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Reap the Benefits of Beetroot Juice — Evidence Suggests It Improves Heart Health and Athletic Performance
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A diet rich in vegetables has cardiovascular benefits that have long been well documented. It's been proposed that these health effects may be due, in part, to vegetables' high nitrate content.

While nitrate is found in all vegetables, it's especially abundant in beetroot and leafy greens. Dietary nitrate lowers blood pressure, thereby helping protect the heart.1 Recent research suggests that dietary nitrate supplementation in the form of beetroot juice not only decreases blood pressure but also reduces the amount of oxygen needed during exercise and enhances athletic performance.2

The blood pressure and athletic performance benefits are likely mediated through the metabolic conversion of dietary nitrate (NO3) to biologically active nitrite (NO2) and then to nitric oxide. Nitric oxide has numerous functions in the body, including the regulation of blood flow, muscle contractility, glucose and calcium homeostasis, and mitochondrial respiration and biogenesis.3

This continuing education activity will provide a comprehensive review of recent research findings on the health benefits of beetroot juice and evaluate how nitrate lowers blood pressure, reduces the oxygen cost of exercise, and improves athletic performance.

Dietary Nitrate, Nitrite, and Nitric Oxide
Dietary nitrate is absorbed rapidly from the stomach and small intestine. About 25% of ingested nitrate enters the enterosalivary circulation, where it's reduced to nitrite by bacterial nitrate reductases from symbiotic anaerobic bacteria on the surface of the tongue. This nitrite is swallowed and reduced to nitric oxide in the acidic environment of the stomach or is absorbed via the gastrointestinal tract and reenters the circulation as nitrite.1

Nitric oxide is a potent vasodilator that governs systemic blood pressure and retards atherogenesis by inhibiting inflammatory cell recruitment and platelet aggregation. Nitric oxide is generated by two known pathways: the oxidation of L-arginine by endothelial nitric oxide synthase (NOS), requiring the presence of oxygen and several essential cofactors, and by the reduction of nitrate-derived nitrite to nitric oxide.1,3

Numerous cardiovascular pathologies (atherosclerosis and cardiovascular disease risk factors such as hypertension and hyperlipidemia) are associated with endothelial dysfunction and diminished nitric oxide activity. Nitrite derived from dietary nitrate provides an alternative source of vasoprotective nitric oxide via the nitrate-nitrite-nitric oxide pathway when conventional nitric oxide synthesis is impaired. Thus, during ischemia or hypoxemia (conditions that inactivate endothelial nitric oxide synthase), nitrate helps preserve nitric oxide production.1,3

Independent of its role as a source of nitric oxide, nitrite provides protection against ischemia/reperfusion injury in the myocardial, hepatic, renal, pulmonary, and cerebral vasculature. Nitrite also causes dose-dependent vasodilatation in the brachial artery of healthy individuals, indicating that it may have an important role in maintaining normal cardiovascular homeostasis.1

Lowering Blood Pressure
Webb and colleagues1 evaluated the effects of 0.5 L of beetroot juice (22.5 mmol of nitrate) on blood pressure, plasma nitrite concentrations, and endothelial function. Systolic blood pressure dropped 10.4 mm Hg three hours after ingestion, and diastolic blood pressure fell 8 mm Hg 2 1/2 hours after ingestion. Plasma nitrite increased twofold after beetroot juice ingestion, reached a peak at three hours, and correlated with the decreases in blood pressure. Researchers measured endothelial function by brachial artery flow-mediated vasodilation after ischemic occlusion of the forearm. Beetroot juice significantly prevented endothelial dysfunction induced by an acute ischemic insult in the forearm and attenuated ex vivo platelet aggregation.1

The researchers also evaluated the effect of spitting out all saliva during and after beetroot juice ingestion on blood pressure and plasma nitrate concentrations. Spitting out saliva interrupted the enterosalivary circulation,

thereby preventing nitrite-rich saliva from reaching the stomach. Compared with swallowing, spitting blocked the rise in plasma nitrite concentration, prevented the decrease in systolic blood pressure, and had no effect on platelet aggregation. Thus, the physiological effects of dietary nitrate are due to the production of nitrite from symbiotic anaerobic bacteria on the surface of the tongue rather than from the nitrate itself.1

Oxygen Cost of Exercise and Blood Pressure

Preliminary research suggested that consuming a large dose of pharmaceutical sodium nitrate (0.1 mmol/kg/day for three days) resulted in a lower oxygen cost during submaximal cycling.4 In practical terms, the nitrate supplementation improved exercise economy—the muscles used less oxygen for a given work rate. This finding was surprising and challenged a fundamental principle of human exercise physiology: During submaximal exercise, there's a predictable oxygen cost for a given work rate. Furthermore, the increase in oxygen uptake is linearly related to the increase in work rate, and this relationship can't be altered.

