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Review Article

The Effects of Dietary Nitrate Consumption on Performance in Various Exercises: A Mini Review

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ABSTRACT

Background. There has been an increase in interest in the use of nitrate (NO3) supplementation to enhance exercise-related performance during the past ten years. Nitric oxide, a free radical gas involved in several physiological processes such as blood vessel vasodilation, mitochondrial respiration, and skeletal muscle contractile function, can be formed from dietary NO3 after ingestion. **Objectives.** This study aimed to review the literature on the effects of dietary nitrate consumption on performance in various exercises. M**ethods.** The narrative review is used to reach the aim of the study. **Results.** Increasing evidence suggests that dietary NO3 supplementation improves endurance performance through a combination of increased tissue oxygenation and improved metabolic efficiency in working skeletal muscle. Further data points to dietary NO3 exerting direct control over the skeletal muscle's contractile processes via altering calcium availability and sensitivity. **Conclusions.** The efficiency of dietary NO3 for improving exercise performance is influenced by response heterogeneity and sizable variability in the nitrate content of beetroot juice products; thus, the dose and the quality of the product, as well as training history, sex, and individual-specific features, should be taken into mind.

KEYWORDS: ***Nitrate, Sports, Performance, Nitric Oxide, Dietary Supplements, Exercise Science.***

INTRODUCTION

Dietary nitrate (NO3) supplementation to boost athletic performance in endurance and power-dependent sports has gained popularity during the past ten years. Ample oxygen delivery and utilization to active skeletal muscle tissue is required for endurance activities, distinguished by rhythmic contractions of large muscle groups lasting longer than 2 minutes such as 800-m run and 200-m swim (1). On the other hand, achieving success in power-dependent events (like Olympic weightlifting or the shot put) depends mainly on producing maximum force as rapidly as feasible.

Nitric oxide (NO), a free-radical gas involved in various physiological activities such as blood vessel vasodilation, mitochondrial respiration, and skeletal muscle contractile activity, is formed from the precursor compound NO3 (2). The L-arginine pathway is responsible for the ongoing endogenous production of NO in both the tissues and the vascular endothelium (3). However, NO

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can also be created by reducing NO3 to nitrite (NO2), particularly in circumstances involving intense physical effort when the demand for oxygenated blood to active tissue rises (4). The quantity of oxygen required by contracting skeletal muscles increases as exercise intensity increases, producing more metabolic waste products (such as hydrogen ions). Repeated contractions speed up the conversion of dietary NO3 to bioavailable NO by reducing the oxygen tension and pH level in the skeletal muscle microenvironment.

The pathways of nitric oxide (NO) production and exercise. The endogenous production of nitric oxide from L-arginine and the conversion of inorganic NO3 present in dietary sources (such as beets and spinach) to nitric oxide occur simultaneously. Saliva has a high concentration of NO3, which, when eaten, is quickly converted to NO2 by anaerobic bacteria in the mouth cavity. The upper gastrointestinal system absorbs any residual NO2 into the plasma as digestion occurs in the highly acidic conditions of the stomach. When there is a higher metabolic demand, such as during physical exercise, more oxygen is drawn from the peripheral circulation per unit of time by contracting skeletal muscles (5-7), further reducing NO2 to NO (4, 5) (Figure 1).

