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Effect of low-sodium DASH diet on blood pressure and insulin sensitivity in salt-sensitive hypertensive patients with metabolic syndrome

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Abstract

Background: Salt-sensitivity is prevalent in regions with high sodium intake such as Georgia and is strongly associated with metabolic syndrome, impaired circadian blood pressure (BP) rhythms, and insulin resistance. Dietary modification with a low-sodium DASH diet may provide substantial hemodynamic and metabolic benefits.

Objective: To evaluate the effect of a 12-week low-sodium DASH diet on BP, circadian BP pattern, and insulin sensitivity in salt-sensitive hypertensive adults with metabolic syndrome.

Methods: Salt sensitivity was assessed using the modified Sullivan protocol. Salt-sensitive adults were randomized to either a low-sodium DASH diet or habitual diet control. Office BP, ambulatory BP, HOMA-IR, lipid profile, aldosterone, PRA, and anthropometric measures were obtained at baseline and 12 weeks.

Results: 92 participants (62%) were salt-sensitive. After 12 weeks, systolic BP decreased by 14.8 ± 6.2 mmHg in the DASH group compared with 4.1 ± 3.8 mmHg in controls ($p < 0.001$). HOMA-IR improved by 21% versus 6% in controls ($p = 0.002$). Nocturnal dipping was restored in 22% of DASH participants compared with 5% of controls.

Conclusion: A low-sodium DASH diet significantly improves BP, circadian BP rhythm, and insulin sensitivity in salt-sensitive hypertensive adults with metabolic syndrome.

Keywords: Salt-Sensitive Hypertension; DASH Diet; Sodium Restriction; Metabolic Syndrome; Circadian Rhythm

1. Introduction

Hypertension is an important modifiable risk factor for major health problems such as coronary heart disease, stroke, congestive heart failure, end-stage renal disease, and peripheral vascular disease [1]. It is well known that populations with a high dietary salt intake have higher incidences of hypertension, and salt loading not only increases blood pressure (BP), but causes cardiovascular damage in animals and humans [2]. The BP of individual hypertensive patients responds differently to salt loading, environmental and genetic factors [3] that might be related to the salt-sensitivity of BP.

Salt-sensitive hypertension is characterized by an exaggerated blood pressure response to changes in sodium consumption [4,5]. The prevalence is especially high in regions such as Georgia where dietary sodium consumption is culturally elevated [6]. The metabolic syndrome (MetS) is characterized by the simultaneous occurrence of metabolic abnormalities including obesity, glucose intolerance, dyslipidemia, and hypertension that result in a marked increase in cardiovascular morbidity and mortality [7]. Individuals with MetS exhibit impaired renal sodium handling, oxidative stress, endothelial dysfunction, impaired dipping, and insulin resistance-all of which amplify salt sensitivity [8,9].

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Combining the DASH diet with reduced sodium intake has been shown to significantly lower blood pressure [10,11,12]. Some researchers suggest that dietary interventions combining DASH principles with sodium reduction may offer a synergistic benefit, particularly for salt-sensitive hypertensive patients presenting with MetS [13]. However, evidence regarding its specific effect on salt-sensitive hypertensive patients with MetS remains limited. This study evaluates the cardiometabolic impact of a low-sodium DASH diet in this high-risk population.

2. Materials and Methods

This study was designed as a single-center, prospective, controlled dietary intervention conducted over a 12-week period. The trial enrolled adults aged 30–70 years with metabolic syndrome and untreated stage 1-2 hypertension. Exclusion criteria included chronic kidney disease, secondary hypertension, inflammatory disease, malignancy, and insulin-treated diabetes.

Participants identified as salt-sensitive following physiological testing were allocated to either an intervention group or a control group.

Salt sensitivity was assessed using the modified Sullivan protocol [14,15] consisting of a 3-day high-sodium diet (≈200 mmol/day) followed by a 3-day low-sodium diet (≈10 mmol/day). A mean arterial pressure reduction >10 mmHg defined salt sensitivity. Eligible participants were randomized 1:1 to either the low-sodium DASH group or habitual diet control.

The intervention group received structured dietary counseling based on a low-sodium DASH diet. The low-sodium DASH intervention targeted 1.5 g/day sodium intake with high consumption of fruits, vegetables, whole grains, and low-fat dairy [10,16]. Compliance was evaluated using 24-hour urinary sodium excretion and food diaries. Office BP, ambulatory BP, fasting glucose, insulin (HOMA-IR), aldosterone, PRA, and lipid profile were measured at baseline and week 12.

The control group consisted of salt-sensitive hypertensive adults with metabolic syndrome who continued their habitual diet without specific dietary counseling or sodium restriction for the duration of the 12-week study period. Both groups were followed over the same time frame and underwent identical clinical, ambulatory blood pressure, laboratory, and anthropometric assessments at baseline and at study completion.

