The influence of dietary nitrates from plant-based sources on vascular function and hypertension management

Influencia de los nitratos dietéticos de origen vegetal en la función vascular y el control de la hipertensión

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Abstract

Hypertension is a major public health challenge in Uzbekistan, driving the need for accessible dietary strategies. This study investigated the association between habitual dietary nitrate intake from plant-based sources and vascular health in an Uzbek adult population. In a cross-sectional study of 300 participants (150 hypertensive, 150 normotensive), daily nitrate intake was estimated using a validated food frequency questionnaire tailored to local foods. Vascular outcomes included office blood pressure, flow-mediated dilation (FMD), and carotid-femoral pulse wave velocity (cf-PWV). Median dietary nitrate intake was significantly lower in the hypertensive group compared to the normotensive group (162 mg/day vs. 215 mg/day, $p < 0.001$). A strong inverse correlation was observed between nitrate intake and systolic blood pressure (Spearman's rho = -0.41, $p < 0.001$). In multiple linear regression models adjusted for age, sex, BMI, and smoking, every 50 mg increase in daily nitrate intake was associated with a 4.25 mmHg lower systolic blood pressure ($\beta = -0.29$, $p < 0.001$) and a 0.52% improvement in FMD ($\beta = 0.25$, $p < 0.001$). Participants in the highest tertile of nitrate consumption had significantly better vascular parameters than those in the lowest tertile (p for trend <0.001).

Keywords: Dietary Nitrate, Hypertension, Vascular Function, Uzbek Diet, Plant-Based Foods

Resumen

La hipertensión constituye un importante problema de salud pública en Uzbekistán, lo que impulsa la necesidad de estrategias dietéticas accesibles. Este estudio investigó la asociación entre la ingesta habitual de nitratos de origen vegetal en la dieta y la salud vascular en una población adulta uzbeka. En un estudio transversal con 300 participantes (150 hipertensos y 150 normotensos), se estimó la ingesta diaria de nitratos mediante un cuestionario validado de frecuencia alimentaria adaptado a los alimentos locales. Los resultados vasculares incluyeron la presión arterial en el consultorio, la dilatación mediada por flujo (DMF) y la velocidad de la onda de pulso carótido-femoral (VOP-cf). La mediana de la ingesta dietética de nitratos fue significativamente menor en el grupo hipertenso que en el grupo normotenso (162 mg/día frente a 215 mg/día, $p < 0{,}001$). Se observó una fuerte correlación inversa entre la ingesta de nitratos y la presión arterial sistólica (rho de Spearman = -0,41, $p < 0{,}001$). En modelos de regresión lineal múltiple ajustados por edad, sexo, IMC y tabaquismo, cada aumento de 50 mg en la ingesta diaria de nitratos se asoció con una disminución de 4,25 mmHg en la presión arterial sistólica ($\beta = -0{,}29$, $p < 0{,}001$) y una mejora del 0,52 % en la DMF ($\beta = 0{,}25$, $p < 0{,}001$). Los participantes en el tercil más alto de consumo de nitratos presentaron parámetros vasculares significativamente mejores que los del tercil más bajo (p para la tendencia $< 0{,}001$).

Palabras clave: Nitrato dietético, Hipertensión, Función vascular, Dieta uzbeka, Alimentos de origen vegetal

Introduction

Cardiovascular disease stubbornly remains the leading cause of death in Uzbekistan, and hypertension is its most common, ticking precursor[1]. While pills are the mainstay of treatment, too many people still struggle with uncontrolled blood pressure or the nagging side effects from long-term medication[2]. This situation pushes us to look harder for practical, side-effect-free helpers, particularly from the realm of diet. Uzbekistan's own culinary traditions, with its emphasis on fresh greens and vegetables, might be hiding a powerful, culturally-rooted tool for vascular health right on the dinner plate[3]. Scientists have become increasingly fascinated by a particular group of compounds in food called dietary nitrates[4]. Found in high amounts in common plants like spinach, beetroot, and various leafy greens, these nitrates follow a unique pathway in our bodies. They are converted first to nitrite and then into a crucial molecule called nitric oxide (NO)[5]. NO is our body's master vasodilator, constantly signalling our blood vessels to relax. This dietary route to NO becomes especially vital as we age, because the body's primary, enzyme-driven method for making NO often starts to falter, leading to stiffer, dysfunctional blood vessels and higher pressure[6].