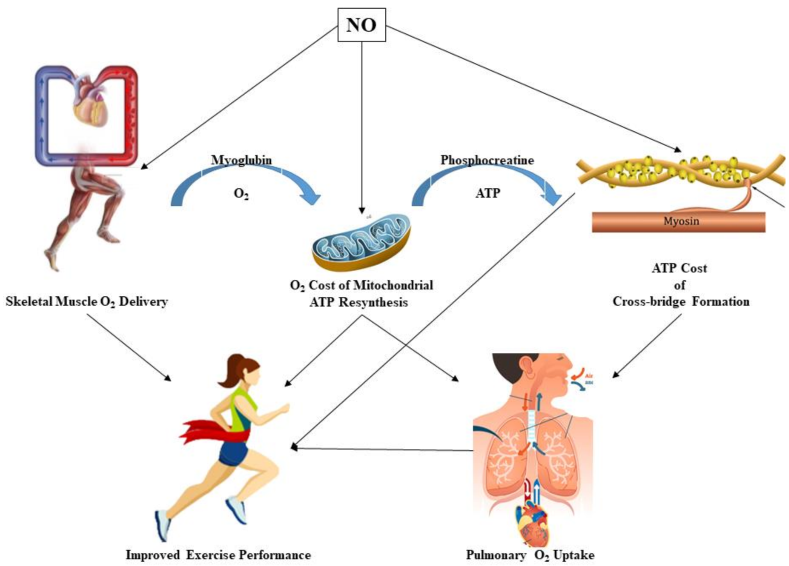

Figure 1. Physiological actions of Nitric oxide (Adapted from Hernández et al., 2012 (8))

A higher amount of NO is available to trigger effects on blood vessels and skeletal muscles during exercise than in resting or sedentary settings (9). The process by which exercise affects the conversion of NO3 to NO is shown in Figure 1. Athletic performance is impacted by NO's many roles in the control of blood flow, oxygen absorption, and skeletal muscle contractions (2, 10). So, in high-quality, placebo-controlled, double-blinded experiments, it has been demonstrated that dietary NO3 supplementation causes modest but substantial increases in the performance of endurance and power-dependent disciplines.

However, the degree to which dietary NO3- ingestion may affect performance varies and is probably influenced by elements such as the dosage of NO3 eaten, training history, sex, and other person-specific traits.

Dosing Methods and Supplements for Increasing Performance. Most research examining the impact of dietary NO3 supplementation on exercise performance relied on bottled beetroot juice drinks. Even though many leafy green and root vegetables contain NO3 (for example, Beetroot juice), a concentrated form of dietary NO3 provides more NO3 per volume. It is a desirable alternative for consumption before physical activity. For instance, an athlete might take 12 cups of raw spinach to get the same quantity of NO3 as in a single 140 mL (2/3 cup) dosage of beetroot juice sold commercially (11, 12). However, no guidelines exist for the bare minimum dietary NO3 required to increase exercise performance.

Improvements in endurance, power-dependent, and high-intensity intermittent exercise performance have been seen with doses of dietary NO3 ranging from 3.2 to 10.4 mg/kg body mass/1 taken either acutely (2–3 hours before exercise to coincide with peak plasma NO2 and NO3 levels) or chronically (over a few days to weeks) (Table 1). A minimum effective dosage of 527 mg has been proposed, comparable to 7.5 mg per kilogram of body weight for a 70 kg person (2). It is essential to remember that the NO3 level of commercially accessible beetroot juice varies widely and is seldom independently tested to substantiate the manufacturer's claims. For instance, 24 various beetroot juice drinks targeted at athletes had NO3 levels that varied by a factor of 50, according to Gallardo and Coggan14. Notably, only 2 of the evaluated items consistently supplied nitrate levels over the recommended minimum dosage (527 mg) for improving exercise performance in most people (2, 12). Therefore, it is advised that studies examining the impact of Nitrate supplementation on athletic performance use substances of known quality and dose and that researchers further confirm that the product's NO3 content is equal to the amount specified by the manufacturer through independent laboratory testing.

Nitrate Consumption Methods. The amount of Nitrate given varied from 4.84 mmol to 12.9 mmol per serving for acute studies and from 5.2 mmol per day to 29.0 mmol per 36 hours for chronic studies. In chronic studies, people consumed different amounts of nitrates. The lowest intake was 15. 6 mmol over three days, while the highest was 364. 0 mmol over 28 days. Most studies gave the participants Nitrate or beetroot juice 2 to 3 hours before exercise, except one study gave them an additional dose 1.5 hours before exercise (13).

