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Mini Review

Impact of Dietary Nitrate from Beetroot Juice on Hemodynamics and Physical Performance: A Systematic Review and Meta-Analysis

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Introduction

Beetroot Juice (BRJ) has gained popularity among athletes due to its high nitrate (NO_3^-) content, which can boost nitric oxide production and enhance exercise performance. However, the nitrate concentration in beets can vary widely, making it challenging to determine the exact amount of NO_3^- in any given product [1]. After consumption, dietary nitrate is converted into nitrite within the body, which is then stored and circulated in the bloodstream. Under low-oxygen conditions, nitrite can be further converted into nitric oxide—a molecule that plays a key role in regulating vascular function and metabolism [1]. Supplementation with dietary nitrate has been shown to increase plasma nitrite levels and lower resting blood pressure [1]. Interestingly, it also appears to reduce the oxygen demand of submaximal exercise and, in some cases, may improve exercise endurance and performance [2]. Nitric oxide has been found to enhance mitochondrial efficiency by increasing the amount of oxygen reduced per ATP produced—a measure known as the mitochondrial P/O ratio [3]. This mechanism may help explain the benefits observed in prior studies examining the cardiorespiratory aspects of aerobic exercise [3]. Evidence from a recent meta-analysis indicates that BRJ supplementation over periods ranging from 2 to 56 days can reduce Systolic Blood Pressure (SBP) by approximately 3.55 mm Hg and Diastolic Blood Pressure (DBP) by about 1.32 mm Hg in populations with and without arterial hypertension [4]. These findings are clinically significant, as even a modest 2 mm Hg decrease in blood pressure is associated with a 7% reduction in mortality from ischemic heart disease [4]. Some studies suggest that BRJ lowers blood pressure—particularly in individuals with hypertension—and may improve exercise performance, possibly by enhancing blood flow and muscle function. However, other studies have found no significant effects on blood pressure or exercise capacity, especially in healthy individuals. The objective of this analysis is to systematically assess the overall impact of beetroot juice supplementation on blood pressure, exercise performance, and nitrate levels by synthesizing data from multiple studies in athletes. It aims to determine whether BRJ consistently influences these outcomes, and to quantify both the extent and direction of its effects.

Methods

The search was performed across the Cochrane, Scopus, and PubMed databases without applying any language restrictions. The only studies that were included were randomized control trials and cohort studies with the intervention of beetroot juice. The mean age of participants across all studies was in between 17-31 years. Comparison was made in between beetroot juice group and the control group. The outcomes reported were diastolic blood pressure, systolic blood pressure, plasma nitrites, plasma lactates, heart rate, muscle power and oxygen demand. Baseline characteristics and outcomes were noted down on a excel spreadsheet. Data extraction and quality assessment were carried individually by 2 reviewers. For each outcome mean difference with 95% Confidence Intervals (CI) were extracted and pooled using the Mantel– Haenszel random-effects inverse variance model. Heterogeneity was evaluated using Higgins' I^2 statistic, with a threshold of 50% or lower deemed acceptable. Sensitivity analyses were conducted by excluding studies identified as outliers in the forest plot. All statistical analysis was done using review manager.

Results

This meta-analysis included a total of 20 studies, comprising both randomized controlled trials and cohort studies [3,5-23]. to evaluate the differences in outcomes between the beetroot juice group and the control group. The pooled analysis showed a significant increase of plasma nitrites levels in the beetroot juice group compared to the control group (MD: 6.80; [95% CI: 3.17, 10.43]; P=0.0002; Figure 1A). Moreover use of beetroot juice supplementation increased diastolic blood pressure (MD: 2.14; [95% CI: -4.33, 8.62]; P = 0.5167; Figure 1B), decreased heart rate (MD: -0.44; [95% CI: -2.85, 1.97]; P = 0.7219; Figure 1C), decreased plasma lactate levels (MD: -0.14; [95% CI: -0.71, 0.43]; P = 0.6249; Figure 1D), increased muscle power (MD: 6.06; [95% CI: -2.03, 14.14]; P = 0.1420; Figure 1E), and decreased systolic blood pressure (MD: -2.50; [95% CI: -5.31, 0.30]; P = 0.0806; Figure 1F) but these results were statistically insignificant. Furthermore, no difference was seen in oxygen demand in both groups (MD: -0.00; [95% CI: -0.01, 0.00]; P = 0.0837; Figure 1G).