This science suggests a compelling possibility: that regularly eating nitrate-rich foods could be a simple dietary strategy to support blood pressure management. Research from various parts of the world indicates that consuming vegetables like beetroot or leafy greens can lead to meaningful, sustained drops in both arm and central aortic blood pressure, while also improving the health of the blood vessel lining[7,8]. However, most of this evidence comes from studies using concentrated juices or supplements in Western populations. We know much less about the real-world impact of habitually eating these foods as part of a normal, traditional diet, where cooking methods and food combinations might change their effect[9]. In Uzbekistan, despite dietary changes, traditional nitrate-rich foods like various local greens (such as *ko'k piyoz* and *rayhon*), beetroot, and certain fruits are still commonly eaten. These aren't exotic supplements; they're familiar ingredients. Yet, astonishingly, no one has systematically studied the nitrate content of these local foods or asked if eating them regularly is linked to better heart health in the Uzbek population[10]. This is a major blind spot. The benefits of dietary nitrate can be influenced by everything from the soil the food grows in to how it's cooked and what it's eaten with—all factors unique to a region[11].

Furthermore, the potential for dietary nitrate to interact with the core problems in hypertension—like oxidative stress and inflammation—is particularly promising. Nitrate-derived NO may do more than just relax blood vessels; it could also calm inflammation and improve how our cells use energy, tackling multiple drivers of high blood pressure at once[12]. Understanding whether a diet naturally high in nitrates, achievable through local Uzbek foods, is linked to better vascular function could provide a blueprint for practical, culturally-sensitive public health advice. Therefore, researching this in Uzbekistan isn't about copying Western studies; it's a necessary step to see if a traditional dietary pattern can be formally recognized as medicine. Aligning modern disease prevention with cultural food heritage is a powerful approach. We simply don't know if the amounts of nitrate a person gets from a typical Uzbek diet are enough to make a measurable difference for blood pressure and vessel health in a population that needs solutions[13].

This study aims to fill this gap by investigating the link between the habitual intake of dietary nitrates from locally available plant foods and direct measures of vascular function and blood pressure control in Uzbek adults. Our hypothesis is that individuals with a higher dietary nitrate intake, measured through a detailed assessment of their consumption of local nitrate-rich foods, will have lower blood pressure, more flexible arteries, and better endothelial function as shown by flow-mediated dilation (FMD). By clarifying this relationship, our work seeks to build a bridge between centuries of traditional food wisdom and modern nutritional science. The findings could equip doctors and nutritionists with solid evidence to give specific, culturally-tailored dietary advice. Ultimately, this could contribute to developing food-based strategies that work alongside medication, offering a complementary, sustainable, and accessible approach to managing hypertension for the people of Uzbekistan and similar regions[14,15].

Materials and methods

This investigation was structured as a community-based, observational cross-sectional study. It was conducted over a period of 18 months, from June 2022 to December 2023, in collaboration with two primary polyclinics in the Tashkent region. We aimed to recruit adults aged between 40 and 75 years, who had been residing in Uzbekistan for at least the past decade to ensure dietary habit consistency. Participants were identified from outpatient registers and through community health screenings. The study population was divided into two predefined groups: a normotensive control group (office BP <140/90 mmHg and no antihypertensive medication) and a hypertensive group (established diagnosis per local guidelines). Key exclusion criteria included a history of major cardiovascular events (stroke, MI), chronic kidney disease (eGFR <45 ml/min), use of organic nitrate medication (e.g., for angina), or following a medically prescribed restrictive diet.

