ORIGINAL ARTICLE

Efficacy of a tart cherry juice blend in preventing the symptoms of muscle damage

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Background: Numerous antioxidant and anti-inflammatory agents have been identified in tart cherries.
Objective: To test the efficacy of a tart cherry juice blend in preventing the symptoms of exercise induced muscle damage.
Methods: This was a randomised, placebo controlled, crossover design. Fourteen male college students drank 12 fl oz of a cherry juice blend or a placebo twice a day for eight consecutive days. A bout of eccentric elbow flexion contractions (2 × 20 maximum contractions) was performed on the fourth day of supplementation. Isometric elbow flexion strength, pain, muscle tenderness, and relaxed elbow angle were recorded before and for four days after the eccentric exercise. The protocol was repeated two weeks later with subjects who took the placebo initially, now taking the cherry juice (and vice versa). The opposite arm performed the eccentric exercise for the second bout to avoid the repeated bout protective effect.
Results: Strength loss and pain were significantly less in the cherry juice trial versus placebo (time by treatment: strength $p<0.0001$, pain $p = 0.017$). Relaxed elbow angle (time by treatment $p = 0.85$) and muscle tenderness (time by treatment $p = 0.81$) were not different between trials.
Conclusions: These data show efficacy for this cherry juice in decreasing some of the symptoms of exercise induced muscle damage. Most notably, strength loss averaged over the four days after eccentric exercise was 22% with the placebo but only 4% with the cherry juice.

Cyclo-oxygenase inhibitory flavonoids[1 2] and anthocyanins with high antioxidant and anti-inflammatory activities[1 3 4] have been identified in tart cherries, which are considered good sources of phenolic compounds. This has led to speculation that cherry consumption may be effective in alleviating symptoms in inflammatory conditions.[4] Anti-inflammatory drugs and food products containing antioxidant nutrients have been studied extensively in the treatment and prevention of exercise induced muscle damage and its associated symptoms. Some studies have shown efficacy with anti-inflammatory drugs[5–10] whereas others have not.[11–14] Similarly, studies examining the effect of antioxidants—for example, vitamins C and E—on the symptoms of muscle damage have yielded inconsistent results.[15–20] Discrepancies in the observed effects may, in part, be related to factors such as differences in muscle groups studied, differences in magnitude of muscle damage between studies, study sample sizes relative to interindividual differences in symptoms of damage, between group study designs versus crossover designs, whether the treatment was given before eccentric exercise, after eccentric exercise, or both, and differences in dosages.

Consumption of about 45 cherries a day has been shown to reduce circulating concentrations of inflammatory markers in healthy men and women.[21 22] Considering the natural anti-inflammatory and antioxidant capacity of tart cherries, it is plausible that cherry consumption before and after eccentric exercise may have a protective effect. Therefore the purpose of this study was to test the effect of a tart cherry juice blend taken before and after eccentric exercise on the symptoms of muscle damage.

METHODS

Sixteen men (mean (SD) age 22 (4) years, height 1.78 (0.76) m, weight 90 (18) kg) volunteered to participate in this study. The protocol was approved by the institutional review board, and all subjects gave written informed consent.

Protocol

Four days before eccentric exercise, subjects reported to the laboratory for baseline testing and to be provided with the cherry juice or placebo. Their arms were randomly assigned to a treatment or placebo trial and randomly assigned to perform the treatment or placebo trial first. Pain, muscle tenderness, relaxed elbow angle, and isometric elbow flexion strength were measured. Inclusion criteria were no elbow flexor pain, no upper extremity strength training in the past three months, and no history of elbow or shoulder injury. Subjects were also instructed not to take any anti-inflammatory or pain relieving drugs during the course of the study, not to seek any other treatment for any symptoms of muscle damage, and not to exercise their upper extremities during the study. They were given 12 oz bottles of placebo or cherry juice and instructed to drink one bottle in the morning and the other in the evening for the next eight days. On the fourth day, subjects returned to the laboratory and performed a bout of eccentric elbow flexion contractions. On each of the following four days, pain, muscle tenderness, relaxed elbow angle, and strength were assessed. Two weeks after the initial baseline testing (six days after the end of the first trial), subjects returned to the laboratory and the protocol was repeated on the contralateral arm with either the placebo or cherry juice provided, as determined by previous randomisation. Subjects were scheduled to attend the laboratory for data collection at the same time each day for both the exercise session and four days of follow up data collection.