Table 1. Doses of Nitrate Resulting in Improved Exercise-Related Performance Taken Within 24 Hours before Exercise

	Subject Characteristics	Nitrate Dose≈ (mg/kg Body Mass)
Endurance time-trial performance in events lasting 5–30 min	Combined (14-20)	6.9 (range, 3.2–10.4)
	Endurance-trained men (14-19)	6.9 (range, 3.2–10.4)
	Recreationally active men and women (20)	6.9
Maximal power during single leg extension, cycling, and running exercise	Combined (21-27)	6.5 (range, 4.5–9.8)
	Resistance-trained men or men with previous experience in power-dependent sports (i.e., football, CrossFit) (21, 23, 25-27)	5.1 (range, 4.5–6)
	Mixed sports (i.e., triathlon, tennis) men and women (22)	9.4
	Healthy men and women (24)	9.8
Intermittent high-intensity exercise performance	Combined (21, 28-32)	6.7 (range, 4.5–10.4)
	Team-sports players men (21, 28-32)	6.7 (range, 4.5–10.4)

Furthermore, differences in the subjects' baseline diet have not been considered in other research examining the impact of dietary NO3 on athletic performance. For instance, even though most interventional studies ask their participants to stick to their regular diet throughout the intervention period and to avoid foods high in dietary Nitrate (such as leafy green vegetables and rhubarb), it is frequently difficult to measure the additional dietary Nitrate ingested through dietary recall. Therefore, it is usually uncertain if the predicted 527 mg is the minimum recommended dosage for performance improvement.

Nitrate consumption and endurance performance. Substantial evidence supports the use of dietary NO3 supplementation for enhancing performance in endurance activities (such as cycling, running, and rowing) from placebo-controlled double-blinded trials (14, 16, 33-41). Because NO is a potent vasodilator, it improves blood flow (also known as tissue perfusion), which enhances oxygen supply to skeletal muscles that are metabolically active (17). Furthermore, it has been hypothesized that NO enhances the contractile function of skeletal muscle, implying that more muscular effort may be completed in a given amount of time at a given metabolic expenditure (2, 33, 35, 36, 42) (Table 2). With dietary NO3 supplementation, decreases in the metabolic cost (14, 34-37, 40, 41) and the impression of effort (38) have been seen throughout the continuous submaximal and maximal aerobic activity. This is likely because of enhanced tissue oxygenation and contractile function.

As a result, people have shown increased tolerance to high-intensity aerobic exercise after receiving dietary NO3 supplementation (16, 33, 34, 38, 39). According to the research of Bailey et al. (2009) and Lansley et al. (2011), following a 6-day supplementation treatment with 6 to 8 mg of NO3 per kilogram of body mass per day via beetroot juice, recreationally active males cycled +15 to +16% longer at an effort equivalent to more than 90% of their maximum aerobic capacity (16, 34).

Although dietary NO3 appears to have positive effects throughout high-intensity aerobic exercise, it is not as clear whether improving performance throughout low- to moderate-aerobic exercise, improving performance throughout low- to moderate-aerobic exercise, and improving performance throughout low- to moderate-aerobic exercise will improve performance. One of the most accurate methods for assessing submaximal endurance performance is laboratory-based time trial testing (43). Participants in this style of performance-based assignment must cover a predetermined distance as quickly as possible. Participants in this examination are often blinded to aspects of their performance, such as power, speed, and/or time. With dietary NO3 supplementation of 3 to 10 mg/kg body mass/day in men and women of varied fitness levels, performance increases of 0.5% to 3% for time trial activities lasting 5 to 30 minutes have been reported to occur (14-20, 44).

In contrast, no changes in performance were seen in response to substantially larger dietary NO3 dosages in the range of 18 to 25 mg kg body mass per day (45, 46) or with more extended time trials ranging between 30 and 140 minutes in both men and women (14, 19, 47-53). The computed effect sizes for dietary NO3 dosages relative to body mass that improved endurance performance in placebo-controlled and double-blinded laboratory-based tests are shown in Table 3. According to this graph, dietary NO3 intake and developments in endurance performance have a relationship that resembles an "inverted U" shape, with doses of about 6.8 to 6.9 mg/kg of body mass1 possibly having the best effects on exercise test results (14, 20).

