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ASSOCIATIONS OF BODY MASS INDEX, AGE, AND GENDER WITH SYSTOLIC BLOOD PRESSURE AMONG U.S. ADULTS: NHANES 2021–2023

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Abstract

Background: Systolic blood pressure (SBP) is a major determinant of cardiovascular disease risk and is influenced by demographic and physiological factors such as age, gender, and body mass index (BMI).

Objective: To examine the associations of BMI, age, and gender with systolic blood pressure among U.S. adults using nationally representative data.

Methods: A cross-sectional analysis was conducted using data from 5,805 adults aged 20 years and older from the National Health and Nutrition Examination Survey (NHANES) 2021–2023. Descriptive statistics summarized

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participant characteristics. Pearson correlation analysis assessed the relationship between BMI and SBP. Univariate and multiple linear regression models were applied to evaluate the associations of BMI, age, and gender with SBP. Additionally, binary logistic regression analysis was performed to examine the association of these variables with a categorical outcome. Statistical significance was set at $p < 0.05$.

Results: The mean age of participants was 53.85 years, and the mean BMI was 29.73 kg/m². The average systolic blood pressure was 122.87 mmHg. BMI showed a weak but statistically significant positive correlation with SBP ($r = 0.027$, $p = 0.037$). In multiple linear regression analysis, BMI ($\beta = 0.087$, $p = 0.004$), age ($\beta = 0.404$, $p < 0.001$), and gender ($\beta = -4.21$, $p < 0.001$) were significant predictors of SBP. Age demonstrated the strongest association, with SBP increasing with advancing age. Females had significantly lower SBP compared to males. The model explained approximately 16% of the variance in SBP ($R^2 = 0.1626$). In logistic regression analysis, age remained a significant predictor (OR = 1.07, $p < 0.001$), while BMI and gender were not significantly associated.

Conclusion: Age, gender, and BMI are important factors associated with systolic blood pressure among U.S. adults, with age showing the strongest influence. These findings highlight the importance of targeted monitoring and preventive strategies, particularly among older populations and males, to reduce the burden of hypertension and related cardiovascular risks.

INTRODUCTION

Hypertension remains one of the leading risk factors for cardiovascular disease and mortality worldwide[1]. Data from the Global Burden of Disease Study reported by the World Health Organization indicate that hypertension has been the primary contributor to global morbidity and mortality since 2003 [2]. Despite advances in medical treatment and improved availability of therapies, fewer than one-third of individuals with hypertension are adequately protected against cardiovascular events such as heart attacks and strokes, even when their condition appears to be controlled[3]. The 2023 WHO World Report on Blood Pressure estimates that, by 2019,

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approximately 1.3 billion adults worldwide were living with hypertension. Among these individuals, only 54% had received a formal diagnosis, 42% were undergoing treatment, and just 21% had achieved effective blood pressure control[4] Increased body weight is recognized as a major contributing factor in the development of hypertension, and higher body mass index (BMI) has been consistently associated with an elevated risk of hypertension across different age groups[5][6][7]

In Indonesia, hypertension has been identified as the third leading cause of mortality, with a prevalence of 25.8% among adults aged over 18 years [8] Evidence also indicates that hypertension is approximately twice as common among overweight individuals aged 20–39 years compared to those with normal body weight[9]

Beyond its clinical impact, hypertension represents a substantial economic burden. Between 2011 and 2015, cardiovascular diseases were associated with an estimated economic loss of USD 3.7 trillion in low- and middle-income countries, accounting for about 2% of gross domestic product (GDP) and nearly half of the total economic burden attributed to non-communicable diseases[10]. . In regions such as sub-Saharan Africa, the prevalence of hypertension, heart failure, and kidney disease continues to increase, placing additional pressure on already strained healthcare systems. These patterns highlight hypertension as a major challenge to the development and implementation of effective national health policies and programs, limiting the ability to address the growing global burden of cardiovascular disease [[11]. he association between body mass index and hypertension remains a key public health concern in developing countries, as higher rates of morbidity and mortality from cardiovascular diseases among individuals with overweight and obesity have been consistently reported[12][13][14]