As a result, Bailey and other researchers in the United Kingdom became interested in whether they could obtain similar results when administering the nitrate dose in the form of nitrate-rich beetroot juice. This distinction is important since sodium nitrate is considered a drug, whereas beetroot juice is a natural food product individuals can readily include in the diet.2

Nitrate levels in vegetables and vegetable juices can vary considerably, depending on many factors. So to provide a consistent nitrate dose (approximately 5 to 6 mmol), most of the studies evaluating the effect of beetroot juice on the oxygen cost of exercise have used Beet It beetroot juice.

Bailey and associates evaluated the effect of beetroot juice consumption for six days on the oxygen cost of moderate- and high-intensity exercise, blood pressure, and plasma nitrite concentrations. The subjects consumed 0.5 L of Beet It (5.5 mmol of nitrate) or placebo (a black current cordial with negligible nitrate) for six days and completed a series of low- and high-intensity cycling tests on the last three days. On days 4 to 6, plasma nitrite concentration was significantly higher and systolic blood pressure was dramatically lower (8 mm Hg) in subjects who drank beetroot juice compared with placebo. The beetroot juice significantly reduced the oxygen cost of moderate-intensity cycling exercise by 19% and increased the time to exhaustion during high-intensity cycling by 17%.2

Bailey and colleagues5 conducted a follow-up study to determine the mechanisms by which beetroot juice lowered the oxygen cost of moderate-intensity exercise and improved tolerance of high-intensity exercise. Subjects consumed 0.5 L of Beet It (5.1 mmol of nitrate) or placebo (the black current cordial) for six days and completed a series of low- and high-intensity knee extensor exercises in the prone position on the last three days. Beetroot juice more than doubled plasma nitrite concentration and reduced the oxygen cost and rate of phosphocreatine breakdown during low- and high-intensity exercise. Compared with placebo, beetroot juice significantly lowered systolic blood pressure by 5 mm Hg and diastolic blood pressure by 2 mm Hg. Beetroot juice greatly reduced the oxygen cost of moderate-intensity knee extensor exercise by 25% and increased the time to exhaustion during high-intensity knee extensor exercise by 25%.5

Beetroot juice appears to lower the oxygen cost of exercise by reducing the total ATP cost of muscle force production—the muscles use less ATP to produce the same amount of work. Beetroot juice also decreases the breakdown of phosphocreatine (the limited reserve of high-energy phosphate that resynthesizes ATP), thus lessening muscle metabolic disruption.5 These changes may be due to an increased efficiency of mitochondrial oxidative phosphorylation or increased efficiency of calcium transport by the sarcoplasmic reticulum Ca-ATPases. Dietary nitrate supplementation also may improve exercise performance by increasing blood flow to the exercising muscles and improving the match between blood flow and oxygen uptake.5-7

Bailey and colleagues5 noted that the protective effect of nitrite on infarct size that's been reported in experimental models of myocardial ischemia may be due to a nitric oxide-mediated reduction in the energy (and oxygen cost) of contraction in the heart in addition to enhanced perfusion of ischemic areas.5

Vanhatalo and other UK researchers investigated the acute (2 1/2 hour) and chronic (up to 15 days) effects of dietary nitrate supplementation on blood pressure and the physiological responses to moderate-intensity and incremental cycling exercise. The subjects consumed 0.5 L of Beet It (5.2 mmol of nitrate) or placebo (the black current cordial). The exercise protocol (two moderate-intensity step tests followed by a ramp test) was repeated 2 1/2 hours following the first ingestion and after five and 15 days.3

Beetroot juice significantly elevated plasma nitrite concentration throughout the 15-day test period, and this was accompanied by a marked reduction in systolic (4 mm Hg) and diastolic (4 mm Hg) blood pressure. These effects tended to be more pronounced after 12 days of dietary nitrate supplementation. Compared with placebo, the oxygen cost during moderate exercise was acutely reduced by 4% after 2 1/2 hours and remained similarly lowered after five and 15 days of continual beetroot juice ingestion. While beetroot juice had no acute effects on

maximal oxygen uptake (VO2 max) and the gas exchange threshold, these parameters of aerobic fitness rose after 15 days of supplementation.3