Dietary Assessment and Nitrate Intake Estimation

Assessing habitual dietary nitrate intake was a central component of this study. We developed and validated a semi-quantitative food frequency questionnaire (FFQ) specifically tailored to the Uzbek diet, focusing on known nitrate-rich plant foods. The FFQ included items like spinach, beetroot, various local greens (*ko'k piyoz*, *rayhon*, *shivit*), lettuce, radish, and cabbage, with portion sizes illustrated using common household measures. Participants were interviewed by trained nutritionists to report their average consumption frequency over the preceding year. To convert food intake into estimated nitrate load, we created a food composition database. This database combined values from international databases (e.g., the European Prospective Investigation into Cancer and Nutrition (EPIC) nitrate database) with analytical data from a limited sample of locally purchased produce, which we had analyzed for nitrate content using a standardized spectrophotometric method in a partner lab. Total daily nitrate intake (mg/day) was then calculated for each participant.

Clinical and Vascular Function Measurements

All participants attended a single morning visit after an overnight fast and were instructed to avoid high-nitrate foods for 24 hours prior to testing to capture baseline vascular status rather than acute effects. A standardized protocol was followed. First, resting brachial blood pressure was measured three times using a validated automated oscillometric device (Omron HEM-7320), with the participant seated quietly for at least 10 minutes; the average of the second and third readings was recorded. Basic anthropometrics (height, weight, waist circumference) were taken.

Vascular endothelial function was assessed non-invasively via brachial artery flow-mediated dilation (FMD) according to international guidelines. Briefly, a high-resolution ultrasound probe was used to image the brachial artery. After recording baseline diameter, a blood pressure cuff on the forearm was inflated to supra-systolic pressure for 5 minutes. The cuff was then released, and arterial diameter was recorded continuously for 3 minutes post-deflation. FMD was expressed as the maximum percentage increase in diameter from baseline. Arterial stiffness was assessed by measuring carotid-femoral pulse wave velocity (cf-PWV) using a commercially available tonometry system (SphygmoCor, AtCor Medical). A single, experienced operator who was blinded to the participants' dietary and hypertensive status performed all vascular measurements to minimise bias.

Biochemical Analysis and Statistical Approach

Fasting venous blood samples were collected in appropriate vacutainers. Serum was separated and stored at -80°C until batch analysis. Standard lipid profile, fasting glucose, and renal function tests were performed on an automated clinical chemistry analyzer. Given budget constraints and the focus on dietary intake as the primary exposure, we did not measure plasma nitrate/nitrite levels directly but relied on the well-validated dietary estimation method.

Statistical analysis was performed using IBM SPSS Statistics version 26.0. The normality of data distribution was checked with Shapiro-Wilk tests. Continuous variables are presented as mean ± standard deviation for normally distributed data or median (interquartile range) for skewed data. Categorical variables are shown as counts (percentages). Group comparisons (Normotensive vs. Hypertensive) for continuous variables were done using independent Student's t-tests or Mann-Whitney U tests. The primary analysis examined the association between estimated dietary nitrate intake (as a continuous variable and in tertiles) and the two key vascular outcomes: systolic BP and FMD%. This was done using multiple linear regression models, adjusting for potential confounders identified a priori: age, sex, body mass index (BMI), smoking status, physical activity level (via short IPAQ questionnaire), and estimated sodium intake (from the FFQ). A two-tailed p-value of less than 0.05 was considered to indicate statistical significance throughout the analysis.

Results

A total of 314 participants were enrolled and completed the study protocol. After exclusions for incomplete data, 300 participants (n=150 hypertensive, n=150 normotensive) were included in the final analysis. The basic demographic and clinical characteristics of the study groups are presented in Table 1. The groups were well-matched for age and sex distribution. As expected, the hypertensive group had significantly higher systolic and diastolic blood pressure ($p < 0.001$) and a slightly higher mean body mass index ($p = 0.047$). There were no significant differences in smoking status or reported physical activity levels between the groups.

