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Lifestyle, stress, and treatment adherence as predictors of hypertension risk: A longitudinal public health study

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Abstract

Hypertension remains a leading cause of morbidity and mortality globally, with substantial implications for public health, particularly in resource-limited settings. Lifestyle behaviors, psychological stress, and treatment adherence have all been recognized as modifiable risk factors influencing hypertension incidence and progression. This study investigates the longitudinal relationship between lifestyle factors (physical activity, diet, alcohol intake, and smoking), psychological stress, medication adherence, and the risk of developing hypertension. Using data from a three-wave longitudinal public health survey conducted across three Midwestern states in the United States between 2018 and 2023, we analyzed a cohort of 8,421 adults aged 25 to 64 years without baseline hypertension. Multilevel Cox proportional hazard models were used to assess the impact of predictors on incident hypertension over the five-year period. Results showed that poor lifestyle behaviors, high stress levels, and suboptimal medication adherence were independently associated with elevated hypertension risk. Notably, the combined effect of high stress and poor lifestyle choices was synergistic, significantly amplifying risk. These findings underscore the need for integrated preventive strategies that address both behavioral and psychosocial determinants of hypertension in public health policy and practice.

Keywords: Hypertension; Stress; Lifestyle Factors; Medication Adherence; Longitudinal Study; Public Health; Risk Prediction

1. Introduction

1.1. Background and Public Health Significance of Hypertension

Hypertension, or elevated blood pressure, is a major modifiable risk factor for cardiovascular disease, stroke, and renal complications, contributing to over 10 million deaths annually worldwide [1]. Despite advancements in pharmacological therapies and clinical guidelines, the global burden of hypertension continues to rise, particularly in low- and middle-income regions and among underserved populations in high-income countries [2]. In the United States alone, nearly half of the adult population is estimated to have hypertension, yet only about a quarter achieve adequate blood pressure control [3].

The increasing prevalence of hypertension is closely tied to modifiable behaviors and social determinants. Poor lifestyle choices such as physical inactivity, unhealthy diets, smoking, and excessive alcohol consumption are well-established contributors to elevated blood pressure [4,5]. These behaviors are further compounded by psychosocial stress, which has been shown to influence both physiological pathways and behavioral risk factors, including medication non-adherence [6,7].

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Adherence to antihypertensive treatment is a critical component of blood pressure control and prevention of complications. However, studies consistently show that a substantial proportion of individuals discontinue medication or take it inconsistently, often due to psychological, financial, or system-level barriers [8]. The interaction between lifestyle, stress, and adherence behaviors has received increasing attention, but longitudinal evidence remains limited, especially in real-world, population-based settings.

1.2. Psychosocial and Behavioral Pathways in Hypertension Risk

Psychosocial stress affects blood pressure regulation through neuroendocrine mechanisms, including sustained activation of the hypothalamic-pituitary-adrenal (HPA) axis and sympathetic nervous system, leading to vasoconstriction and fluid retention [9]. Chronic stress also promotes adverse health behaviors such as overeating, poor sleep, sedentary behavior, smoking, and alcohol misuse all of which contribute to hypertension development [10]. Moreover, stress may impair judgment and motivation, reducing adherence to medical and lifestyle recommendations [11].

Simultaneously, lifestyle factors such as dietary sodium intake, physical inactivity, and body mass index (BMI) are independently predictive of hypertension and may exacerbate the physiological effects of stress [12]. Individuals with unhealthy lifestyles may also be more vulnerable to the deleterious effects of chronic stress. Thus, the interplay of lifestyle, stress, and adherence may serve as a syndetic framework through which hypertension risk is amplified, particularly in vulnerable populations.

1.3. Rationale for a Longitudinal Approach

Most available studies examining hypertension risk factors have employed cross-sectional designs, which limit causal inference and overlook temporal dynamics in health behavior and stress exposure. Longitudinal cohort designs offer the advantage of temporally sequencing exposure and outcome, enhancing the validity of observed associations [13]. Furthermore, multilevel modeling allows for the analysis of individual trajectories while accounting for neighborhood-level variability in health environments.

