NITRATE RICH BEETROOT JUICE has become a popular sports supplement because of its proposed ergogenic properties. The effects of dietary nitrate supplementation on exercise performance have been attributed to its capacity to increase nitric oxide (NO) bioavailability. NO modulates many processes that are essential to exercise performance, such as regulation of blood flow, muscle contractility, myocyte differentiation, and glucose and calcium homeostasis (9). Recent evidence indicates that NO bioavailability can be enhanced by supplementing inorganic nitrate by consuming more leafy green vegetables and beetroot juice (2, 26, 27) or by ingesting nitrate salt (e.g., sodium nitrate; NaNO₃) (18, 20). Larsen et al. (18) were the first to report lower oxygen requirements during exercise after 3 days of NaNO₃ supplementation. In a follow-up study (19), the same authors attributed this to improvements in mitochondrial efficiency during exercise, with less oxygen being used to produce a given amount of ATP. Beetroot juice is a product rich in nitrate and is being used by many athletes as a source of nitrate supplementation. Several studies (1, 2, 7, 17, 26) have confirmed nitrate’s oxygen-saving effects after beetroot juice supplementation as previously observed for NaNO₃. Moreover, using beetroot juice, Bailey et al. (2) were the first to study the effect of nitrate supplementation on exercise performance. They and others have now consistently shown that nitrate supplementation can increase the time to exhaustion and improve time-trial performance in trained athletes (2, 4, 7, 15–17, 21, 26, 30). As a consequence, numerous athletes have started to use beetroot juice as an ergogenic aid, including many elite athletes during the London 2012 Olympic Games. Could any of the gold medals won in London be (partially) attributed to the use of beetroot juice?

Whereas several studies have reported increased performance after nitrate supplementation in well-trained athletes (4, 7, 16, 30), others have been unable to confirm these findings (3, 6). Only few studies have investigated the impact of nitrate supplementation in elite, professional athletes (5, 8, 22, 23). One of these studies observed a small but significant decline in oxygen uptake during exercise and an improvement in time-trial performance in kayakers (23). However, the other three studies failed to observe changes in either VO₂ kinetics and/or exercise performance after nitrate supplementation in cross-country skiers (22), cyclists (8), and 1,500 m runners (5). Based on these findings it has become a topic of debate on whether the ergogenic benefits of beetroot juice may be dependent on the training status of the athletes recruited in these studies. It has been hypothesized that highly trained, elite athletes are less responsive to the ergogenic properties of nitrate when compared with recreational athletes (28). In the present Viewpoint we will address the physiological and methodological rationale that could explain the proposed absence of ergogenic properties of beetroot juice supplementation in elite athletes.

Metabolic adaptations. So far, there is little evidence to assume that the elite athlete does not benefit from the ergogenic properties of nitrate supplementation. However, a recent study reports that fitness level affects the impact of nitrate supplementation on reducing oxygen consumption during exercise and increasing exercise performance, suggesting that elite athletes are less likely to benefit from nitrate supplementation (24). As recently reviewed by Jones (14), there are some factors that may restrict the ergogenic properties of nitrate supplementation in the elite athlete. The intense exercise training routine in the elite athlete strongly increases daily energy expenditure and is matched by a 50–100% greater daily energy intake compared with the recreational athlete. When consuming a well-balanced diet, dietary nitrate consumption will be increased accordingly. In line, higher baseline nitrite levels have been reported in more highly trained athletes (25). It could be speculated that greater NO bioavailability in the elite athlete, both through higher nitrate intake and through greater eNOS/nNOS-dependent NO synthesis capacities, renders additional nitrate supplementation ineffective (8, 28). Although it has been suggested that a dose-response relationship exists between nitrate intake and the ergogenic properties (29), the dose of nitrate required to improve performance may differ with training status, exercise mode, or supplementation period. Also, many years or even decades of intense exercise training in the elite may have induced reconditioning responses on cardiovascular function, skeletal muscle vascularization, and mitochondrial efficiency, resulting in greater metabolic and mechanical efficiency (13). Such extensive adaptive responses may negate the impact of nitrate supplementation on mitochondrial efficiency and contractile function and make those effects less relevant for the elite athlete. Furthermore, it should be noted that an elite athlete is elite in a specific sport. Most research so far has focused on submaximal endurance type activities in (highly) trained athletes, during which oxygen delivery rarely restricts performance. Nitrate supplementation may be of greater benefit to those athletes involved in exercise activities performed at both a higher relative as well as absolute workload (28). The greater dependency on type II muscle fiber recruitment and nonoxidative energy provision may provide a setting where greater NO bioavailability could improve contractile function and increase performance (11), as supported...
by the type II muscle fiber-specific increase in microvascular $O_2$ pressure with nitrate (10).

Methodological complications. It is difficult to answer the question whether the effects of nitrate supplementation are the same for the elite athlete competing at the highest international level compared with the recreational athlete. Research in elite athletes has been limited by their busy schedules and conflicting priorities. However, the main problem is that elite athletes are, by definition, scarce. Furthermore, to evaluate the impact of nitrate on elite exercise performance, it will be required to test the athlete in an exercise protocol appropriate to the specific sport and preferably performed in a competitive setting. A performance enhancement of less than 1% generally represents the difference between gold and not even reaching the podium, but such small differences in performance can be difficult to detect in a laboratory setting (12). To detect small, but relevant, effects of nitrate supplementation on an elite athlete’s performance it may be preferred to assess performance repetitively in the same athlete as opposed to the evaluation of performance in a more traditional group-based comparison. Interestingly, some of the “negative” elite studies actually identified a number of individual subjects that seemed to respond very positively to nitrate supplementation (5, 8). As such, the use of a double blinded randomized multiple crossover $n = 1$ design may be more appropriate to evaluate whether nitrate supplementation can improve performance in the true elite athlete.

Conclusion. Recent data tend to suggest that the ergogenic properties of nitrate supplementation are restricted to the recreational athlete and not evident in the highly trained elite athlete. The absence of any measurable ergogenic effect of nitrate supplementation in the elite athlete may be attributed to their greater habitual dietary nitrate intake and/or extensive exercise training reconditioning that negate any further benefit of nitrate supplementation. Additionally, methodological limitations prevent detection of small, but relevant, increases in performance capacity in the elite athlete. Alternative methodologies such as case studies on the true elite athlete and further development of sport-specific testing should be prioritized. Although performance benefits of nitrate supplementation may be of a lesser magnitude in the elite athlete, a minimal increase in speed, strength, or endurance will be of a much greater relevance in an elite, competitive setting.

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REFERENCES