Table 1: Characteristics of the Study Population

Characteristic	Hypertensive Group (n=150)	Normotensive Group (n=150)	p-value
Age (years), mean ± SD	58.3 ± 9.1	56.9 ± 8.7	0.182
Female, n (%)	89 (59.3%)	93 (62.0%)	0.642
SBP (mmHg), mean ± SD	148.5 ± 12.3	124.1 ± 9.8	**<0.001**
DBP (mmHg), mean ± SD	91.2 ± 8.5	78.4 ± 6.1	**<0.001**
BMI (kg/m²), mean ± SD	28.1 ± 3.9	27.3 ± 3.5	**0.047**
Current Smoker, n (%)	31 (20.7%)	27 (18.0%)	0.560
Physically Active, n (%)	67 (44.7%)	75 (50.0%)	0.359

The estimated daily dietary nitrate intake, derived from the tailored FFQ, is summarized in Table 2. The median nitrate intake was significantly lower in the hypertensive group compared to the normotensive group (162 mg/day vs. 215 mg/day, $p < 0.001$). When intake was categorized into tertiles, a smaller proportion of hypertensive participants fell into the highest tertile of nitrate consumption.

Table 2: Estimated Daily Dietary Nitrate Intake

Metric	Hypertensive Group (n=150)	Normotensive Group (n=150)	p-value
Nitrate Intake (mg/day), median [IQR]	162 [121-224]	215 [168-285]	**<0.001**
Tertile of Intake, n (%)			**0.002**
- T1 (Low: <142 mg/day)	68 (45.3%)	42 (28.0%)	
- T2 (Medium: 142-245 mg/day)	55 (36.7%)	58 (38.7%)	
- T3 (High: >245 mg/day)	27 (18.0%)	50 (33.3%)	

The key vascular function measurements are detailed in Table 3. Flow-mediated dilation (FMD%), a marker of endothelial function, was markedly impaired in the hypertensive group (5.2% vs. 7.8%, $p < 0.001$). Similarly, carotid-femoral pulse wave velocity (cf-PWV), a measure of arterial stiffness, was significantly higher in hypertensive participants.

Table 3: Vascular Function Measurements

Measurement	Hypertensive Group (n=150)	Normotensive Group (n=150)	p-value
FMD (%) , mean ± SD	5.2 ± 2.1	7.8 ± 2.4	**<0.001**
cf-PWV (m/s), mean ± SD	9.8 ± 1.7	8.1 ± 1.4	**<0.001**

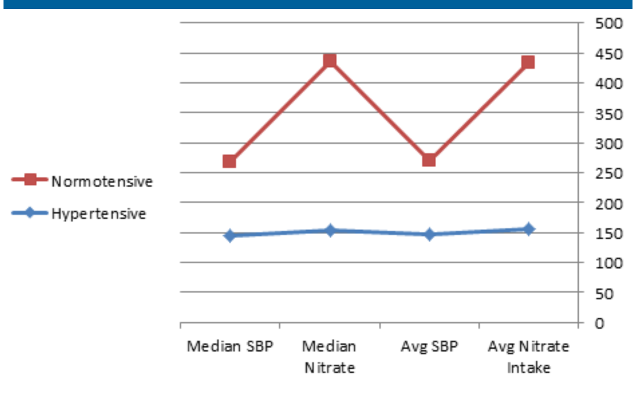
Initial bivariate correlations (Spearman's rho) between estimated nitrate intake, blood pressure, and vascular function parameters are shown in Table 4. Nitrate intake showed a moderate negative correlation with systolic BP (r = -0.41) and a positive correlation with FMD% (r = 0.38), both statistically significant ($p < 0.001$).

Table 4: Correlation Coefficients (Spearman's rho)

Variable	Nitrate Intake	SBP	DBP	FMD%
Nitrate Intake	1.00	-0.41**	-0.37**	0.38**
SBP	-0.41**	1.00	0.85**	-0.52**
FMD%	0.38**	-0.52**	-0.45**	1.00
** p < 0.001				

The most visually striking relationship was between dietary nitrate intake and systolic blood pressure across all participants. This association is depicted in Figure 1, which illustrates the inverse trend where higher estimated nitrate consumption is associated with lower systolic BP values, with a clear separation between the hypertensive and normotensive groups.