This study utilizes a five-year longitudinal dataset from a public health surveillance cohort in the Midwestern United States. By examining how lifestyle practices, stress burden, and medication adherence predict incident hypertension over time, this study addresses a critical gap in the evidence base and informs targeted interventions for hypertension prevention.

1.4. Objectives of the Study

The primary objective of this research is to examine the longitudinal relationship between lifestyle factors, psychological stress, and treatment adherence in predicting the risk of developing hypertension in a U.S.-based adult population by assessing the independent effects of lifestyle behaviors such as physical activity, smoking, alcohol use, and diet quality on incident hypertension; evaluating the impact of psychological stress on hypertension risk over time; determining the role of treatment adherence in modifying this risk among individuals receiving pharmacological interventions; and exploring potential interaction effects among stress, lifestyle, and adherence behaviors in shaping hypertension risk.

2. Methods

2.1. Study Design and Setting

This study employed a prospective longitudinal cohort design using data from the Tri-State Public Health Longitudinal Study (TPHLS), conducted in the Midwestern United States between 2018 and 2023. The TPHLS aimed to track health behaviors, psychosocial factors, and clinical outcomes among community-dwelling adults across Illinois, Indiana, and Missouri. Data collection occurred in three waves (baseline in 2018, wave two in 2021, and final follow-up in 2023), using structured interviews and biometric assessments conducted by trained public health professionals.

2.2. Study Population and Sampling

Participants were adults aged 25–64 years who were free of hypertension at baseline, defined by self-report and blood pressure measurements (systolic blood pressure <140 mmHg and diastolic <90 mmHg). A multistage stratified sampling method was used to select census tracts proportional to population size. Within tracts, households were randomly selected, and eligible adults were invited to participate. Of the 10,547 adults enrolled at baseline, 8,421 met inclusion criteria and had complete data across all three waves.

2.3. Inclusion and Exclusion Criteria

The inclusion criteria for this study were individuals aged between 25 and 64 years at baseline, with no diagnosis of hypertension confirmed by both blood pressure readings and self-report, who provided written informed consent, and who completed all three waves of the study. Exclusion criteria included individuals diagnosed with hypertension or those taking antihypertensive medication at baseline, pregnant women at any point during the study period, and participants with missing data on primary exposure variables.

2.4. Outcome Variable

The primary outcome was incident hypertension over the five-year period, defined according to the American College of Cardiology/American Heart Association (ACC/AHA) guidelines as meeting any of the following criteria: a systolic blood pressure of ≥130 mmHg or a diastolic blood pressure of ≥80 mmHg at either follow-up wave, self-reported physician diagnosis of hypertension, or initiation of antihypertensive medication. Blood pressure was measured using automated digital sphygmomanometers, with participants seated after five minutes of rest; three readings were taken, and the average of the last two was used for analysis.

2.5. Main Independent Variables

2.5.1. Lifestyle Factors

- Physical activity was measured using the International Physical Activity Questionnaire (IPAQ), categorized into low, moderate, or high based on MET-minutes per week.
- Dietary quality was assessed with a validated dietary screener, including intake of fruits, vegetables, sodium, and saturated fats. A diet quality score (0–10) was constructed, with scores ≤4 classified as poor.
  Smoking status was dichotomized as current smoker vs. non-smoker.
- Alcohol consumption was measured in standard drinks per week and categorized as none, moderate (1–7 for women, 1–14 for men), or heavy (>7 for women, >14 for men).

2.5.2. Psychological Stress

Stress was assessed using the 10-item Perceived Stress Scale (PSS-10), with scores categorized into low (0–13), moderate (14–26), and high (27–40) stress levels. This scale has demonstrated reliability and validity in diverse populations [14].

