de la protéine C-réactive (CRP) dans le plasma a été observée à la deuxième semaine, et ces niveaux bas étaient maintenus jusqu’à la cinquième semaine. Une réduction de la vitamine C plasmatique était accompagnée d’une augmentation des F2-isoprostanes, indicateurs du stress oxydatif. L’activité des enzymes superoxyde dismutase et glutathion péroydase a augmenté durant les premières deux semaines, mais est retournée au niveau initial vers la cinquième semaine. Nos résultats indiquent que la restriction calorique en combinaison avec l’escalade à plein air influence : la perte de poids et de gras corporel qui pourrait influencer le niveau de TG et CRP plasmatique, ainsi affectant positivement des marqueurs du système cardiovasculaire; et une augmentation du stress oxydatif avec une réduction d’antioxydants plasmatiques. D’autres recherches sont nécessaires pour déterminer si des suppléments d’antioxydants ou une augmentation d’apport calorique pourrait réduire le stress oxydatif.

Mots-clés : escalade, composition corporelle, restriction calorique, stress oxydatif, antioxydants, protéine C-réactive.
Introduction

Rock climbing is a high-energy sport. Elite rock climbers have a small to moderate body stature, with great shoulder girdle endurance, high overall strength, a high grip strength to body weight ratio, and a very low percentage of body fat (Watts et al. 1993, 2003; Grant et al. 1996). A lower percentage of body fat in elite climbers has been positively correlated with level of difficulty. This may influence laxative and diuretic use, as well as the development of eating disorders, among rock climbing competitors who want to decrease fat mass. In other situations, budget, access to food, and food preparation are limited for outdoor rock climbers. These factors, separately or combined, could lead to low nutritional status in this athletic group, where no sport-specific nutrition information exists.

Studies of energy-restricted athletes generally show decreased performance, although results can be controversial. High-intensity treadmill exercise and cycle test performance declined when participants were restricted to 40% of usual energy intake (Bender and Martin 1986) and to 20 kcal·kg⁻¹·day⁻¹, respectively (Rankin et al. 2006). However, Zachwieja et al. (2001) showed consumption of 750 kcal·day⁻¹ for 2 weeks did not impair performance in treadmill running or resistance exercises, despite the loss of lean muscle mass. There is currently no information regarding energy restriction in rock climbers.

Oxidative stress (OS) may decrease athletic performance. OS is characterized by a rise in free radical production, including reactive oxygen species (ROS), that outweighs antioxidant defense (Finaud et al. 2006), causing cell damage or cell death. During and immediately after aerobic and anaerobic exercise, levels of ROS in circulation and skeletal muscle tissue increase. In an overtraining athlete, ROS generation increases while antioxidant defenses decrease (Balakrishnan and Anuradha 1998). This imbalance of oxidants and antioxidants may contribute to muscular fatigue during prolonged or intense exercise (Reid 2001; Finaud et al. 2006). Interestingly, energy restriction has been shown to decrease OS (Lee and Yu 1990; Drew et al. 2003). The combined effect of energy restriction and exercise on OS is of interest.

This case study was designed to examine OS in outdoor rock climbers during prolonged reduced dietary and, thus, energy intake. Consequences on anthropometric parameters, body composition, and OS-related markers were examined. This information would be useful to competitive and recreational climbers who desire weight and fat loss, or who have difficulty with meal planning in an outdoor setting.

Materials and methods

Subjects

Two healthy male adult rock climbers planned a 1 month self-organized rock climbing and camping trip. Their restricted budget ($1 each per day) limited dietary intake. During the week, they consumed primarily short-grain white rice, bannock, soup, tuna, and peanuts; on the weekends, they received donations from visitors. This lifestyle and restricted diet were self-imposed by the 2 males, which attracted the attention of the authors. The subjects (ROCK1 and ROCK2) were 21 years of age, Caucasian, nonsmoking, nonvegetarian, and generally healthy university students who resided in the city. Height (cm), mass (kg), and body mass index (kg·cm⁻²) for ROCK1 were 188.4, 82.5, and 23.2, respectively; and for ROCK2 were 175.2, 81.7, and 26.6, respectively. ROCK1 and ROCK2 are described as having an intermediate climbing ability; their most difficult climbs were 5.11 and 5.11a on top rope, and V4 and V5 in bouldering, respectively, on the Yosemite Grading Scale (Sheel 2004). The study was approved by the Joint-Faculty Research Ethics Board, in accordance with the Tri-Council Policy Statement, at the University of Manitoba, and subjects gave written informed consent.