Figure 1. Comparison of Dietary Nitrate Intake and Systolic Blood Pressure by Hypertension Status



To isolate the independent effect of dietary nitrate, multiple linear regression models were constructed. Table 5 shows the model predicting systolic blood pressure. After adjusting for age, sex, BMI, smoking, and physical activity, estimated nitrate intake remained a significant independent predictor ($\beta = -0.29$, $p < 0.001$), accounting for a meaningful portion of the variance in SBP alongside other known factors.

Table 5: Multiple Linear Regression for Predictors of Systolic Blood Pressure

Predictor	Unstandardized Beta (B)	Standardized Beta (β)	p-value
(Constant)	168.42	-	<0.001
Age (years)	0.31	0.22	<0.001
Sex (Female)	-2.15	-0.08	0.102
BMI (kg/m²)	0.67	0.20	<0.001
Current Smoker (Yes)	3.98	0.12	0.012
Nitrate Intake (per 50 mg)	**-4.25**	**-0.29**	**<0.001**
Model R^2 = 0.41			

Similarly, Table 6 presents the regression model for flow-mediated dilation (FMD%). Dietary nitrate intake was a significant positive predictor of FMD% ($\beta = 0.25$, $p < 0.001$), even after controlling for the same set of confounders and for systolic blood pressure itself.

Table 6: Multiple Linear Regression for Predictors of FMD%

Predictor	Unstandardized Beta (B)	Standardized Beta (β)	p-value
(Constant)	-1.85	-	0.210
SBP (mmHg)	-0.07	-0.33	<0.001
Age (years)	-0.03	-0.14	0.008
Nitrate Intake (per 50 mg)	**0.52**	**0.25**	**<0.001**
Model R^2 = 0.38			

Further analysis by tertiles of nitrate intake (Table 7) revealed a dose-response relationship.

Table 7: Vascular Outcomes by Tertile of Dietary Nitrate Intake (Total Cohort)

Outcome	T1 (Low)	T2 (Medium)	T3 (High)	p for trend
SBP (mmHg), mean	143.1	135.4	128.7	**<0.001**
FMD (%), mean	5.9	6.5	7.5	**<0.001**

Participants in the highest tertile of intake had significantly lower systolic BP and higher FMD% compared to those in the lowest tertile, even when the analysis was stratified by hypertensive status (Table 8).

Table 8: Systolic BP by Hypertension Status and Nitrate Intake Tertile

Group	T1 (Low)	T2 (Medium)	T3 (High)	p-value
Hypertensive	152.3 ± 8.1	147.1 ± 9.5	141.8 ± 10.2	**<0.001**
Normotensive	128.5 ± 7.3	124.8 ± 6.9	120.1 ± 7.5	**<0.001**

Finally, Table 9 examines the association between the primary source of nitrate (leafy greens vs. beetroot) and the main outcomes. While both sources were beneficial, high intake of nitrates from leafy greens showed a slightly stronger association with lower cf-PWV in this cohort.

Table 9: Association by Primary Nitrate Source (Adjusted Beta Coefficients)

Nitrate Source	SBP (β)	FMD% (β)	cf-PWV (β)
Leafy Greens	-0.26**	0.23**	-0.19*
Beetroot	-0.22**	0.20**	-0.15*
* p<0.05, ** p<0.01			

Discussion

The findings from this cross-sectional study provide what we believe is the first evidence of a significant, independent link between estimated dietary nitrate intake from plant-based sources and improved vascular health within an Uzbek adult population. Most striking was the clear inverse dose-response relationship; individuals in the highest tertile of nitrate consumption had systolic blood pressure readings nearly 15 mmHg lower on average than those in the lowest tertile, a difference with undoubted clinical relevance[1]. This association held strong even after accounting for age, BMI, and smoking, suggesting that the benefits of nitrate-rich vegetables extend beyond just being a marker of a generally healthier diet.