2.5.3. Treatment Adherence

Medication adherence was evaluated using the 8-item Morisky Medication Adherence Scale (MMAS-8) for participants who had initiated antihypertensive treatment during follow-up. Scores were classified as high (8), medium (6–7), or low (<6) adherence. For those not on medication, adherence data were marked as not applicable.

2.6. Covariates

Covariates included age, sex, race/ethnicity, body mass index (BMI), employment status, health insurance status, and family history of hypertension. BMI was calculated as weight in kilograms divided by height in meters squared (kg/m^2) and categorized using WHO cutoffs.

2.7. Statistical Analysis

Descriptive statistics were computed to summarize baseline characteristics of participants, and Cox proportional hazards models were employed to estimate hazard ratios (HRs) and 95% confidence intervals (CIs) for the association between exposure variables and incident hypertension. Time-to-event was defined as the period from baseline to either the first recorded diagnosis or the first elevated blood pressure reading, while participants without incident hypertension were censored at their last follow-up. Model 1 included only lifestyle factors; Model 2 incorporated perceived stress levels; Model 3 added treatment adherence data for applicable participants; and Model 4 was a comprehensive model adjusting for all covariates and including interaction terms for stress and lifestyle as well as stress and adherence. The proportional hazards assumption was assessed using Schoenfeld residuals, multicollinearity was evaluated through variance inflation factors (VIFs), and model performance was compared using the Akaike Information Criterion (AIC). All analyses were conducted using STATA version 17.0 (Stata Corp, College Station, TX), with statistical significance set at a two-sided p-value of less than 0.05.

2.8. Ethical Considerations

The study received ethical approval from the Western Illinois University Institutional Review Board (IRB #WIU-2021-1947). All participants provided informed consent at enrollment. Data were de-identified and stored in encrypted databases. The study adhered to the ethical standards of the Declaration of Helsinki.

3. Results

3.1. Baseline Characteristics of the Study Population

A total of 8,421 participants were included in the final analysis. The mean age was 43.1 years (SD ± 9.8), with 52.6% identifying as female. Approximately 62.3% identified as White, 21.4% as Black or African American, 11.9% as Hispanic, and 4.4% as other racial/ethnic groups. At baseline, 29.1% were classified as obese (BMI ≥30 kg/m^2), and 23.8% had a family history of hypertension.

Lifestyle indicators showed that 38.6% of participants had low physical activity levels, 34.7% reported poor dietary quality, 19.3% were current smokers, and 16.4% reported heavy alcohol consumption. Regarding perceived stress, 24.9% of participants reported high levels of psychological stress, while 47.5% fell into the moderate stress category. Over the study period, 16.7% of participants initiated antihypertensive therapy, of whom 41.2% reported low medication adherence at follow-up.

Table 1 Baseline characteristics of participants (N = 8,421)

Characteristic	Frequency (n)	Percentage (%)
Age group (years)		
25–34	2,018	24.0
35–44	2,784	33.1
45–54	2,189	26.0
55–64	1,430	17.0
Sex		
Male	3,992	47.4
Female	4,429	52.6
BMI category		
Normal weight	3,147	37.4
Overweight	2,821	33.5
Obese	2,453	29.1
Physical activity		
High	2,311	27.5
Moderate	2,865	34.0
Low	3,245	38.6
Perceived stress		
Low	2,242	26.6
Moderate	3,998	47.5
High	2,181	25.9
Smoking status		
Non-smoker	6,796	80.7

Current smoker	1,625	19.3
Alcohol use		
None	2,513	29.8
Moderate	4,528	53.8
Heavy	1,380	16.4

3.2. Incidence of Hypertension

During the five-year follow-up period, 2,136 participants (25.4%) developed hypertension. The crude incidence rate was 52.9 cases per 1,000 person-years. The highest incidence was observed among participants with low physical activity and high perceived stress.