Study timeline

Subjects were observed at baseline, 1 week prior to their departure, and for 5 weeks (W1, W2, W3, W4, and W5) during a climbing and camping trip in an Ontario portion of the Canadian Shield, 3 h from the city of Winnipeg. Frequent weekly sampling was planned to observe closely any changes in experimental parameters. At the end of each week (Saturday), a trained technician was sent out to the campsite to conduct assessments and to obtain the subjects’ journals. Blood samples were only collected at baseline, W2, and W5.

Diet analysis

Subjects were instructed by a registered dietitian and provided with regular kitchen measuring cups, food scales, and journals to document 5 day dietary records (Wednesday, Thursday, Friday, Saturday, and Sunday) for all timepoints (baseline to W5). Energy, macronutrient, and micronutrient intakes were analyzed using Diet Analysis Plus (version 7, Thomson Wadsworth, Thomson Corporation).

Activity level

Subjects were provided with journals to describe all activities, including the following information: type and duration of exercise, difficulty and number of attempts of rock climbing routes, and number of hours of rest. Energy expenditure (kcal) was estimated each day, using metabolic equivalents (METs) (American College of Sports Medicine 2005). Activity-specific METs, representing energy expended while actually gripped onto a route, were multiplied by the number of hours of activity (or rest), and the sum was divided by 24 h to obtain the average activity factor. This value was then multiplied by the subjects’ resting metabolic rates, predicted from the Mifflin equation (Frankenfield et al. 2003), to yield energy expenditure for that day.

Physical assessment

Fasted body mass and subcutaneous fat (skinfold) were measured every week. Skinfold measurements were taken with a 60 mm caliper, to the nearest 0.5 mm, at 8 sites on the right side of the body: triceps, bicep, subscapula, abdominal, iliac crest, supraspinale, front thigh, and mid calf. Fat mass and fat-free mass were assessed using a portable bioelectric impedance analysis body composition analyzer (Quantum II, RJL Systems, Clinton Township, Mich.). All measurements were performed routinely, at a similar time in the morning (just after waking), before any food or beverage.  

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age consumption and before exercise. Measurements were always taken on the right side of the body.

Blood collections

Whole blood was collected at baseline, W2, and W5, after at least 14 h of fasting. At W2 and W5, blood was collected in a local clinic, by special arrangement, on a Wednesday and a Thursday, respectively. After centrifugation, plasma and red blood cells (RBCs) were aliquoted into microcentrifuge tubes and stored at −80 °C.

Oxidative stress

Vitamin C

Plasma was diluted 10 times with 5% trichloroacetic acid (TCA), and then centrifuged for 5 min at 8000 r-min⁻¹. The supernatant (300 µL) was combined with 100 µL of DTC solution (0.1 g thiourea, 0.0125 g CuSO₄, and 0.75 g 2,4-dinitrophenyl hydrazine, brought to 25 mL in 9 N H₂SO₄), 65% H₂SO₄ was added, and the mixture was incubated at 37 °C for 3 h. After incubation, 500 µL of 65% H₂SO₄ was added, and the mixture was incubated at room temperature for 30 min. Samples were read by spectrophotometry at 520 nm, and compared with a known standard curve from ascorbic acid (Sigma, St. Louis, Mo.) dissolved in 5% TCA.

Lipid peroxidation

Plasma F2-isoprostanes were assayed using an 8-Isoprostane EIA kit (Cayman Chemical, Ann Arbor, Mich.). Special attention ensured that the samples did not undergo any previous freeze–thaw cycles, since this increases the concentration of F2-isoprostanes.

Antioxidant enzymes

Superoxide dismutase (SOD), glutathione peroxidase (GPx), and catalase (CAT) activities were measured in RBCs. SOD analysis was done with a kit (R & D Systems Inc., Minneapolis, Minn.). During RBC preparation, Mn- and Fe-SOD were inactivated with chloroform–methanol (37.5:62.5, v/v), as indicated in the kit protocol. GPx activity was assessed with a colorimetric assay (Oxford Biomedical Research, Oxford, Mich.). CAT activity in RBCs was calculated directly, using the difference in absorbance at 240 nm in the presence of hydrogen peroxide. All spectrophotometry readings for antioxidant enzyme kinetics used SWIFT kinetics software, version 1.01 (Amersham Pharmacia Biotech, Uppsala, Sweden). All antioxidant enzyme results were expressed as U-mg⁻¹ RBC protein. RBC protein was determined using the Bradford assay with bovine serum albumin standard (Sigma, St. Louis, Mo.).