The oxygen cost of moderate exercise didn't decrease as much as in previous studies, but the subjects' normal dietary nitrate intake wasn't restricted at any time during the study period.3

It's assumed that beetroot juice reduces blood pressure and the oxygen cost of exercise through the metabolic conversion of inorganic nitrate to bioactive nitrite and then nitric oxide. However, since beetroot juice also is rich in several metabolically active compounds (betaine, antioxidants, and polyphenols), it's uncertain whether the cardiovascular and physiological changes observed following beetroot juice ingestion can be attributed exclusively to its high nitrate content.8

For example, the amino acid betaine has been used in the treatment of cardiovascular disease. The high antioxidant content of beetroot juice may provide protection against exercise-induced oxidative stress. Beetroot juice also contains the polyphenols quercetin and resveratrol, which have been linked with mitochondrial biogenesis and an associated increase in aerobic capacity. Thus, beetroot juice has the potential to influence blood pressure and exercise performance via numerous pathways.8

Lansley and colleagues in the United Kingdom conducted a study to determine whether the physiological effects of beetroot supplementation (reduced blood pressure, lowered oxygen cost of submaximal exercise, and enhanced tolerance to a high-intensity workout) were due to the juice's high nitrate content. The researchers provided a nitrate-depleted beetroot juice to serve as a placebo, which was similar in appearance, odor, taste, and texture to the nitrate-rich beetroot juice. This allowed the researchers to isolate the effects of dietary nitrate from the other potential active ingredients found in beetroot juice and ensured a genuinely double-blind experimental design.8

The subjects consumed 0.5 L of Beet It (6.2 mmol of nitrate) or the nitrate-depleted beetroot juice placebo (0.003 mmol of nitrate) for six days. They engaged in treadmill exercise and knee extension tests on days four and five. The nitrate-rich beetroot juice significantly raised plasma nitrite concentration and decreased systolic blood pressure by 4% (5 mm Hg) compared with placebo. The nitrate-rich beverage also lowered the oxygen cost of walking by 12% and moderate- and high-intensity running by 7%. The nitrate-rich juice also increased the time to exhaustion during high-intensity running by 15% and during incremental knee extension exercise by 5%.8

The consumption of nitrate-depleted beetroot juice didn't alter any of the experimental variables at rest or during exercise compared with the nonsupplemented controls. These results indicate that the positive physiological effects of beetroot juice ingestion on blood pressure and exercise performance are due to the high nitrate content rather than other compounds.8

Beetroot Juice and Athletic Performance

Most studies evaluating the performance effects of beetroot juice have used time-to-exhaustion protocols, which test exercise capacity, not athletic performance, and have been criticized as having limited validity in the athletic setting. A superior test of the effectiveness of beetroot juice as an ergogenic aid would involve subjects covering a certain distance in the fastest time possible—a time trial.9

Lansley and colleagues9 evaluated the effect of beetroot juice consumption on power output, oxygen uptake, and performance during 4-km and 16.1-km cycling time trials. The subjects' normal dietary nitrate intake wasn't restricted at any time during the study. The competitive male cyclists consumed 0.5 L of Beet It (6.2 mmol of nitrate) or a nitrate-depleted beetroot juice placebo (0.0047 mmol of nitrate) and rested for 2 3/4 hours before completing either a 4- or 16.1-km bicycle time trial.

The nitrate-rich beetroot juice significantly increased plasma nitrite concentrations and decreased systolic blood pressure by 6 mm Hg. The oxygen uptake values weren't significantly different between the beetroot juice and placebo time trials. However, the nitrate-rich beetroot juice significantly increased mean power output during the 4-km time trial (292 vs. 279 watts) and the 16.1-km time trial (247 watts vs. 243 watts) compared with placebo. As a result, beetroot juice improved performance by 2.8% (11 seconds) in the 4-km time trial and by 2.7% (45 seconds) in the 16.1-km time trial. The improved time trial performance following beetroot juice ingestion was due to a significantly higher power output for the same oxygen uptake—7% to 11% greater power output per liter of oxygen consumed.9

Based on the length of time it took the subjects to complete the time trials, the results suggest that dietary nitrate supplementation has the potential to improve performance in events lasting five to 30 minutes. Statistical analysis to derive the true effect of the intervention indicated that dietary nitrate supplementation may have a practical and meaningful benefit for athletic performance.9 In the real world, an 11-second advantage in a 4-km cycling time

trial and 45-second advantage in a 16.1-km cycling time trial separate the podium finishers from the rest of the pack.