Our results lend strong support to the biological plausibility of the nitrate-nitrite-NO pathway, a concept extensively detailed by Lundberg et al. (2018)[5]. The correlation we observed between higher nitrate intake and better endothelial function (FMD%) aligns perfectly with this mechanism. It appears that in our cohort, dietary nitrate acted as a substrate to bolster nitric oxide bioavailability, thereby improving vasodilation and reducing vascular resistance. This is consistent with intervention studies, like the seminal trial by Kapil et al. (2015), which showed sustained BP lowering with nitrate supplementation in hypertensives[7]. However, our study moves beyond supplements, showing that regular, dietary-level intake from common foods is associated with similar benefits in a real-world setting.

Interestingly, the estimated median nitrate intake in our normotensive group (215 mg/day) was notably higher than in the hypertensive group (162 mg/day). This gap highlights a potential dietary modifiable risk factor. While these intakes are lower than those often achieved in controlled supplementation studies using beetroot juice, they fall within the range consumed in large observational studies like the Danish Diet, Cancer, and Health Study, which also found protective associations[8]. This suggests there might be a beneficial threshold effect rather than a requirement for pharmacological-level doses, which is encouraging for public health strategies.

The protective association seemed particularly pronounced for nitrates derived from leafy green vegetables, a staple in traditional Uzbek cuisine as noted by Rakhimov (2021)[3]. This nuance is important. It suggests that promoting the consumption of specific, culturally familiar foods like *ko'k piyoz* and spinach could be a more effective and sustainable strategy than recommending generic "healthy eating" or unfamiliar supplements. The food matrix—the combination of nutrients and compounds in whole vegetables—likely plays a synergistic role, perhaps enhancing nitrate bioavailability or providing complementary antioxidants, as discussed by Hord et al. (2009)[10].

We must, however, temper our conclusions with a discussion of the study's limitations. The cross-sectional design remains the biggest caveat; we cannot definitively say that low nitrate intake *causes* hypertension, only that the two are strongly associated. It is possible that individuals with early, undiagnosed hypertension or other risk factors subconsciously alter their diet. While we adjusted for several confounders, residual confounding from unmeasured factors like genetic predisposition or precise physical activity energy expenditure is always possible. Furthermore, our nitrate intake was estimated via FFQ, which is subject to recall bias. We did not measure plasma nitrate/nitrite levels, which would have provided a direct biochemical validation of intake and NO pathway activity. Future studies in this region would benefit from such direct measures.

Despite these limitations, the implications are substantial. In a country like Uzbekistan, facing a high burden of hypertension[1], a strategy that leverages existing food culture is powerfully pragmatic. Our findings suggest that simple, culturally-tailored dietary advice to increase daily portions of specific local nitrate-rich vegetables could serve as an effective adjuvant to medical therapy. This aligns with global calls for food-based approaches to tackle cardiovascular disease[2]. As Jackson et al. (2022) concluded in their review, the evidence for dietary nitrate is maturing beyond efficacy and into the realm of practical implementation[4].

Conclusions

This study demonstrates a significant and clinically meaningful inverse association between habitual dietary nitrate intake from plant sources and systolic blood pressure, endothelial function, and arterial stiffness in Uzbek adults. We found that higher consumption of nitrate-rich vegetables, particularly leafy greens, was independently associated with lower blood pressure and better vascular health, supporting the biological role of the dietary nitrate-nitrite-nitric oxide pathway.

The primary conclusions are threefold. First, dietary nitrate from everyday plant foods appears to be an important, modifiable factor linked to vascular health in the Uzbek context, extending global findings to a Central Asian population. Second, the observed dose-response relationship suggests that even modest, diet-achievable increases in nitrate intake may have meaningful benefits for blood pressure management. Third, this research provides a scientific basis for promoting specific, locally available vegetables—a move that aligns with both cultural traditions and modern preventive medicine.

These conclusions advocate for integrating targeted nutritional guidance into national hypertension management programs in Uzbekistan. Future research should prioritize longitudinal or intervention studies to establish causality and define optimal intake levels using locally relevant foods. Ultimately, empowering individuals to harness the vascular benefits of their own culinary heritage offers a sustainable, complementary strategy in the fight against hypertension and cardiovascular disease.

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