Cardiovascular parameters

Test kits were used to determine plasma triacylglycerols (Diagnostics Chemicals Ltd., Oxford, Conn.), free fatty acids (Zen-Bio Inc., Research Triangle Park, N.C.), and C-reactive protein (CRP; ALPCO Diagnostics, Windham, N.H.) with a CRP detection limit of 0.124 ng·mL⁻¹.

Results

Subjects

Both subjects completed the trip without serious injury. Although no empirical data were collected, subjects indicated that they suffered some overuse injuries, notably soreness in the hands and fingers. Overall, upon return, subjects reported feeling in better physical shape.

Dietary intake

Dietary intake was consistent from Monday to Friday; subjects consumed around 2000 kcal·d⁻¹, roughly 1200 kcal less than their required energy needs, representing an energy restriction of approximately 40% (Table 1). Weekend energy balance was inconsistent; varied intakes were due to indulgences of donor-provided food and beverages. Subjects did not maintain adequate carbohydrate or protein intake, but consumed sufficient fat on weekdays (from cooking oil, prepared instant soup noodles, and peanuts). Intakes of vitamins A, C, D, and E, and of calcium, zinc, and riboflavin were poor from W1 to W5. Poor intakes of vitamin C, vitamin E, and magnesium were present at baseline (Tables 2 and 3), according to Dietary Reference Intakes (Institute of Medicine 2001). Subjects maintained hydration, with an average daily water intake of 2–3 L.

Physical assessment

By W5, ROCK1 and ROCK2 had lost 4.2% and 7.3% of their total body mass, respectively (Fig. 1a). Fat-free mass dropped and remained below baseline values throughout the 5 week period, with the most notable loss (2.7% and 5.6% of total fat-free mass, respectively) occurring at W3 for both subjects (data not shown). Fat loss at W5 was 14.9% for ROCK1 and 17.4% for ROCK2 (Fig. 1b). Subcutaneous fat loss occurred mostly around the iliac crest and abdomen. (Fig. 2)

Oxidative stress

Vitamin C concentration in plasma decreased from baseline to W5 (Table 3). Plasma vitamin C in ROCK1 plummeted to just below normal range at W2 and W5. ROCK2 was below the normal range at baseline, and continued to decrease until W2. No changes were identified in vitamins A or E.

The oxidative stress biomarker F2-isoprostanes continued to increase in plasma from baseline to W5 (Table 3). Antioxidant enzyme activities of SOD and GPx increased from baseline to W5; CAT decreased oxidant enzyme activities of SOD and GPx increased from baseline to W2, and then decreased at W5; CAT decreased from baseline to W2, and then increased at W5 (Table 3).

Cardiovascular parameters

Plasma triacylglycerols and free fatty acids decreased from baseline to W5 (Fig. 3). No changes were identified in cholesterol. CRP, the inflammatory and cardiovascular risk marker, decreased dramatically in plasma, by 97%–99%, from baseline to W2, and remained relatively stable, at low concentrations (<0.2 µg·mL⁻¹), until W5. Concentrations of CRP were within normal range for healthy persons (<5 µg·mL⁻¹) at W5, according to CRP ELISA kit notes (ALPCO Diagnostics, version 02.06.03).

Discussion

This is the first study to consider both energy restriction and oxidative stress in rock climbers. The most interesting
findings of this study were the important loss of fat mass, specifically in the abdominal region, the oxidative stress that occurred while antioxidant defenses seemed depressed, and the reduction in cardiovascular risk markers.

Physical assessment
The amplitude of change in fat-free mass varies among investigations. Our study showed that combined energy restriction and physical activity caused a decrease in fat-free mass, which agrees with others (Johnson et al. 1994; Friedlander et al. 2005). The preferential depletion of subcutaneous fat from the abdominal region supports the notion that energy restriction and exercise promote abdominal fat loss (Wirth and Steinmetz 1998; Ibañez et al. 2005). Whether rock-climbing-specific exercise promotes higher rates of abdominal fat reduction cannot be concluded.