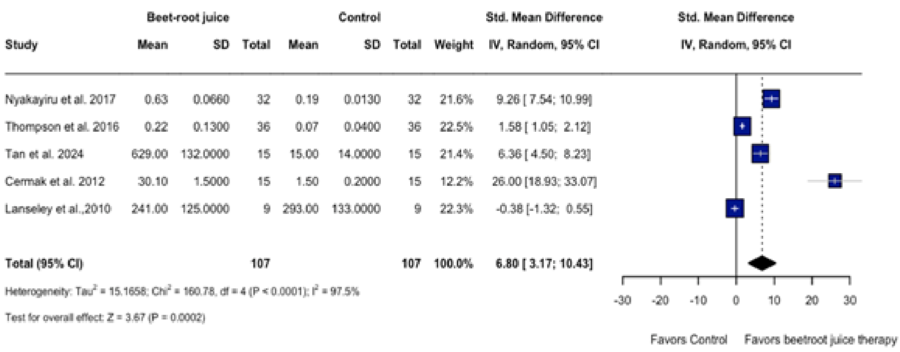

Figure 1A: Plasma Nitrites

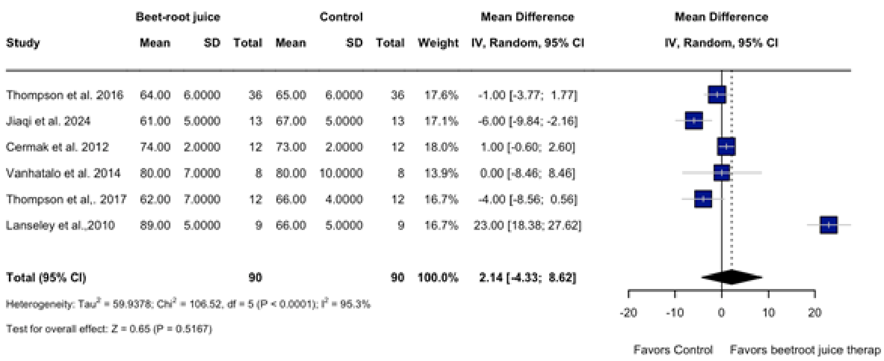

Figure 1B: Diastolic Blood Pressure

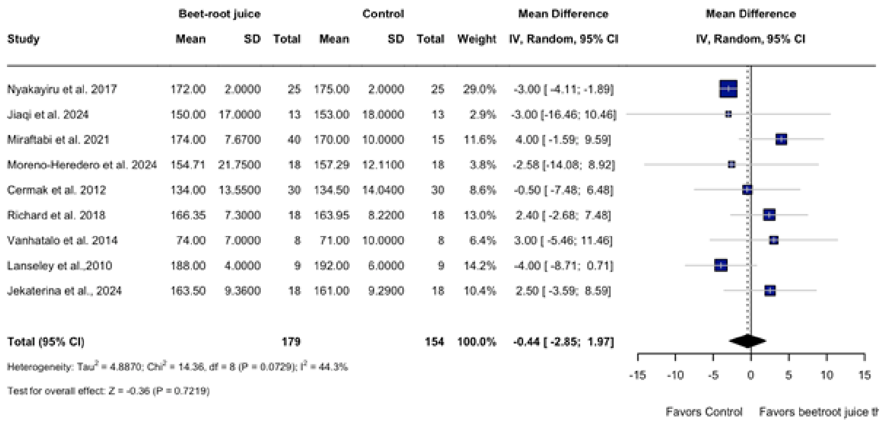

Figure 1C: Heart Rate

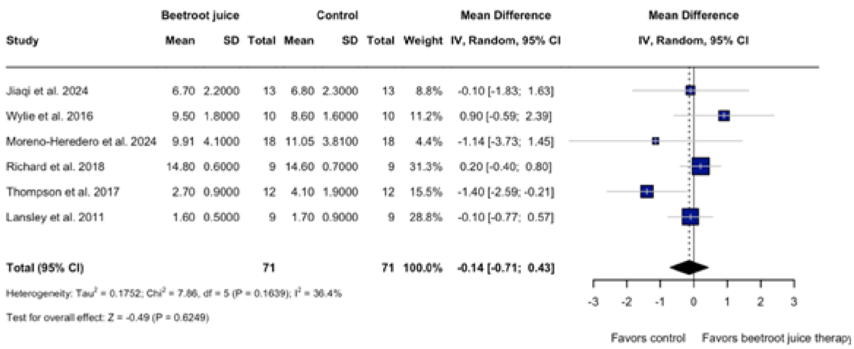

Figure 1D: Plasma Lactate

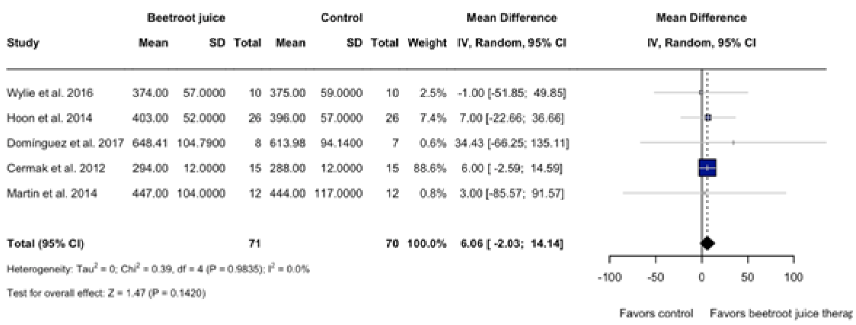

Figure 1E: Muscle Power

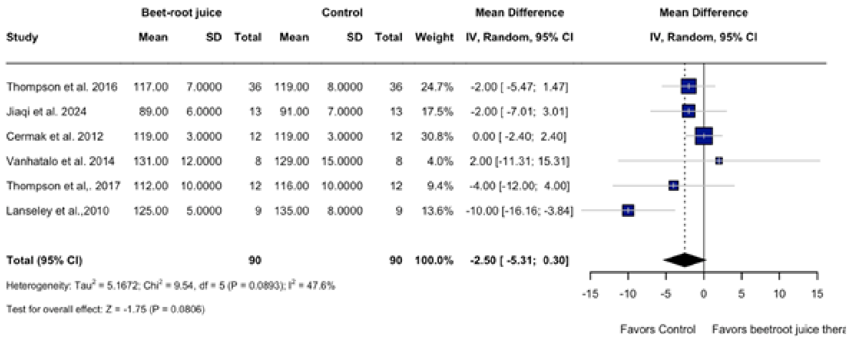

Figure 1F: Systolic Blood Pressure

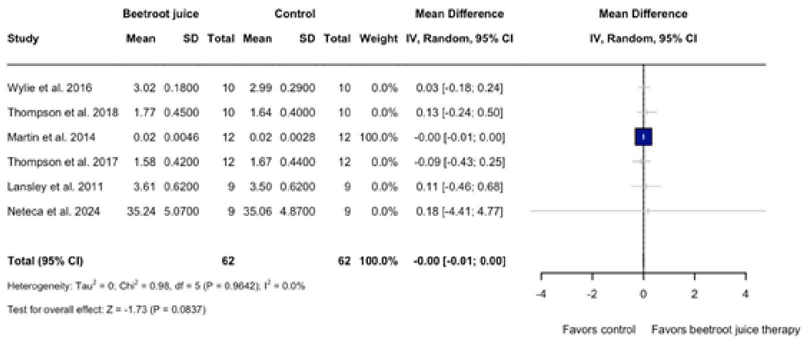

Figure 1G: Oxygen demand

Discussion

The systematic review and meta-analysis showed that beetroot juice supplementation increased plasma nitrite levels by approximately 6.8 µM more than control (95% CI, 3.17–10.43), confirming effective nitrate delivery and NO bioavailability. However, this biochemical effect did not translate into consistent physiological or performance benefits. No significant changes were observed in systolic or diastolic blood pressure, heart rate, or exercise performance metrics such as muscle power, blood lactate, or oxygen demand compared to placebo. These findings indicate that while beetroot juice activates the nitrate–nitrite–NO pathway, its functional effects on hemodynamics and exercise capacity in healthy individuals are minimal.

This robust increase in plasma nitrite is biologically plausible, as beetroot provides inorganic nitrate that is converted to nitrite via oral bacteria and subsequently to NO in vivo [24,25]. NO plays a central role in exercise physiology, affecting vascular tone, mitochondrial respiration, and muscle contractility [26]. While previous research shows nitrate can lower resting BP and reduce the oxygen cost of exercise [24], the absence of such effects in our study likely reflects the normotensive status of participants, where endothelial function and NO production are already optimal. Indeed, the hypotensive effects of nitrate appear more pronounced in hypertensive individuals, with meta-analyses showing ~3–5 mmHg systolic BP reductions in this population [27]. Similarly, no consistent improvements in exercise performance were observed, aligning with previous findings that beetroot juice may not benefit all exercise types or populations [26,28]. Some studies have reported performance improvements in nitrate “responders,” with variability in outcomes