Therefore, factors relating to the quantity of NO3-ingested and/or the intensity and consequent length of the event may impact the performance-enhancing effects of dietary NO3. In real life, the duration of a performance trial and the intensity that may be sustained during it are inversely connected. In the research by Shannon et al. (2017), for instance, endurance-trained men performed a 1500 m (5 minutes) and a 10000 m (45 mins) running time trial at an effort comparable to 86% and 78%, respectively, of their maximum aerobic capacity (19). Only the 1500 m time trial showed performance enhancement following acute Nitrate consumption (19). Dietary NO3 supplementation may be more advantageous for shorter-duration endurance races than longer-duration events.

Higher-intensity physical activity causes proportionally more cellular disturbances that lower oxygen and pH levels in the skeletal muscle following the frequency of shorter-duration events. As a result, after dietary NO3 supplementation, short-duration (30 minutes) endurance sports may enhance the decrease of NO2 to NO (5).

Nitrate consumption and power-dependent performance. Supplementation with NO3 may improve exercises that need quick bursts of power, such as sprinting (21) or weightlifting (28). Research from high-quality, placebo-controlled, and double-blind NO3 supplementation interventions shows that maximal power during single-leg knee extension, cycling, and running exercise is enhanced when dietary NO3 supplementation is administered either chronically for 5 to 6 days in men and women with different training histories or acutely within 2 to 3 hours of exercise (21, 22, 26, 27, 54). Changes in calcium availability and/or sensitivity in the contracting muscle fibers can be to blame, albeit the precise processes underlying increases in maximum power generation remain primarily unclear (24). Dietary NO3 dosages of between 5.5 and 23 mg/kg body mass have been shown to improve the contractile activity of muscles (23, 55).

These advantages of dietary NO3-induced increases in maximum power may transfer to improved performance in team sport-specific assessments. Dietary NO3 supplementation, whether acute or chronic, has improved total work output (13, 21, 28-31) and average power maintained33 throughout intermittent high-intensity laboratory-based testing with dosages corresponding to 4.5 to 10.4 mg/kg body mass. Others, however, have shown no benefit in team sport performance assessments when nitrate dosages of 10.4 mg/kg of body mass were given to young male basketball players or 10.8 mg/kg of body mass to top female water polo players (56).

The total effort completed during simulated team-sport matches and response times in male team-sport players were higher after 7 days of Nitrate supplementation than 10.4 mg/kg body mass/day of NO3. Thompson et al. (2015) also showed that male team sport players had quicker reaction times (30). According to Wylie et al. (2016), acute administration of Nitrate in male team sport players resulted in a 5% improvement in mean power output during repeated cycling sprints lasting six seconds each (32). This suggests that dietary NO3 intake may benefit specific forms of intermittent exercise performance.

In contrast, there was no variance in mean power for repeated sprints lasting 30 or 60 seconds (32). However, Dominguez et al. (2017) discovered that Nitrate increased peak power (23). However, the benefit was only present for the first five seconds of a 30-second maximal cycling assessment in men who had previously trained in sports that required power (23). No differences were found in the exercise sessions' later stages (23). Potential changes in muscle activation patterns may explain the discrepancies in exercise performance with NO3.

According to specific theories, dietary NO3 may target fast-twitch skeletal muscle fibers (57). If so, significant performance improvements following dietary NO3 supplementation would be anticipated during shorter-duration, explosive actions that call for fast-twitch muscle fibers. Coggan et al. (2018), however, found no correlation between baseline knee extensor muscle contractile properties, such as maximal shortening velocity or fatigue resistance (surrogate markers of muscle fiber type distribution), and the magnitude of the increase in muscle power after NO3 ingestion in healthy, untrained men and women (24). Supporting these conclusions, López-Samanes et al. (2020) discovered that the performance of movements requiring the recruitment of fast-twitch muscle fibers (i.e., countermovement jump height, 10 m/20 m sprint time, agility) in young male basketball players was unaffected by the administration of a beetroot juice supplement containing 10.4 mg/kg of body mass/day of NO3 (58).