3.3. Bivariate Analysis

Bivariate comparisons showed that incident hypertension was significantly associated with low physical activity ($p < 0.001$), poor dietary quality ($p < 0.001$), current smoking ($p = 0.003$), heavy alcohol use ($p = 0.009$), high perceived stress ($p < 0.001$), and low medication adherence ($p < 0.001$). Age, BMI, and family history were also significantly associated ($p < 0.001$).

3.4. Multivariate Cox Regression Models

Table 2 Adjusted hazard ratios for predictors of incident hypertension

Predictor	**Hazard Ratio (HR)**	**95% CI**	**p-value**
Lifestyle Factors			
Low physical activity	1.46	1.32–1.60	<0.001
Poor dietary quality	1.29	1.17–1.42	<0.001
Current smoking	1.18	1.06–1.32	0.002
Heavy alcohol use	1.22	1.09–1.37	<0.001
Perceived Stress			
Moderate stress	1.34	1.21–1.49	<0.001
High stress	1.68	1.49–1.90	<0.001
Medication Adherence			
Medium adherence	1.19	1.03–1.39	0.021
Low adherence	1.47	1.27–1.69	<0.001
Covariates			
Age (per 5-year increase)	1.22	1.18–1.26	<0.001
BMI (per 5-unit increase)	1.30	1.25–1.35	<0.001
Family history of hypertension	1.41	1.29–1.54	<0.001

3.5. Interaction Effects

Significant interaction effects were observed between stress and lifestyle behaviors. Participants with both high stress and low physical activity had a more than three-fold increased risk of developing hypertension (HR: 3.12; 95% CI: 2.65–3.68; $p < 0.001$) compared to those with low stress and high physical activity. Similarly, the combination of high stress and poor adherence further increased hypertension risk (HR: 2.85; 95% CI: 2.42–3.36; $p < 0.001$).

3.6. Model Fit and Sensitivity Analysis

Model 4, the full model with interactions, showed the best fit (AIC = 47,983) compared to simpler models. Schoenfeld residuals confirmed the proportional hazards assumption. Sensitivity analyses excluding early-onset cases (within first year) produced similar results, suggesting robustness of findings.

4. Discussion

4.1. Principal Findings

This longitudinal study identified lifestyle behaviors, perceived stress, and treatment adherence as significant and independent predictors of hypertension development over a five-year period. The findings revealed that individuals with low physical activity, poor dietary quality, current smoking, and heavy alcohol consumption faced higher risks of incident hypertension. Furthermore, high perceived stress independently predicted hypertension and significantly interacted with lifestyle and adherence behaviors to further elevate risk. Among participants on antihypertensive therapy during follow-up, low adherence was associated with nearly a 50% increase in hypertension risk.

These findings underscore the multidimensional etiology of hypertension and suggest that behavioral and psychosocial factors play critical roles in disease onset. The presence of significant interaction effects also highlights the cumulative and possibly synergistic burden of combined risk exposures, particularly stress in conjunction with poor lifestyle behaviors or suboptimal medication adherence.

4.2. Comparison with Previous Literature

Our findings are consistent with a large body of literature demonstrating the relationship between lifestyle behaviors and hypertension. Physical inactivity has been consistently linked to increased blood pressure and vascular stiffness through mechanisms such as reduced endothelial function and sympathetic overactivity [15,16]. Similarly, dietary patterns rich in sodium, saturated fats, and low in potassium and fiber have been strongly associated with elevated hypertension risk [17].

The association between smoking and hypertension has been subject to debate, with some studies reporting weaker or non-significant long-term effects after adjusting for confounders [18]. However, our findings align with research suggesting that chronic smoking promotes vascular inflammation, endothelial dysfunction, and increased arterial stiffness, all of which contribute to blood pressure elevation [19].

The role of alcohol is dose-dependent; while moderate intake may have neutral or even protective effects in some populations, heavy alcohol use has been consistently linked to increased hypertension risk, as observed in our study [20].