Treatment and placebo drinks

The cherry juice blend was prepared by mixing freshly prepared tart cherry juice with commercially available apple juice in a proprietary ratio (Cherrypharm Inc, West Hartford, Connecticut, USA). Frozen tart cultivar Montmorency cherries were used to prepare the cherry juice following standard procedures that simulate industrial processing. The blended juice was pasteurised by heating it to 85°C, hot packed into

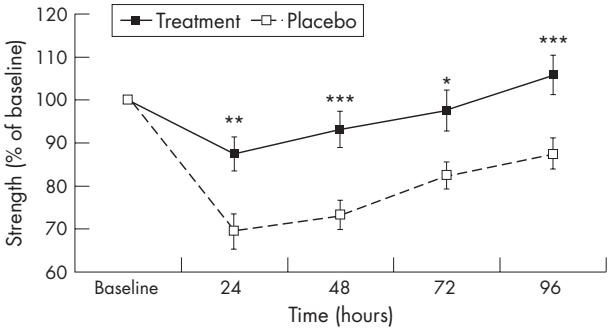

Figure 1 Isometric elbow flexion strength (expressed as a percentage of baseline strength) after eccentric exercise. Displayed values are averaged across all three test angles. Time by treatment $p<0.0001$; *$p<0.05$, **$p<0.01$, ***$p<0.001$ pairwise comparisons with Bonferroni corrections for treatment versus placebo values. Values are mean (SE).

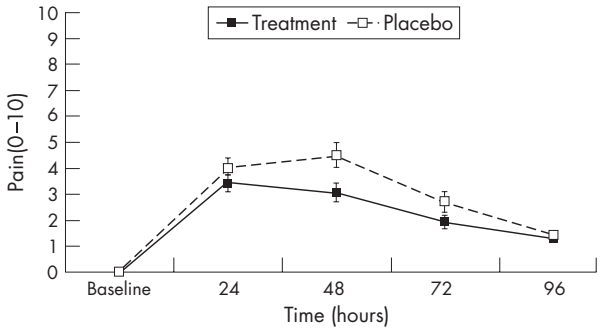

Figure 2 Subjective report of pain in the elbow flexors after eccentric exercise (0–10 scale). Time by treatment, $p = 0.017$. Values are mean (SE).

12 oz glass bottles with a three minute hold time to achieve commercial sterility, and then forced cooled in a water bath. One 12 oz bottle of the juice provided at least 600 mg phenolic compounds, expressed as gallic acid equivalents by the method of Singleton and Rossi,[23] and at least 40 mg anthocyanins, calculated as cyanidin-3-glucoside equivalents by the pH differential method described by Giusti and Wrolstad.[24] Each bottle contained the equivalent of 50–60 cherries.

The placebo was prepared by mixing unsweetened black cherry Kool-aid soft drink mix (Kraft Northamerica, Ryebrook, New York, USA; ingredients listed: citric acid, salt, calcium phosphate, red 40, artificial flavour, ascorbic acid, blue 1) with water in the proportion recommended by the manufacturer (about 2 g/l). Sugar was added to match the concentration of soluble solids in the cherry juice blend to a final concentration of 13 Brix (total percentage soluble solids by weight). The flavoured beverage was then pasteurised and bottled following the procedure used for the juice blend.

Eccentric exercise protocol

The exercise regimen for the induction of delayed onset muscle soreness consisted of 40 (2 × 20) maximal eccentric contractions of the elbow flexors using a modified preacher curl apparatus. In this study, the subject was instructed to apply maximal resistance through use of their elbow flexor musculature, while the investigator forced the subject's elbow into full extension. This was accomplished by pulling down on a lever that extended about 60 cm past an adjustable handle used to grip the lever by the subject. The added length of the lever past the handle provided a mechanical advantage over the subject's maximal flexion force, while requiring only limited effort to be exerted by the investigator. The subject's starting elbow angle position for each maximally resisted movement was full active elbow flexion (about 130° flexion). Subjects performed two sets of 20 maximal eccentric contractions, with a three minute rest period between sets. Each eccentric contraction lasted approximately three seconds, with 12 seconds of rest between actions.