Table 2. Summary of the studies that investigated the effect of Nitrate Consumption on Explosive Power

Study	Study design	Nitrate dosage	Exercise Mode and Muscle Group Tested	Outcome
Aucouturier et al. (2015) (29)	N=12 (males), physically active (22.8 ± 3.1 y) r, sb, crossover	500 mL beetroot juice (12.9 mmol NO3-) for 4 days, including the testing day (2 h prior exercise)	Isometric contractions (Knee extensors)	↔ MVC (N)
Bender et al. (2018) (59)	N=12 (males), recreationally active (16.8 ± 1.0 y) r, db, crossover	140 mL beetroot juice (12.9 mmol NO3-) 2.5 h prior exercise	Isometric contractions (mid-thigh)	↑ MVC (N)

Table 2. Continue

Clifford et al. (2016) (60)	N=20 (males), team-sports athletes (22 ± 2 y)	250 mL beetroot juice 2x/day (18.4 mmol NO3- day) 24, 48, and 72 h prior testing	Isometric contractions (Knee extensors)	↔ MVC (N)
Coggan et al. (2015) (54)	N=12 (7 males), normally active (36 ± 10 y) r, db, crossover	140 mL beetroot juice (11.2 mmol NO3-) 2h prior exercise	Isometric and isokinetic contractions (Knee extensors)	↔ MVC (Nm/kg) ↔ Peak Torque (Nm/kg) ↑ Peak Torque (% of isometric) at 360o.s-1
Coggan et al. (2015) (61)	N=9(5 males), patients with heart failure (57 ± 10 y) r, db, crossover	140 mL beetroot juice (11.2 mmol NO3-) 2h prior exercise	Isometric contractions (Knee extensors)	↔ MVC (Nm/kg)
Coggan et al. (2020) (62)	N=12 (6 males), older people (71 ± 5 y) r, db, crossover	140 mL beetroot juice (13.4 mmol NO3-) 3h prior exercise	Isokinetic contractions (Knee extensors)	↔ Peak Torque (Nm/kg) ↑ Peak Torque (% of isometric) at 360o.s-
de Oliveira et al. (2017) (63)	N=12 (3 males), older people (68.8 ± 3.5 y) r, db, crossover	100 g beetroot gel (12.2 mmol NO3-) 2.5 h prior exercise	Isometric contractions (Forearm flexors)	↔ MVC (N) ↑ Diff-MVC (N)
Fernandez-Elıas et al. (2020) (64)	N=9 (males), tennis players athletes (24.9 ± 4.2 y) r, db, crossover	70 mL beetroot juice (6.4 mmol NO3-) 3h prior exercise	Isometric contraction (Forearm flexors)	↔ MVC (N)
Fulford et al. (2013) (65)	N=8 (males), physically active (24 ± 4 y) r, db, crossover	500 mL beetroot juice (10.2 mmol NO3- day) for 5-15 days, including the testing day (2.5 h prior exercise)	Isometric contractions (Knee extensors)	↔ MVC (N)
Haider and Folland (2014) (66)	N=19 (males), untrained (21 ± 3 y) r, db, crossover	70 mL beetroot juice (9.7 mmol NO3- day) for 7 days, including the testing day (2.5 h prior exercise)	Isometric contractions (Knee extensors)	↔ MVC (N)
Hoon et al. (2015) (67)	N=18 (12 males), normally active (29 ± 6 y) r, db, crossover	250 mL beetroot juice (8.1 mmol NO3- day) for 4 days including the testing day (4 h and 2 h prior exercise)	Isometric contractions (Knee extensors)	↔ MVC (N)
Husmann et al. (2019) (38)	N=12 (males), recreationally active (27 ± 5 y) r, db, crossover	70 mL beetroot juice (6.5 mmol NO3- day) for 5 days, including the testing day (2 h prior exercise)	Isometric contractions (Knee extensors)	↑ Diff MVC (%)
Jonvik et al. (2020) (68)	N=15 (males), recreationally active (25 ± 4 y) r, db, crossover	140 mL beetroot juice (15.8 mmol NO3- day) for 6 days, including the testing day (3 h prior exercise)	Isometric contractions (Knee extensors)	↔ MVC (Nm)

