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Dietary nitrate increases exercise tolerance in patients with non-ischemic, dilated cardiomyopathy—a double-blind, randomized, placebo-controlled, crossover trial

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Non-ischemic dilated cardiomyopathy (NIDCM) is defined as left ventricular dysfunction in the absence of causative coronary artery disease. It typically presents with impaired effort tolerance, which is a major prognostic factor.1

Nitric oxide (NO), a potent systemic vasodilator, is vital for skeletal muscle contraction and contributes to matching of blood flow and oxygen delivery necessary in active skeletal muscle. NIDCM is associated with dysregulated NO production, including decreased endothelial NOS expression and NO release. Furthermore, NO therapy has been shown to improve systemic circulation in NIDCM by reducing right ventricular after-load.

There are 2 pathways facilitating NO synthesis in vivo. The L-arginine–NO synthase pathway is well characterized and, until recently, was considered the sole source of endogenous NO. A second, NO synthase–independent pathway has recently been discovered and was found to be involved in simple reduction of dietary, inorganic nitrate to nitrite and NO.2,3 Acute nitrate consumption has been shown to increase blood nitrate/nitrite levels and exercise performance in healthy, athletic, pulmonary vascular disease (PVD),4 chronic obstructive pulmonary disease (COPD)5 and heart failure (HF) subjects.2 We hypothesized that dietary nitrate supplementation could acutely improve exercise capacity in NIDCM.

We recruited a group of ambulatory outpatients with NIDCM (New York Heart Association Functional Class II or III) who were on optimized therapy. Exclusion criteria were use of organic nitrate therapy, and diabetes or conditions affecting mobility. Our study received local institutional review board approval.

Subjects were tested on 2 separate days, 7 days apart, in a crossover fashion after consuming a light, self-selected, low-nitrate breakfast and taking usual medications. On both days, in an identical manner and at the same time of day, we performed resting blood pressure (BP) measures, blood draws and incremental shuttle-walk tests (ISWTs) before and 3 hours after beverage consumption, as this time-line has been shown to correspond to near peak blood nitrite concentrations after nitrate consumption.6

Upon completion of Day 1 pre-supplementation assessments, subjects were randomized in a double-blind, crossover trial design to consume 140 ml of either nitrate-rich beet-root juice (NO3; 12.9 mmol nitrate) or nitrate-depleted beet-root juice (PL; < 0.5 mmol nitrate). The PL preparation was identical in taste and appearance but had the nitrate removed by anion exchange, as described in a previous study.5 At each visit, subjects underwent baseline assessments followed by consumption of 140 ml of beverage (NO3 or PL) and rested quietly for 150 minutes.

Immediately before and after each of the 4 ISWTs, subjects rated their dyspnea and leg fatigue on the Borg scale and had oxygen saturation (SpO2, in percent) and heart rate (HR) measured. BP was measured at the brachial artery using a manual sphygmomanometer and stethoscope before all 4 ISWTs.

Measurement of NO derivatives (nitrate/nitrite) in biologic fluids reflects NO bioavailability and was analyzed using the current “gold standard,” ozone-based chemiluminescence analysis, on an NO analyzer (NOA280i; Sievers).

We based the sample size on our recent study with an identical protocol among COPD subjects where a significant treatment effect of nitrate on ISWT was observed on a sample of 11 subjects.3 ΔNO3 and ΔPL data were compared by using 2-tailed, paired t-tests for normally distributed data and Wilcoxon’s test for non–normally distributed data. Correlations were assessed using Pearson’s correlation coefficient. The presence of a carryover effect was assessed using 2-tailed, unpaired t-tests by comparing the observed ISWT difference among those who received NO3 followed by PL compared with those who received PL followed by NO3.
by PL with those who received the opposite. All statistical tests were conducted at the 2-sided 0.05 significance level using SPSS for Windows (version 15.0).

Twelve subjects were recruited. There was 1 drop-out due to loss to follow-up. Thus, 11 subjects completed the study (Table 1). After NO3 consumption, mean ISWT distance increased by 65 ± 41 meters (431 to 496 meters, 15%), whereas there was a decrease of 5 ± 35 meters (437 to 433 meters, 1%) after PL (p = 0.0056). The mean and individual ISWT distances after NO3 and PL are shown in Figure 2a.

Figure 1  Trial design. Assessments included resting blood pressure, blood draw, resting, pre-ISWT dyspnea and arterial oxygen concentration, ISWT, post-ISWT dyspnea and arterial oxygen concentration. BRJ, beet-root juice; PL, placebo.
Ten of the 11 subjects walked further after NO₃ (30 to 140 meters), whereas 1 had a decreased exercise capacity (−10 meters). However, after PL, only 4 subjects had increased walking capacity (10 to 80 meters), but 7 walked shorter distances (−10 to −60 meters). There was no significant difference regarding SpO₂, HR, dyspnea or leg fatigue score (data not shown). Also, there was no difference in ISWT distance, regardless of treatment sequence (p = 0.24), suggesting no carryover effect of the intervention.