Measurement of pain

Pain scores were obtained by asking subjects to verbally rate their overall discomfort during active elbow flexion and extension with activities of daily living on a scale of 0–10. A score of 0 indicated no discomfort whatsoever. A score of 10 indicated extreme pain and discomfort. Subjects were given a standard description for examples of daily activities which included brushing teeth, opening a bottle, driving a car, or opening doors.

Measurement of muscle tenderness

Muscle tenderness scores were assessed using a standard manual muscle myometer. Measurements were made just proximal to the distal tendon of the biceps brachii. All measurements are reported in Newtons (N). Force was applied via the probe through a 1 cm diameter head until the subject indicated pain or discomfort. At this point the force value (N) was recorded. Tenderness scores on the days after eccentric exercise were subtracted from baseline scores to provide a measure of tenderness, where zero equalled no tenderness. Previous studies have used a ceiling of 40 N for detecting muscle tenderness,[25 26] but it was felt that this obscured interindividual differences in tenderness sensitivity. For example, six subjects reported discomfort at less than 40 N at baseline on the treatment arm, and five subjects reported discomfort at less than 40 N on the placebo arm. Baseline tenderness was 47 (17) N on the treatment arm and 46 (15) N on the placebo arm. The system was calibrated daily using a balanced 1 kg mass, 2 kg mass, and 3 kg mass converted into Newtons (mass × 9.81 N).

Assessment of relaxed elbow angle

Elbow range of motion was assessed using a standard plastic goniometer (Lafayette Instrument, Lafayette, Indiana, USA) with the subject standing. The axis of the goniometer was placed over the lateral epicondyle of the elbow. The stationary arm of the goniometer was placed in line with the long axis of the humerus pointed at the acromion process. The movement arm was placed in-line with the long axis of the forearm. The placement locations of the goniometer axis, movement arm, and stationary arm were marked with permanent ink for consistency throughout trials.

Measurement of isometric elbow flexion strength

Subjects were tested on a modified, seated, arm curl (preacher) bench with the upper arm supported by a padded bench in about 45° shoulder flexion. Isometric strength was tested at three different elbow flexion angles: 130°, 90°, and 30°. The subjects grasped the handle attached to a movement lever mounted on the arm curl device. Force was recorded by a force transducer (model L-2352; Futek Inc, Irvine, California, USA) in series with chains attached to the test apparatus. Two trials were performed at each test angle with each contraction lasting three seconds, and 60 seconds rest between contractions. Peak strength values were recorded in Newtons, and the mean of the two trials served as the maximal isometric contraction strength score at that angle.

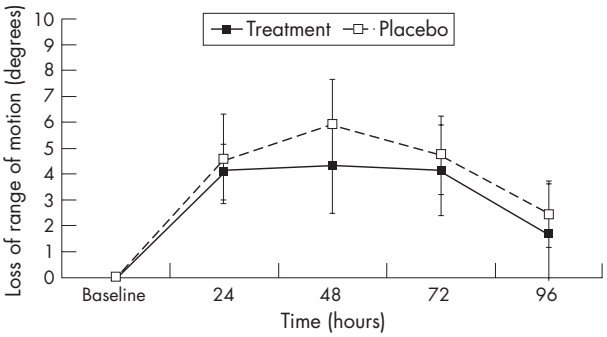

Figure 3 Changes in relaxed elbow angle after eccentric exercise. Time by treatment, p = 0.85. Values are mean (SE).

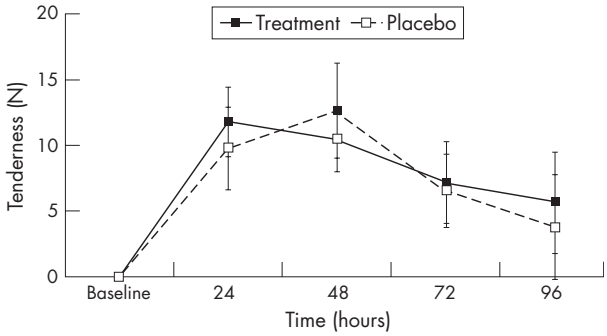

Figure 4 Changes in muscle tenderness after eccentric exercise. Time by treatment, p = 0.81. Values are mean (SE).