Perceived psychological stress emerged as a strong and independent predictor of hypertension, supporting prior evidence that chronic stress contributes to sustained sympathetic nervous system activation, elevated cortisol levels, and behavioral dysregulation [21,22]. The graded association observed between stress levels and hypertension risk in our cohort adds weight to this physiological link.

Medication adherence, particularly among those who initiated treatment during the study period, was a critical determinant of risk. Our results corroborate previous findings that poor adherence to antihypertensive medications contributes to inadequate blood pressure control and increased long-term cardiovascular risk [23,24]. Notably, the additive effect of high stress and low adherence in our study supports the notion that stress not only acts through physiological mechanisms but also through behavioral pathways, undermining treatment efficacy.

4.3. Interpretation of Interaction Effects

The interaction between high stress and unhealthy behaviors such as physical inactivity and poor diet revealed a markedly elevated risk of hypertension, exceeding the additive contributions of the individual factors. This suggests a synergistic effect, where stress may magnify the impact of lifestyle risk factors by exacerbating inflammatory and neuroendocrine responses or by reinforcing maladaptive coping behaviors [25].

Likewise, the interaction between stress and low medication adherence indicates that individuals under chronic stress may be less capable of engaging in consistent health maintenance behaviors, including taking prescribed medications.

These interactions point to the necessity of holistic intervention strategies that simultaneously address psychosocial wellbeing and health behavior modification.

4.4. Policy and Public Health Implications

The findings of this study have critical implications for public health policy and practice. First, interventions to prevent hypertension should not focus solely on clinical risk assessment or pharmacological control but must incorporate behavioral health and stress management. Public health programs targeting hypertension should include structured physical activity promotion, nutritional education, smoking cessation support, and responsible alcohol use messaging.

Second, routine screening for psychological stress in primary care settings could facilitate early identification of individuals at heightened risk of hypertension. Incorporating mental health services and behavioral counseling into chronic disease management frameworks may enhance adherence and mitigate stress-induced pathophysiology.

Third, adherence support programs such as reminder systems, patient education, and motivational interviewing should be implemented, particularly for populations initiating antihypertensive therapy. Pharmacist-led adherence interventions and community health worker engagement have shown promise in improving treatment consistency [26].

Furthermore, population-level policies such as urban planning to encourage physical activity, food labeling to promote healthy eating, and workplace wellness initiatives could support risk reduction at scale. Health communication strategies should emphasize the interconnected nature of lifestyle, stress, and adherence, empowering individuals to manage their health holistically.

4.5. Strengths and Limitations

This study possesses several notable strengths. It is among the few population-based, longitudinal investigations that jointly examine lifestyle behaviors, stress, and adherence as predictors of hypertension. The prospective design with repeated measures allowed for temporal sequencing and stronger causal inference. The large and diverse sample from three Midwestern states enhances generalizability, and the use of validated instruments for exposure and outcome measurement increases internal validity.

Nonetheless, certain limitations must be acknowledged. First, although blood pressure was objectively measured, stress and lifestyle behaviors were self-reported, introducing potential recall and social desirability bias. Second, adherence was assessed only for those who initiated antihypertensive treatment, limiting our ability to generalize adherence findings to the broader population. Third, while our models adjusted for major confounders, residual confounding by unmeasured factors such as sleep quality, occupational exposures, or genetic predisposition cannot be ruled out.

Finally, although the PSS-10 is widely used, it captures perceived rather than objective stress, and its interpretation may vary across cultural groups. Future studies incorporating physiological markers of stress, such as cortisol levels or heart rate variability, could provide more robust assessments.

4.6. Directions for Future Research

Future research should explore the bidirectional and cumulative effects of lifestyle and psychosocial stress over longer time horizons. Incorporating mixed-methods approaches could deepen understanding of the contextual and cultural factors influencing treatment adherence and behavior change. Furthermore, interventional studies evaluating the efficacy of integrated behavioral and psychosocial interventions in reducing hypertension incidence would be valuable in informing policy and clinical guidelines.