The median and individual plasma nitrate and nitrite concentrations pre- and post-beverage (NO₃ and PL) are shown in Figure 2b and c. After NO₃, median plasma nitrate increased by 811.1 (range 649.5 to 1,142.2) μmol/liter, with little change after PL (p = 0.003). Similarly, median plasma nitrite increased by 319.7 nmol/liter (250.6 to 978.2) after NO₃, whereas there was a small decrease after PL (−10 nmol/liter; p = 0.003). There was no correlation between absolute change in plasma nitrite and absolute change in ISWT distance (r = 0.0007, p = 0.99; Figure 2d).

Mean systolic and diastolic BP and mean arterial pressure (MAP) decreased after NO₃ (−2.7, −1.4 and −2 mm Hg, respectively), but increased after PL (4.5, 2.7 and 3.3 mm Hg, respectively). Changes did not reach statistical significance.

We found that acute consumption of NO₃ (12.9 mmol) significantly increased plasma nitrate/nitrite and significantly increased exercise capacity in NIDCM patients. Our findings are supported by previous reports of increased exercise capacity in selected clinical groups, including subjects with HF and HFpEF. It is of interest to note that our trial and these trials utilized the same dose of NO₃.

We also observed an 18% increase in ISWT distance with NO₃ (−1.5% to 39%), whereas PL led to a 2% decrease (−17.6% to 11.6%). Similar to the NO response, there was marked variation regarding ISWT response to NO₃. It is probable that differences in baseline fitness/NO bioavailability, medications and NIDCM severity contribute to this variation. Nevertheless, 10 of 11 subjects had increased ISWT distance post-NO₃.

Exercise capacity is regarded as a principal variable for the evaluation of new therapeutic approaches in NIDCM. Further, we have demonstrated that exercise capacity represents an important prognostic factor related to future mortality in NIDCM. Controversy remains regarding the optimal test to assess exercise capacity in NIDCM. Herein we have utilized the ISWT as our primary end-point, which represents a standardized procedure and has been shown to strongly predict maximal aerobic capacity and future outcome in HF.

Our observations are supported by recent trials in HF patients. One trial used constant-intensity cycle cardiopulmonary exercise testing to assess 17 HF patients with preserved ejection fraction. Although there was no change in exercise efficiency (primary end-point), there were significant increases in exercise oxygen consumption, total work performed, exercise duration and plasma NO metabolites. A second trial used isokinetic dynamometry to assess 9 HF patients with NIDCM and showed acutely increased peak knee extensor power. It is of interest to note that our trial and these trials utilized the same dose of NO₃.
dietary nitrate delivered in the same fashion in a crossover design. It is difficult to compare our results directly. We noted an 18% increase in ISWT distance, whereas Zamani et al described a comparable 14% increase with constant-intensity cardiopulmonary exercise testing. Our use of ISWT does not allow detailed physiologic data to be gathered. However, we believe that the increased exercise capacity we observed post-NO₃ is probably related to the same mechanistic pathways uncovered in those earlier HF trials, namely increased cardiac output, muscular oxygenation and post-occlusive hyperemic flow, reduced aortic augmentation index² and increased skeletal muscle...
As expected, NO₃ supplementation led to a significant increase in plasma nitrite (≥8.5-fold) and particularly nitrate (≥28-fold). Similar to our COPD trial, we observed marked variation in response to exogenous nitrate despite an identical dose and time interval (Figure 2b and c). We cannot explain these variations, but it is likely that differences in oral bacteria and stomach acidity, age and medication are contributing factors. Further, we recently reviewed data demonstrating a variation in metabolism of exogenously administered nitrate when measured at a single time-point (e.g., 3 hours), yet the extent of nitrite/nitrate production (across 24 hours) was found to be largely similar. The importance of our placebo-controlled design is illustrated by our earlier demonstration of intra-individual variability with repeat doses of NO₃.

Pharmacologic preparations of organic nitrate are used, with varied success, to treat HF and NIDCM. It should be noted that, despite their similar physiologic effects, organic and inorganic nitrate (such as dietary nitrate) possess different chemical structures and pharmacokinetics. The potency of inorganic nitrate is much lower than that of organic nitrate. However, organic nitrate may result in tolerance and, when discontinued, rebound effects are often evoked. In contrast, inorganic, dietary nitrates do not show any signs of tolerance, and physiologic effects may be potentiated with long-term ingestion.

Although our trial has some major limitations, including the acute nature of the assessments and the small sample size, we utilized a robust trial design among a cohort of well-characterized NIDCM subjects. Dietary nitrate has potential as a novel, therapeutic strategy to increase exercise tolerance in NIDCM. Our preliminary results require confirmation among larger samples in the long-term setting.

**Disclosure statement**

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**References**