Sample size and statistical analysis

The sample size for this study was based on the difference in symptoms of muscle damage between arms using the same eccentric exercise protocol.[27] Based on the SD of the difference in strength loss between arms, it was estimated that, with a sample of 16 subjects, a 14% difference in strength loss could be detected between the placebo and cherry juice trials ($p<0.05$; power = 80%). The corresponding estimated effect sizes were 1.2 points for pain, 6 N for tenderness, and 6° for motion loss.

Changes in the symptoms of muscle damage (pain, tenderness, relaxed elbow angle, strength) between the cherry juice and placebo trials were assessed using treatment (cherry juice versus placebo) by time (baseline, 24, 48, 72, and 96 hours) repeated measures analyses of variance, with Bonferroni corrections on pairwise comparisons between placebo and treatment trials. Mean (SD) is reported in the text, and mean (SE) is shown in the figures.

RESULTS

Of the 16 subjects who started the protocol, two withdrew before completion. Both were students who left school at the end of the semester before completing the protocol. The remaining 14 subjects completed the study.

Isometric elbow flexion strength loss was significantly greater in the placebo trial than the cherry juice trial (treatment by time $p<0.0001$; fig 1). This effect was not different between test angles (angle by treatment by time p = 0.41). Strength loss (averaged across all three test angles) was 22 (12)% over the four days after the placebo trial but only 4 (15)% after the cherry juice trial ($p<0.0001$). Strength loss was not different between test angles (p = 0.31). In the placebo trial, strength loss was 24 (13)% at 130° of elbow flexion (short muscle length), 20 (16)% at 90°, and 20 (13)% at 30° (long muscle length). In the cherry juice trial, these values were 5 (19)%, 5 (18)%, and 2 (13)% respectively.

The development of pain in the elbow flexors after eccentric exercise was also significantly different in the placebo and cherry juice trials (treatment by time, p = 0.017; fig 2). Pain values (averaged across the four days) tended to be higher in the placebo trial (3.2 (1.1)) compared with the cherry juice trial (2.4 (0.7); p = 0.051). Pain peaked at 24 hours in the cherry juice trial (3.4 (1.2)) and subsequently declined, whereas pain continued to increase in the placebo trial to peak at 48 hours (4.5 (1.7)).

Loss of range of motion with the relaxed elbow angle measurement was not different between cherry juice and placebo trials (treatment by time, p = 0.85; fig 3). Mean motion loss for the four days after the cherry juice trial was 3.5 (6.0)° and 4.4 (5.6)° after the placebo trial.

Muscle tenderness was also not different between cherry juice and placebo trials (treatment by time, p = 0.81; fig 4). Mean tenderness for the four days after the cherry juice trial was 8.8 (9.7) N and 8.2 (10.1) N after the placebo trial (p = 0.84).

DISCUSSION

To our knowledge, this is the first study to examine the effect of consumption of cherries, or a cherry product, on symptoms of exercise induced muscle damage. Consumption of a cherry juice blend for three days before a bout of eccentric exercise and for the subsequent four days was shown to decrease some of the symptoms of muscle damage. Strength loss and pain were diminished in the cherry juice trial, but motion loss and muscle tenderness were unaffected.