Influences of exercise, energy, and antioxidant restriction on oxidative stress
While energy restriction decreases OS, exercise and overtraining can initiate ROS production. Many animal studies have shown that long-term energy restriction combined with wheel running or swimming can reduce OS markers, enhance antioxidant enzyme activity (Kim et al. 1996; Aydin et al. 2007), and decrease the age-associated rise in OS (Seo et al. 2006). However, our study revealed increasing resting plasma F2-isoprostanes, suggesting that energy restriction for 5 weeks might have little effect on the reduction of OS. Plasma vitamin C in both subjects dropped below the normal range, which indicates reduced antioxidant status. Watson et al. (2003, 2005) demonstrated that inadequate antioxidant intake in athletes leads to OS. Thus, in our study, the OS in the subjects was most likely caused by the combination of high-intensity exercise and the low intake of antioxidants. The effect of energy restriction on decreasing OS may only be possible when the diet provides sufficient antioxidants.

Superoxide dismutase, GPx, and CAT activities tend to increase during and after training sessions, regardless of the physical activity level, as a protective response to free radical insult (Marzatico et al. 1997; Groussard et al. 2003). Moreover, long-term aerobic and anaerobic training leads to decreased generation of free radicals and increased blood and

**Table 1. Total energy and macronutrient intake at baseline, and during weekdays and weekends from week 1 to week 5.**

<table>
<thead>
<tr>
<th>Intake</th>
<th>Energy, kcal</th>
<th>Carbohydrate, g·kg⁻¹ body mass (% total energy intake)</th>
<th>Protein, g·kg⁻¹ body mass (% total energy intake)</th>
<th>Fat, g·kg⁻¹ body mass (% total energy intake)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROCK1 Baseline</td>
<td>3556±477</td>
<td>6.0±1.8 (55)</td>
<td>1.4±0.4 (13)</td>
<td>6.0±0.4 (30)</td>
</tr>
<tr>
<td>(n = 5) Weekend</td>
<td>2142±346</td>
<td>3.7±0.7 (57)</td>
<td>0.8±0.1 (12)</td>
<td>0.9±0.1 (31)</td>
</tr>
<tr>
<td>(n = 9)</td>
<td>3814±1782</td>
<td>5.7±2.3 (49)</td>
<td>1.2±0.4 (11)</td>
<td>2.0±1.0 (36)</td>
</tr>
</tbody>
</table>

**ROCK2 Baseline**
- (n = 5) 2864±779
- Weekday (n = 15) 1892±451
- Weekend (n = 9) 3723±1653

Suggested* 6.0–10.0
1.2–1.7
1.0

Note: ROCK1 and 2 values are means ± SD.

**Table 2. Antioxidant intake at baseline, and during weekdays and weekends from week 1 to week 5.**

<table>
<thead>
<tr>
<th>Vitamin intake</th>
<th>ROCK1 Baseline (5 d)</th>
<th>Weekday (15 d)</th>
<th>Weekend (9 d)</th>
<th>ROCK2 Baseline (5 d)</th>
<th>Weekday (15 d)</th>
<th>Weekend (9 d)</th>
<th>DRI*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitamin C (µg·mL⁻¹)</td>
<td>1456±646</td>
<td>200±157</td>
<td>515±424</td>
<td>876±368</td>
<td>148±134</td>
<td>630±569</td>
<td>900</td>
</tr>
<tr>
<td>C (mg·d⁻¹)</td>
<td>151±73</td>
<td>11±9</td>
<td>35±55</td>
<td>56±35</td>
<td>8±9</td>
<td>11±23</td>
<td>90</td>
</tr>
<tr>
<td>E (mg·d⁻¹)</td>
<td>18±11</td>
<td>7±2</td>
<td>10±11</td>
<td>2±2</td>
<td>4±2</td>
<td>12±14</td>
<td>15</td>
</tr>
</tbody>
</table>

Note: All values are means ± SD. DRI, dietary reference intakes.
*DRR from Food and Nutrition Board, Institute of Medicine, The National Academies (Institute of Medicine 2001).