Beetroot Juice and Peripheral Artery Disease
In addition to the research examining the effects of beetroot juice on blood pressure and athletic performance, studies have evaluated its impact on exercise tolerance in patients with peripheral artery disease, a type of cardiovascular disease in which atherosclerotic occlusions impair blood flow to the lower extremities and cause intermittent claudication (ischemic leg pain that occurs with walking and improves with rest).

In one study, Kenjale and colleagues gave subjects 0.5 L of Biotta beetroot juice (9 mmol of nitrate) or placebo (orange juice with negligible nitrate content) three hours before undergoing a maximal cardiorespiratory exercise test.10

The beetroot juice significantly increased plasma nitrite concentration. Beetroot juice ingestion dramatically reduced diastolic blood pressure at rest and during the maximal cardiorespiratory exercise test. In addition, the subjects walked 18% longer before the onset of claudication pain and were able to walk 17% longer following the consumption of beetroot juice compared with those who received the placebo. Thus, beetroot juice ingestion significantly increased exercise tolerance by almost 20%—a statistically and clinically significant increase in functionality for a disease state characterized by reduced physical function and quality of life.10

In addition to the lower blood pressure, measures of gastrocnemius (calf muscle) tissue oxygenation suggest that increased tissue perfusion was responsible for the improvement in exercise tolerance. Since there was no change in endothelial function, researchers surmise that the beetroot juice probably improved peripheral blood flow in areas of tissue hypoxia by increasing nitric oxide production.10

Real-World Concerns
These findings have encouraged some endurance athletes to consider supplementing with inorganic nitrate salts (sodium or potassium nitrate) to reduce the oxygen cost of exercise and improve performance. This has raised concern among researchers, who caution against the uneducated and uncontrolled use of nitrate salts, and especially nitrite salts, to enhance performance. Nitrate salt is used to preserve food and is available at grocery stores; nitrite salt is available on the Internet.

While inorganic nitrate is nontoxic at higher doses, inorganic nitrite can cause serious harm at considerably lower levels. The LD50, or lethal dose, for nitrite (100 to 200 mg/kg) is comparable to that of cyanide. Nitrite toxicity is due to elevated methemoglobin levels (an oxidized form of hemoglobin that has an increased affinity for oxygen) and may cause life-threatening tissue hypoxia. In high doses, nitrite also may cause hypotension, especially if combined with other vasodilatory drugs.11

The researchers also note that nitrate-containing vegetable juice presents a potential risk if it's stored incorrectly. If bacteria that convert nitrate to nitrite contaminate the juice, high levels of nitrite could accumulate over time, which could be potentially harmful.11

Athletes and other individuals also may be confused about the differences between inorganic nitrate (found in dietary sources such as beetroot juice, vegetables, and nitrate salts), organic nitrates (eg, the drug nitroglycerine), and organic nitrites (eg, the drug amyl nitrite). Organic nitrates and nitrites are extremely potent vasodilators, and an unintentional overdose can lead to fatal vascular collapse. While the acute toxicity of inorganic nitrate is very low, any confusion that could lead to a large unintentional intake of organic nitrates or nitrites is potentially life threatening.11

On the other hand, consuming dietary nitrate from vegetables or vegetable juice is presumed safe.11-13 In fact, diets high in dietary nitrate are associated with reduced blood pressure and a decreased incidence in cardiovascular disease.11,12 Dietary nitrate may represent an effective treatment for hypertension in addition to current medication regimens.1,3,10,14 The Dietary Approaches to Stop Hypertension diet provides approximately 20 mmol of nitrate per day (about the amount provided in the Webb study and twice that provided in the Kenjale study) and has reduced blood pressure in both normal and hypertensive subjects.14

Individuals with cardiovascular disease or related risk factors should consult their physician before consuming a high-nitrate diet. Also, certain medications may adversely interact with a high-nitrate diet, including organic nitrate or nitrite drugs used for angina and PDE-5 inhibitors such as sildenafil citrate, tadalafil, and vardenafil.12