Table 2. Continue

Kramer et al. (2016) (27)	N=12 (males), CrossFit athletes (23 ± 5 y) r, db, crossover	2 capsules potassium nitrate (8 mmol NO3 - day) for 6 days (not including testing day)	Isometric and isokinetic contractions (knee extensors and flexors)	↔ MVC (N) ↔ Diff MVC (%)
Lee et al. (2019) (69)	N=35 (26 males), physically active (23.6 ± 3.6 y) r, db, crossover	70 mL beetroot juice (4 mmol NO3-) 12 h and 2.5 h prior exercise	Isokinetic contractions (Knee extensors)	↔ Peak Torque (Nm)
Porcelli et al. (2016) (70)	N=7 (males), recreationally active (25 ± 2 y) r, sb, crossover	High nitrate diet (8.2 mmol NO3- day) for 6 days including the testing day	Isometric contractions (Knee extensors)	↔ MVT (Nm/kg)
Trexler et al. (2019) (71)	N=27 (males), recreationally active (22 ± 4 y) r, db, crossover	70 mL beetroot juice (6.4 mmol NO3-) 2h prior exercise	Isokinetic contractions (Knee extensors)	↔ Peak torque (N.m)
Wickham et al. (2019) (45)	N=12 (females), recreationally active (23 ± 1y) r, db, crossover	280 mL beetroot juice (26 mmol NO3- day) for 8 days, including the testing day (2.5 h before exercise)	Isometric contractions (Plantar flexors)	↔ MVC (Nm)

↑: significant elevation; **↔:** no effect; **MVC:** maximal voluntary contraction; **NO3:** Nitrate; **r:** randomized; **sb:** single-blind. **db:** double-blind;

Nitrate consumption and resistance training performance. Compared to running and cycling, moderately few have inspected the impact of nitrate supplementation on resistance Training out an execution (e.g., muscle control), and thinks to date have yielded clashing comes about (72). For case, in lower body resistance preparation utilizing the back squat, an intense dosage of Nitrate (~6.4-13.0 mmol or 400-800 mg nitrate) has been detailed to make strides (73), and has no impact on control yield amid the back squat (74). In upper body resistance preparation, one consideration has been distributed to date that appears the impact of nitrate supplementation looks at the control yield amid the chest press, with this ponder detailing that control and speed moved forward by ~19% and ~7%, individually (75) considering that The upper body contains a more prominent extent of sort II filaments (76) and Nitrate has been recommended to bring out more prominent physiological reactions in sort II strands (77) Nitrate supplementation may have more noteworthy energy-generating potential amid upper-body resistance preparing compared to lower-body resistance preparing the restricted number of ponders assessing the energy-generating potential of Nitrate amid resistance preparing, particularly lower-body resistance preparing, it emphasizes the require for more inquire about in this field.

Table 3. Studies assessing the effects of dietary NO3 Consumption on Resistance exercise performance

Reference	Subjects	Supplementation	Exercise Protocol	Findings
Flanagan et al. (2016) (72)	Fourteen resistance-trained men	Three days and 60 min before exercise ingestion of 2 _NO3 -rich bars (32.5 mg NO3_d□1)	Smith machine box squats: three sets x 3-s isometric squats interspersed with 120-s rest, then dynamic box squats @ 60%1RM with 10% increases up to 90%1RM, then 10% decreases to 60%1RM, then RTF on the last 60%1RM set	↔ RTF: @1.5% (599 _ 5 *vs.* 608 _ 5 reps) ↑ EMG amplitude: +5% (83 _ 3 *vs.* 79 _ 4%)