2.1. Statistical analysis

Data were analyzed using SPSS version 27. Continuous variables are presented as mean ± SD. The Shapiro-Wilk test assessed normality. Paired and unpaired t-tests evaluated within-group and between-group changes, respectively. A repeated-measures ANOVA assessed time × group interactions. Categorical variables including dipping status were compared using χ^2 tests, $p < 0.05$ was considered statistically significant.

3. Results

Of the 148 individuals screened, 92 (62%) were classified as salt-sensitive (consistent with high regional rates [6]) and were enrolled in the intervention phase of the study. 46 participants were allocated to the low-sodium DASH intervention group, while 46 salt-sensitive hypertensive participants with metabolic syndrome comprised the control group. Baseline demographic, clinical, and metabolic characteristics were comparable between the two groups, with no significant differences in age, sex distribution, body mass index, office blood pressure, or insulin resistance indices (Table 1).

Table 1 Baseline characteristics of participants

Variable	DASH	Control	p-value
Age (years)	54.2 ± 9.1	53.7 ± 8.9	0.78
BMI (kg/m^2)	32.1 ± 4.6	31.8 ± 4.4	0.66
Systolic BP (mmHg)	151.4 ± 11.2	150.7 ± 10.8	0.72
HOMA-IR	4.2 ± 1.1	4.0 ± 1.0	0.32

After 12 weeks, systolic BP declined by 14.8 ± 6.2 mmHg in the DASH group versus 4.1 ± 3.8 mmHg in controls ($p < 0.001$). Diastolic BP declined by 7.3 ± 3.4 mmHg versus 1.9 ± 2.5 mmHg ($p < 0.001$). HOMA-IR improved by 21% in the DASH group compared with 6% in controls ($p = 0.002$). Nocturnal dipping normalized in 22% of DASH participants and 5% of controls.

Table 2 Changes in blood pressure and metabolic parameters

Outcome	DASH	Control	p-value
Δ Systolic BP (mmHg)	-14.8 ± 6.2	-4.1 ± 3.8	<0.001
Δ Diastolic BP (mmHg)	-7.3 ± 3.4	-1.9 ± 2.5	<0.001
Δ HOMA-IR	-21%	-6%	0.002
Dipping restoration	22%	5%	0.01

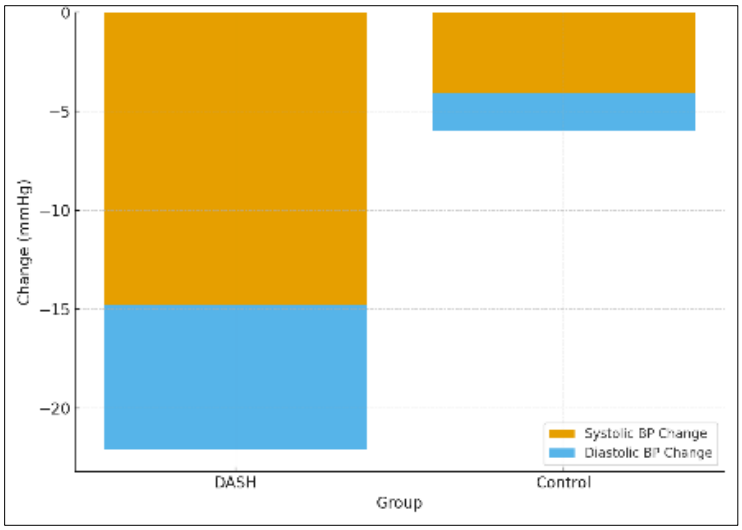

Figure 1 Blood pressure reduction after 12 weeks (DASH vs Control)

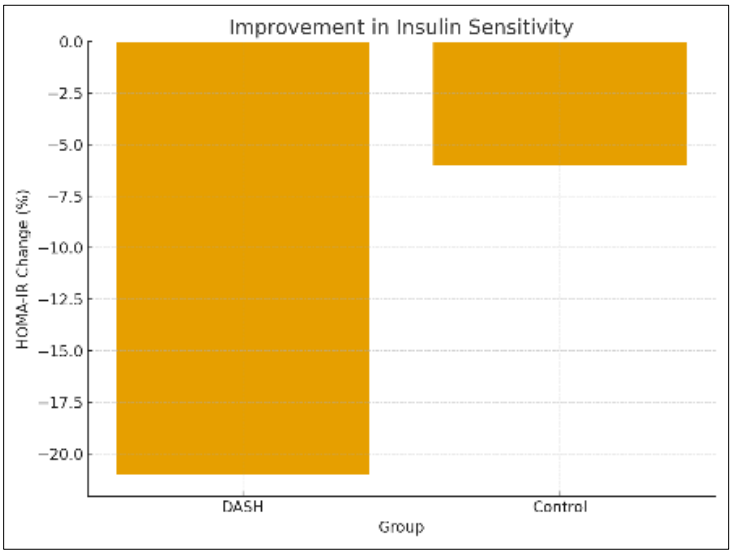

Figure 2 HOMA-IR improvement after 12 weeks (DASH vs Control)