A randomised crossover design was used because the variability in symptoms of muscle damage between limbs within a subject is typically less than the variability in symptoms between subjects.[27 28] The use of the contralateral arm rather than the same arm in the second trial (cherry juice or placebo depending on randomisation) avoided the impact of the repeated bout effect. Although it is well established that symptoms of muscle damage are diminished after a repeated bout of eccentric exercise, this protective effect does not cross over to the non-exercised limb.[28–30] Of the 16 subjects who began the study, nine started with the placebo trial and seven started with the cherry juice trial. However, the two subjects who left school before the end of the study started with the cherry juice trial. Therefore, only five of 14 subjects who completed the study started with the cherry juice trial. To verify that the apparent effect of cherry juice on diminished strength loss and pain was not due to a crossover protective effect, we reanalysed the data for the five subjects who started with the cherry juice trial. Despite the small sample size, the treatment by time interaction was significant for strength loss in this group of five subjects (p = 0.001). Strength loss was 3 (2)% for the cherry juice trial and 24 (3)% for the placebo trial. The treatment by time interaction was not significant for pain in these five subjects (p = 0.83). However, the pattern was similar to the whole group, with pain declining after 24 hours in the cherry juice trial and peaking at 48 hours in the placebo trial.

The lack of effect of cherry juice supplementation on muscle tenderness and relaxed elbow angle indicates that either these symptoms reflect different aspects of the injury response or the measurements were insensitive to real differences between cherry juice and placebo trials. Considering that muscle tenderness and pain typically follow the same time course, peaking two days after eccentric exercise of the elbow flexors,[25 26] it is unlikely that they reflect different aspects of injury. Tenderness and pain also peaked two days after exercise in the present study, and therefore the effect of cherry juice would have been expected to be apparent in both measures. The fact that the tenderness

measurement was only made at one site may have been a limiting factor. Tenderness was measured distally because peak tenderness has been shown to occur distally.[25 31] Although measurements at additional sites may have increased the ability to detect a difference between trials, it is important to note that tenderness values were very similar between the trials, indicating no effect of cherry juice supplementation. However, the tenderness measurement is a measure of the threshold of tenderness—that is, the force at which the subject first experiences discomfort. The measurement does not indicate the magnitude of tenderness for a fixed force application. Two studies have shown an effect of anti-inflammatory drugs on muscle tenderness.[7 8] The target muscle group was the quadriceps in both studies. In one study,[8] the subjects were asked to rate the soreness from 0 to 10 while a force transducer was pressed into the quadriceps at four different locations.[8] In the other study, the force required to elicit soreness was recorded from multiple sites on the quadriceps, and the product of soreness intensity (N) and area (number of 2 cm sites registering a soreness measurement below a ceiling of 50 N) was recorded for analysis.[7] The use of a larger muscle group and multiple sites probably improves the ability to detect treatment effects.

The relaxed elbow angle data reflect a similar lack of effect of cherry juice supplementation. Given that the average loss of motion was less than 5° in each trial and that the estimated effect size was 6°, this negative finding could be attributed to inadequate power to detect a real difference between trials. A more damaging eccentric exercise protocol or a larger sample size may be necessary to assess the effect of cherry juice supplementation on this marker of damage. Of note, only one of the six studies showing efficacy with anti-inflammatory drugs[5–10] used the elbow flexors,[10] and the relaxed elbow angle was not examined in that study.

Plasma or serum measures of myoglobin or creatine kinase activity are often used as markers of muscle damage, but were not used in this study. When using blood markers, it is important to control the activity levels of the subjects immediately before and during the study to ensure that other activities are not causing increases in these markers. Such restrictions were not thought to be necessary in this study because of the crossover design. In this study, subjects were screened for previous upper extremity strengthening exercise and instructed not to use their arms in strenuous activities during the study. However, they were not instructed to avoid exercising other body parts—for example, running—and therefore serum markers were not appropriate. Serum markers might be used in future studies where activity level is strictly controlled.

Although the results of this study indicate a protective effect of cherry juice, it is not possible to conclude that cherry juice supplementation prevented muscle damage, because only two of four indirect markers of damage showed an effect. However, there was clearly a preservation of muscle function attributable to the cherry juice. For the placebo trial, strength loss was 30% at 24 hours and still 12% at 96 hours after eccentric exercise. By contrast, in the cherry juice trial, strength loss was only 12% at 24 hours, and strength was actually 6% above baseline at 96 hours. Other studies have shown a treatment effect on isometric strength, but on a smaller magnitude. Loss of isometric knee extension strength was about 3% 24 hours after eccentric exercise in subjects taking ibuprofen four hours before exercise compared with about 13% for subjects taking a placebo.[7] Loss of isometric knee extension strength was about 15% 24 hours after eccentric exercise in subjects supplemented with vitamin C and E for 30 days compared with 27% in subjects taking a placebo.[19] By contrast, other studies have shown no effect of ibuprofen[11 13 14] or vitamin E and C[15–17 20] on strength loss.