Table 3. Continue

Mosher et al. (2016) (28)	Twelve resistance-trained men	Six days of 1 _ 70 mL NO3 rich BR supplementation (~6.4 mmol NO3_d@1)	Smith machine bench press: three sets of RTF@ 60%1RM interspersed with 2 minutes of recovery between sets	↑ RTF: +19.4% ↑ total weight lifted: +18.9% (2583 _ 864 *vs.* 2172 _ 721 kg)
Williams et al. (2020) (75)	Eleven resistance-trained men	Two hours before exercise ingestion of 1 70 mL NO3 rich BR (~6.4 mmol NO3)	Free-weight bench press: two sets x 2 explosive reps, 5 min rest, then three sets x RTF @ 70%1RM interspersed with 2 min of recovery between sets	↑ RTF: +10.7% (31 _ 6 *vs.* 28 _ 6 reps) ↑ Pmean: +19.5% (607 _ 112 *vs.* 508 _ 118 W) ↑ Vmean: +6.5% (0.66 _ 0.08 *vs.* 0.62 _ 0.08 m_s@1)
Ranchal-Sanchez et al. (2020) (74)	Twelve resistance-trained men	Two hours before exercise ingestion of 1_ 70 mL NO3 rich BR (~6.4 mmol NO3)	Smith machine bench press and back squat: three sets x RTF @ 60□70□80%1RM with 2 min of recovery between sets. After the eccentric phase of each rep, participants rested for 1.0□1.5 s	↑ RTF back squat: +23.4% (60 _ 20 *vs.* 46 _ 16 reps) ↑ RTF total (sum bench press and back squat): +17.7% (89 _ 25 *vs.* 75 _ 21 reps)

↑: significant increase; ↔: no change; **1RM:** one-repetition maximum; **BR:** beetroot juice; **EMG:** surface electromyography; **m_s:** meters per second; **min:** minutes; **NO3:** Nitrate; **Pmean:** mean power of bench press; **reps:** repetitions; **RTF:** repetitions to failure; **s:** seconds; **Vmean:** mean velocity of bench press; **W:** Watts.

Acute and chronic consumption of Nitrates. The acute dosages of Nitrate may be more viable in improving resistance exercise performance, at least for RTF. Our information recommends a more significant impact of nitrate supplementation estimate on muscle control gains after acute nitrate administration compared to more extended periods of nitrate supplementation (78). Other considerations have included direct comparisons between acute and chronic consumption, which have detailed clashes with chronic nitrate consumption moving forward cycling performance (20). Diminished O2 fetched protected exercise compared to acute Nitrate but did not influence running performance (46).

Given the methodological contrasts between existing studies that have compared the efficacy of acute and short-term Nitrate admissions to progress performance, drawing conclusive conclusions about whether acute or chronic nitrate supplementation accomplishes execution improvement during resistance exercise is challenging. Acute nitrate admissions can rapidly increase plasma and muscle nitrate, which provides a platform for excess nitric oxide production. Thus, acute nitrate admissions may induce second flag-bearers through cyclic guanosine monophosphate signaling to influence calcium affectability or induce reversible post-translational adjustments on essential contractile proteins (79).

Since more extended periods of nitrate admissions can actuate fundamental changes in proteins that direct contractility and increment basal levels of plasma and skeletal muscle nitrate, conceivably leading to a greater capacity to retain and/or increment the bioavailability of nitric oxide on request (80), we cannot rule out the possibility that expanding the admissions period past 4 days might deliver an ergogenic impact.