likely due to differences in nitrite bioavailability [29]. However, these effects may be diluted in meta-analyses that include non-responders. Also, many studies assessed short-duration or maximal efforts where NO-mediated enhancements (e.g., blood flow, efficiency) may have limited impact. Evidence suggests the greatest ergogenic effects occur in middle-distance efforts (2–10 minutes) or under hypoxic conditions [30].

Significant heterogeneity across studies further complicates interpretation. Trials varied widely in nitrate dose (5–15 mmol), supplementation duration, and exercise protocols, and included diverse participant types from sedentary to elite athletes. A meta-regression of 123 trials found that nitrate benefits were most evident in events lasting 2–10 minutes and when NO synthesis was compromised, such as under oxygen stress [31]. Moreover, highly trained individuals may derive less benefit due to already-optimized NO production [29]. Our review's strengths include comprehensive database searches, duplicate screening, and use of the Hartung–Knapp random-effects model for pooled estimates. Sensitivity analyses showed no single study unduly influenced outcomes. However, limitations include small sample sizes, male predominance, short intervention durations, and inconsistent control of dietary nitrate or oral microbiome factors. With few trials per outcome, publication bias remains possible.

Conclusion

In conclusion, beetroot juice reliably increases nitrate and nitrite levels, confirming NO pathway activation, but does not significantly affect blood pressure or exercise performance in healthy adults. Future trials should examine longer interventions, diverse populations, and mechanistic biomarkers to clarify individual responses and long-term effects. For now, BRJ may serve as a safe, situational ergogenic aid rather than a broadly effective intervention.

Declaration of Competing Interest

The authors state that they do not have any known conflicting financial interests or personal relationships that could have influenced the work documented in this paper.

Data availability statement

All data sources utilized are available in the result and supplementary section and cited in the references.

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