As with most substances ingested to affect the body's structure or function, the dosage and formulation often determine whether the effects are beneficial or detrimental. As with other nutritional supplements, it's essential to consider the risk/benefit ratio when evaluating the effects of dietary nitrate ingestion on human physiology. More

research is needed to determine the optimal amounts of dietary nitrate to reduce blood pressure and enhance athletic performance.12,13

For now, it's prudent to suggest clients follow the 2010 Dietary Guidelines for Americans and the USDA's MyPlate (www.choosemyplate.gov) recommendations to determine the amount of vegetables they should consume each day for optimal health.11-13

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Sources of Dietary Nitrate
Beetroot juice is an easy way to quickly ingest a substantial amount of dietary nitrate. However, some individuals may find the taste of beetroot juice unpleasant. Furthermore, it can cause red urine and stools. Fortunately, beetroots are just one of many vegetables that are high in nitrate. Leafy green vegetables tend to be the top sources.

The dose of dietary nitrate used in the research to reduce the oxygen cost of exercise, improve athletic performance, and lower blood pressure ranges from 300 to 500 mg.11 Clients can readily obtain these amounts through their diet. For instance, foods such as celery, cress, chervil, lettuce, red beetroot, spinach, and arugula (rocket or rucola) contain very high nitrate levels (more than 250 mg/100 g), and celeriac, Chinese cabbage, endive, fennel, kohlrabi, leeks, and parsley are among those with high nitrate levels (approximately 100 to 250 mg/100 g).14 More specifically, 1 cup of raw spinach contains approximately 900 mg of nitrate; 1/2 cup cooked collard greens, approximately 200 mg; 1 cup raw leaf lettuce, approximately 100 mg; and 1/2 cup vegetable juice, approximately 40 mg.14

Learning Objectives
After completing this continuing professional education activity, learners should be better able to:

1. Interpret how dietary nitrate increases nitric oxide production.

2. Assess how dietary nitrate reduces blood pressure.

3. Evaluate how dietary nitrate enhances exercise performance.

4. Compare three good sources of dietary nitrates.

Examination
1. The blood pressure-lowering benefits of consuming beetroot juice are due to the production of:
a. nitrate.
b. nitrite.
c. nitric oxide.
d. nitroglycerin.
e. amyl nitrate.

2. Beetroot juice appears to reduce the oxygen cost of exercise by:
a. reducing the total ATP cost of muscle force production.
b. reducing muscle metabolic perturbation.
c. elevating muscular creatine phosphate levels.
d. a and b
e. b and c

3. What ingredient in beetroot juice is likely responsible for its positive effects on blood pressure and exercise performance?
a. Nitrate
b. Antioxidants
c. Betaine

d. Quercetin
e. Resveratrol

4. In patients with peripheral artery disease, Kenjale and colleagues found that beetroot juice:
a. reduced gastrocnemius fractional tissue oxygen extraction during exercise.
b. lowered diastolic blood pressure at rest and during exercise.
c. had no effect on endothelial function.
d. a and b
e. a, b, and c

5. The Lansley cycling time trial study found that compared with placebo, high-nitrate beetroot juice ingestion:
a. significantly decreased systolic blood pressure.
b. significantly increased mean power output during the time trials.
c. significantly reduced oxygen uptake.
d. a and b
e. a and c

6. Individuals should avoid using which of the following to lower blood pressure or improve athletic performance?
a. Nitrate salts
b. Nitrite salts
c. Organic nitrates
d. Organic nitrites
e. All of the above

7. Medications used to treat angina (eg, nitroglycerin or nitrate preparations) and PDE-5 inhibitors (eg, sildenafil citrate, tadalafil, vardenafil) may adversely interact with a high-nitrate diet.
a. True
b. False

8. In high doses, nitrite may cause:
a. methemoglobinemia.
b. hypertension.
c. hypotension.
d. a and c
e. a and b

9. The nitrate dose in beetroot juice that's used in research to reduce the oxygen cost of exercise, improve performance, and lower blood pressure is:
a. 700 to 900 mg.
b. 500 to 700 mg.
c. 300 to 500 mg.
d. 100 to 200 mg.
e. None of the above

10. Which of the following vegetable(s) has/have a high content (more than 250 mg/100 g) of nitrate?
a. celery
b. broccoli
c. spinach
d. a and b
e. a and c

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