Potential influences of consumption of Nitrate on performance. *Endurance Training History.* Regular aerobic exercise training increases the expression and activity of the enzymes involved in the endogenous production of NO (5, 81). As a result, those with previous endurance training experience have more plasma NO3, NO2, and NO reserves that may be released in reaction to stresses like those at the start of exercise (82). Endurance-trained athletes do not have "NO limited" and hence have little to gain from dietary NO3 supplementation, possibly due to a more extensive capability for producing endogenous NO during exercise (44). In support, Carriker et al. (2016) found that after 4 days of NO3 supplementation, low-but-not-high aerobically trained male runners had decreases in oxygen use during submaximal activity (40). Others, however, have shown that dietary NO3 intake enhances time trial performance for endurance training and competing endurance athletes (such as cyclists and triathletes) (15, 16, 18, 19).

Possible Sexual Differentiation. Limited research shows that females might be more likely to benefit from dietary NO3 supplementation than males due to the impact of sex hormones on NO bioavailability (24). According to earlier research, women had lower plasma NO3 levels than men (83). Additionally, NO-dependent vascular function may vary depending on the stage of the menstrual cycle. In comparison to the follicular phase (12–3 days after the commencement of menses), when estrogen is increased, NO-dependent vascular activity is decreased when progesterone increases throughout the initial to mid-luteal phase of the menstrual cycle (20–3 days following the onset of menses) (84).

Given these variations, women may benefit more from dietary NO3 supplementation than males in terms of performance-related outcomes. Additionally, supplementing with NO3 may have a more considerable performance advantage in the middle of the luteal phase of the menstrual cycle. Given that women have been disproportionately underrepresented in this field of study, it is unfortunate that the impact of gender on variations in exercise responses to dietary NO3 supplementation remains unresolved.

The Biological Activity of a Nitrate-Reducing Agent. As was already established, the conversion of dietary NO2 to NO plays a significant role in the ergogenic impacts of NO3 intake. However, not every person reacts the same way to dietary NO3 consumption (17, 47). According to a recent study by Coggan et al. (25), some people show a significant rise (400%) in plasma NO2 after consuming a consistent dosage of dietary NO3, while others showed no such increase. Notably, performance increases significantly correlate with an elevation in plasma NO2 following acute Nitrate consumption (24, 47).

Therefore, individual variations in oral microbiota and/or additional agents involved in the NO3-NO2-NO pathway (such as NO3-reductase and stomach pH) may affect how each individual responds to dietary NO3 supplementation (85). Strong evidence suggests that routine mouthwash usage may reduce the effects of dietary NO3 by killing the anaerobic bacteria that start the conversion of NO3 to NO2 in the oral cavity, even if genetic factors may be relatively stable (86). Based on these findings, dietary NO3 supplementation may have a greater chance of improving performance-related outcomes if mouthwash usage is restricted.

CONCLUSION

Nitrate and other concentrated forms of dietary NO3 appear to slightly but significantly increase endurance, high-power explosive, and high-intensity intermittent exercise performance. Dietary NO3 might specifically benefit from short-duration (i.e., 30 minutes) endurance exercises or power-dependent, explosive movements, according to adequate proof from placebo-controlled trials. The chance of improved performance may be increased by doses of around 6 to 7 mg NO3 kg body mass per day, chronically over multiple days to weeks or acutely during 2 to 3 hours after exercise. It is advised that more research be done to ascertain whether dietary NO3 supplementation has a more significant positive impact on the exercise performance of specific groups (such as women who have undergone endurance training). Additional NO3 intervention trials are needed to regulate the subject diet or measure the increased intake of items with moderate to high quantities of NO3 utilizing dietary recall analysis.

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Study concept and design: S. M. Tayebi, M. M. Mohebian. Acquisition of data: M. M. Mohebian. Analysis and interpretation of data: M. M. Mohebian, S. M. Tayebi. Drafting of the manuscript: M. M. Mohebian, S. M. Tayebi. Critical revision of the manuscript for important intellectual content: I. Laher, F. Malekian. Statistical analysis: N/A. Administrative, technical, and material support: S. M. Tayebi, I. Laher.

ARTIFICIAL INTELLIGENCE (AI) USE

The author declares no AI usage.

CONFLICT OF INTEREST

The author declares no conflict of interest concerning the authors' contribution and article's publication.

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