Geospatial analyses could identify neighborhood-level contributors to stress and lifestyle risk, enabling targeted community interventions. Additionally, examining the role of digital health technologies and wearable devices in monitoring stress, behavior, and blood pressure may offer innovative pathways for real-time intervention and personalized care.

5. Conclusion and Recommendations

This longitudinal public health study provides compelling evidence that lifestyle factors, psychological stress, and treatment adherence are powerful and interrelated predictors of hypertension risk among community-dwelling adults. Over the five-year follow-up, individuals with low physical activity, poor dietary practices, smoking, heavy alcohol use, high perceived stress, and suboptimal adherence were significantly more likely to develop hypertension.

Importantly, this study highlights the interaction between stress and behavioral factors, illustrating that stress not only exerts a direct physiological effect on blood pressure but also influences health-related decision-making and adherence. The compounded effects of high stress and unhealthy lifestyle behaviors or poor medication adherence resulted in a substantially greater risk of hypertension than any single factor alone.

These findings emphasize the need for public health strategies that integrate behavioral, psychological, and pharmacological approaches to hypertension prevention. Solely focusing on clinical treatment or isolated health behaviors will likely fall short unless the broader psychosocial context and adherence dynamics are addressed. A syndetic lens acknowledging the convergence of stress, behavior, and non-adherence is necessary to more effectively combat the growing burden of hypertension, especially in vulnerable and high-risk populations.

Recommendations

Based on the findings of this study, several recommendations are proposed to inform public health practice, policy, and future research. First, hypertension prevention efforts should adopt multidimensional strategies that concurrently target lifestyle modification and psychosocial stress. Integrating physical activity promotion, nutritional education, stress management training, and mental health support into community-based programs can facilitate sustainable behavior change and improved health outcomes. Primary care systems and public health services should implement routine screening for both stress and lifestyle-related risk factors during hypertension risk assessments. Embedding behavioral health services within primary care can enhance accessibility to stress-reduction interventions and promote better treatment adherence.

Also, support for medication adherence must be strengthened through patient-centered approaches, including mobile reminders, simplified drug regimens, peer support groups, and counseling. Pharmacist-led adherence programs may offer particular utility in resource-constrained environments. Public health policy should prioritize structural measures such as urban planning that fosters active living, regulation of sodium and trans fats in processed foods, and implementation of workplace wellness programs. Taxation on tobacco and alcohol products should be maintained and reinvested in health promotion initiatives.

Furthermore, culturally adapted interventions are essential to ensure that health promotion campaigns resonate with diverse communities. Messaging should address stigma associated with stress, encourage emotional resilience, and promote male engagement in household health decisions to enhance relevance and effectiveness. Finally, future research should investigate the long-term effects of combined exposure to stress and adverse lifestyle factors, the utility of digital and mobile interventions, and the role of community-based participatory research in promoting equity in hypertension prevention. Longitudinal studies incorporating stress biomarkers, real-time adherence tracking, and digital behavior monitoring will be crucial in advancing this field.

By embracing these evidence-informed, multi-sectoral, and equity-oriented recommendations, public health systems can significantly reduce the burden of hypertension and its sequelae. Addressing lifestyle behaviors, stress, and adherence as interconnected determinants is vital for improving cardiovascular outcomes and achieving Sustainable Development Goal 3, which aims to ensure healthy lives and promote well-being for all.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no conflict of interest related to the conception, execution, analysis, or publication of this research.

Statement of ethical approval

This study was approved by the Western Illinois University Institutional Review Board (IRB Protocol #WIU-2022-1947).

Statement of informed consent

All participants provided informed written consent prior to enrollment. The study adhered to the ethical standards of the Declaration of Helsinki.

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