What is already known on this topic

- Numerous antioxidant and anti-inflammatory agents have been identified in tart cherries, and consumption of cherries reduces circulating concentrations of inflammatory markers
- Many interventions have been studied for the prevention and treatment of exercise induced muscle damage but few have shown efficacy

What this study adds

- Consumption of cherry juice before and after eccentric exercise significantly reduced symptoms of muscle damage
- This is a practical intervention for alleviating the symptoms of muscle damage

Although it was not within the scope of this study to establish a specific mechanism of the preservation of strength, the hypothesis was that antioxidant and anti-inflammatory effects of cherry juice supplementation may lessen the damage response. The initial damage response of eccentric contractions is a mechanical disruption of myofibrils and injury to the cell membrane. When myofibrillar disruption is extensive, this triggers a local inflammatory response that leads to an exacerbation of damage.[32] Leukotrienes increase the vascular permeability, attracting neutrophils to the injury site, resulting in free radical production.[33] It is possible that the anti-inflammatory and/or the antioxidant effects of cherry juice mediated this secondary response and avoided the proliferation of myofibrillar disruption. This possibility could be examined in future work by measuring neutrophil and monocyte activation after eccentric exercise.

The apparent efficacy of this particular cherry juice in diminishing some of the symptoms of exercise induced muscle damage may be a function of the formulation of the drink. Consumption of about 45 cherries a day has been shown to reduce circulating concentrations of inflammatory markers in healthy men and women.[21] In the present study, each 12 oz bottle of cherry juice contained the equivalent of 50–60 cherries, and therefore subjects were consuming the equivalent of 100–120 cherries a day. In addition, the juice contained fresh cherries—that is, not from concentrate—and it is likely that this helped to preserve the phenolic compounds and anthocyanins. The concentrations of phenolic compounds and anthocyanins reported in the methods section can provide a reference for future studies examining the efficacy of similar supplements.

In conclusion, these data show efficacy for this cherry juice in decreasing some of the symptoms of exercise induced muscle damage. Most notably, strength loss averaged over the four days after eccentric exercise was 22% with the placebo but only 4% with the cherry juice. These results have important practical applications for athletes, as performance after damaging exercise bouts is primarily affected by strength loss and pain. In addition to being an efficacious treatment for minimising symptoms of exercise induced muscle damage, consumption of cherry juice is much more convenient than many of the treatments that have been presented in the literature.[33]

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Competing interests: the authors each have 2.5% equity in Cherrypharm Inc.

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COMMENTARY 1

The investigation offers originality and a significant contribution in the area of delayed onset muscle soreness and antioxidant/anti-inflammatory treatments. There are many studies in the literature on the use of more commonly known antioxidants such as vitamin C and vitamin E, with varying results. So this is both potentially promising and interesting.

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COMMENTARY 2

The question of what to do when muscles are sore and damaged has persisted for many years. An increasing number of studies have attempted to treat the symptoms of exercise induced muscle damage with strategies of growing complexity. Such treatments have included transcutaneous electrical stimulation, pulsed ultrasound, immobilisation, hyperbaric oxygen therapy, combined low intensity laser therapy/phototherapy, and compression sleeves, just to name a few. In many ways, these treatment strategies do not represent a practical or realistic option for either the competitive or recreational athlete. Other choices available for people with sore and damaged muscle are pharmacological treatments such as non-steroidal anti-inflammatory drugs; however, some may hesitate to ingest these pharmacological agents because of potential side effects or gastric discomfort. Thus the choices for relief from exercise induced muscle damage are limited. This study may have taken an important step toward providing a sensible and realistic treatment option for those suffering from sore and damaged muscles. The scientific question of how to treat the damaged muscle is an important one, and these researchers should be applauded for finding a potential treatment that is not only practical, but one that can be enjoyed!

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