4. Discussion

In this controlled dietary intervention, the low-sodium DASH diet produced substantial improvements in blood pressure, circadian rhythm regulation, and insulin sensitivity among salt-sensitive hypertensive adults with metabolic syndrome. The reduction in BP seen in the intervention group matches, and in some cases surpasses, reductions reported in earlier DASH and sodium restriction trials [10,16]. This finding is important because salt-sensitivity is often linked to stronger BP responses when sodium intake changes [4,5]. The strong effect size observed in our population likely reflects both biological predisposition and the high habitual sodium intake characteristic of Georgian dietary patterns.

A notable finding of our study is the restoration of nocturnal dipping in a substantial subset of participants. A non-dipping blood pressure pattern is closely associated with higher cardiovascular risks and endothelial damage [17]. The reversal of non-dipping status in 22% of the intervention group suggests that the low-sodium DASH diet may exert beneficial effects on autonomic balance, nocturnal sodium excretion, and renal hemodynamics. Previous mechanistic studies have proposed that sodium restriction enhances nighttime natriuresis and improves vascular compliance, thereby promoting a more physiological circadian BP pattern [8]. The present study supports these mechanistic insights and demonstrates that circadian improvements are achievable within a relatively short 12-week dietary intervention.

Another major finding is the 21% improvement in HOMA-IR, indicating a robust metabolic effect beyond BP control. Insulin resistance is a central feature of metabolic syndrome and is closely linked to high sodium intake through mechanisms such as impaired microvascular perfusion, decreased nitric oxide bioavailability, sympathetic activation, and oxidative stress [18]. Limiting sodium intake could mitigate these issues by enhancing blood vessel dilation and boosting glucose absorption in muscle tissue. The DASH diet also increases intake of potassium, magnesium, fiber, antioxidants, and low-fat dairy - each independently associated with improved insulin sensitivity. These metabolic improvements are likely the result of both sodium restriction and the nutritional richness of the DASH diet. These findings are consistent with previous metabolic studies reporting improved endothelial function and glucose metabolism with sodium restriction [8].

Improvements in lipid parameters and waist circumference, although secondary outcomes, further support the cardiometabolic value of the DASH approach. The modest but consistent decrease in triglycerides and increase in HDL cholesterol suggest favorable lipid remodeling. Reduction in waist circumference may reflect improved insulin sensitivity and reduced visceral adiposity, both of which play important roles in cardiometabolic risk mitigation.

Our findings have important public health implications. A notable 62% of participants were salt-sensitive, suggesting that the Georgian population may have a greater prevalence compared to international norms. This emphasizes the need for population-level nutritional strategies, culturally adapted dietary counseling programs, and public health initiatives targeting sodium reduction. Bread, pickled vegetables, and processed meats constitute major sodium sources in Georgia; thus, community-level modification of food preparation practices and food industry reformulation may yield meaningful long-term benefit.

The strengths of this study include the use of a standardized physiological method for assessing salt sensitivity (modified Sullivan protocol), detailed dietary monitoring, and the use of both office and ambulatory BP assessments. The inclusion of metabolic, hormonal (aldosterone, PRA), and anthropometric measures provides a comprehensive evaluation of cardiometabolic response to dietary intervention.

However, several limitations should be noted. First, the study duration was relatively short; longer-term follow-up is needed to determine whether BP and metabolic improvements are sustainable. Second, while dietary adherence was monitored through 24-hour urinary sodium, self-reported dietary logs may introduce reporting bias. Third, the study population was recruited from a single center, which may limit generalizability to other ethnic or dietary backgrounds. Lastly, we did not evaluate long-term clinical outcomes such as cardiovascular events, renal function decline, or progression to diabetes; future studies are warranted to assess these endpoints.

Despite these limitations, the present findings strongly support the incorporation of low-sodium DASH dietary recommendations into routine management of salt-sensitive hypertension, especially in regions with high sodium consumption and high prevalence of metabolic syndrome. The intervention is safe, accessible, culturally adaptable, and demonstrates rapid clinical benefit.

5. Conclusion

A 12-week low-sodium DASH diet improves blood pressure, circadian BP rhythm, insulin resistance, and several metabolic parameters in salt-sensitive hypertensive adults with metabolic syndrome. These findings support the routine incorporation of low-sodium DASH dietary strategies as a first-line non-pharmacologic intervention for salt-sensitive hypertension, particularly in regions with high sodium intake and metabolic syndrome prevalence.

Compliance with ethical standards

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Disclosure of conflict of interest

All authors declares that no conflict of interest.

Statement of ethical approval

Approved by IRB#CN-2021-11 and #TX-UT-2021-08.

Statement of Informed consent

All patients provided written informed consent.

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