**Table 3. Antioxidant status and oxidative stress at baseline and from week 1 to week 5.**

<table>
<thead>
<tr>
<th>Antioxidant status in plasma</th>
<th>ROCK1 Baseline</th>
<th>Week 2</th>
<th>Week 5</th>
<th>ROCK2 Baseline</th>
<th>Week 2</th>
<th>Week 5</th>
<th>Normal range*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitamin C (µg·mL⁻¹)</td>
<td>7.2</td>
<td>4.8</td>
<td>4.7</td>
<td>1.5</td>
<td>0.9</td>
<td>0.9</td>
<td>5.0–14.0</td>
</tr>
<tr>
<td>SOD (U·mg⁻¹ RBC protein)</td>
<td>0.0052</td>
<td>0.0070</td>
<td>0.0061</td>
<td>0.0013</td>
<td>0.0084</td>
<td>0.0060</td>
<td></td>
</tr>
<tr>
<td>GPx (mU·mg⁻¹ RBC protein)</td>
<td>34.51</td>
<td>41.20</td>
<td>35.73</td>
<td>31.37</td>
<td>34.34</td>
<td>29.69</td>
<td></td>
</tr>
<tr>
<td>CAT (U·mg⁻¹ RBC protein)</td>
<td>48.5</td>
<td>34.6</td>
<td>42.8</td>
<td>41.1</td>
<td>37.6</td>
<td>41.0</td>
<td></td>
</tr>
<tr>
<td>Plasma F2-iso (pg·mL⁻¹)</td>
<td>8.08</td>
<td>20.92</td>
<td>23.89</td>
<td>14.04</td>
<td>17.28</td>
<td>29.88</td>
<td></td>
</tr>
</tbody>
</table>

Note: SOD, superoxide dismutase; GPx, glutathione peroxidase; CAT, catalase; RBC, red blood cell; F2-iso, F2-isoprostanes.
*Normal range for plasma vitamin C is for males; values obtained from Mahan and Escott-Stump (2008).
tissue antioxidant enzyme activities immediately after exercise and at rest (Hellsten et al. 1996; Ortenblad et al. 1997; Miyazaki et al. 2001). In the current study, it seems that a protective response by SOD and GPx occurred within the first 2 weeks of rock climbing, since activity levels at rest were increasing during this time period. However, a decline in activities from W2 to W5 suggests a weakening of the antioxidant enzyme system due to overwhelming free radical production. This is supported by the increasing plasma F2-isoprostanes observed, although this conclusion cannot be confirmed here.

Cardiovascular parameters

CRP is a useful biomarker of inflammation and can be used to identify cardiovascular disease (Danesh et al. 2004). Long-term exercise decreases circulating CRP at rest (Pihl et al. 2003). Trained athletes and physically active former athletes had much lower resting CRP (0.4 and 0.8 μg·mL⁻¹, respectively) than sedentary controls and sedentary former athletes (1.5 and 1.59 μg·mL⁻¹, respectively) (Tomaszewski et al. 2003; Pihl et al. 2003). Furthermore, plasma concentrations below 1 μg·mL⁻¹ are associated with a very low risk of cardiovascular disease (Tomaszewski et al. 2003). Dietary n-3 fatty acid (especially docosahexaenoic acid) found in fish oil has been shown to decrease exercise-induced inflammation, by reducing CRP and IL-6, in healthy subjects (Phillips et al. 2003). However, n-3 fatty acid intake level or plasma concentration was not measured in this study. The level of CRP in both subjects decreased markedly below this level at W2, and stayed low until W5.

Fontana et al. (2004) showed that individuals consuming an energy restricted diet for 3–15 years had lower levels of triacylglycerols and CRP; CRP values were 1.6 μg·mL⁻¹ in controls and 0.3 μg·mL⁻¹ in the energy restricted group. Thus, energy restriction may have contributed to the sharp decline in CRP in our study subjects. Taken together with the loss of fat mass and the decrease in plasma triacylglycerols levels, markers of cardiovascular disease risk were improved in both subjects.
Conclusion

This study showed that prolonged energy restriction during high-energy-demanding rock climbing resulted in an increase in oxidative stress, but a decrease in risk markers of cardiovascular disease. Exactly how long these last beyond the study period is not known. Oxidative stress may have been caused by daily intense exercise, a lack of antioxidants in the diet, or a combination of both. These results reflect a case study of only 2 subjects; therefore, caution needs to be taken when generalizing to all outdoor rock climbers. However, this study needs the work and the great potential for further studies in this unique athletic group. Future studies should involve control groups for energy restriction, exercise, and antioxidant intake to allow for the determination of their independent and combined effects on oxidative stress and inflammatory markers. Antioxidant supplementation has proven benefits in other disciplines and, thus, warrants investigation in the sport of outdoor rock climbing.

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