Increasing body weight plays a significant role in the development of hypertension, and higher body mass index (BMI) is consistently associated with an elevated risk of hypertension across all age groups[15] Overweight and obesity are estimated to account for nearly 40% of new hypertension cases, while obesity alone contributes to approximately 65–78% of primary hypertension[16]

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Furthermore, the prevalence of hypertension is markedly higher among obese individuals (60–77%) compared to those with normal body weight (approximately 34%)[17]

Obesity has emerged as a major global public health concern affecting individuals across all age groups, including not only middle-aged adults but also younger populations. Recent evidence indicates that the prevalence of obesity has continued to rise, with further increases observed during the COVID-19 pandemic[18]

This study therefore aims to assess the relationships between BMI, age, gender, and systolic blood pressure using data from the nationally representative NHANES 2021–2023 survey. By examining how demographic and anthropometric factors relate to variations in systolic blood pressure, the study seeks to generate insights that can inform public health initiatives focused on early detection, monitoring, and management of hypertension, ultimately helping to reduce the burden of cardiovascular disease among adults. The research Questions are:

1) Does higher BMI independently predict elevated systolic blood pressure after controlling for age and gender?

2) Are there differences in systolic blood pressure patterns between males and females across different age groups?

3)

Methodology

Study Design and Data Source

This study employed a cross-sectional design using secondary data obtained from the National Health and Nutrition Examination Survey (NHANES) collected during the 2021–2023 cycle. NHANES is a large-scale, ongoing surveillance program conducted in the United States that aims to assess the health and nutritional status of the civilian, non-institutionalized population. The survey integrates structured interviews, physical examinations, and laboratory testing to provide comprehensive health-related information.

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The dataset is widely recognized for its methodological rigor and national representativeness, as it utilizes a complex, multistage probability sampling design. This ensures that findings can be generalized to the broader U.S. adult population when appropriate sampling weights are applied. For the purpose of this study, publicly available anonymized data were accessed and analyzed.

Study Population

The study population consisted of adults aged 20 years and older who participated in the NHANES survey during the selected period. Inclusion criteria were based on the availability of complete data for key variables, including body mass index (BMI), systolic and diastolic blood pressure, age, and gender.

Participants with missing or incomplete records for any of these variables were excluded from the analysis to ensure data consistency and reliability. After applying the inclusion and exclusion criteria, a final sample of 5,805 individuals was obtained. Among them, 2,619 were male (45.1%) and 3,186 were female (54.9%).

Variables and Measurements

Body Mass Index (BMI)

BMI was used as an indicator of body adiposity and was calculated using the standard formula: weight in kilograms divided by height in meters squared (kg/m^2). Weight and height measurements were obtained during physical examinations conducted by trained health professionals using standardized equipment and procedures, ensuring measurement accuracy and consistency across participants.

Blood Pressure

Blood pressure was measured using calibrated and validated automated devices during physical examinations conducted by trained NHANES personnel. Both systolic blood pressure (SBP) and

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diastolic blood pressure (DBP) were recorded. To improve reliability and reduce measurement error, multiple readings were taken for each participant, and the average of these readings was used in the final analysis. Systolic blood pressure was considered the primary outcome variable for the statistical analysis.

Age and Gender

Age was recorded as a continuous variable based on participant self-report during structured interviews. Gender was also self-reported and categorized as male or female. These variables were included as key demographic predictors in the statistical models.

Statistical Analysis

All statistical analyses were performed using R software. Data cleaning, transformation, and analysis were conducted systematically to ensure accuracy and reproducibility of results.

Descriptive Statistics

Initially, descriptive analyses were carried out to summarize the characteristics of the study population. Continuous variables such as age, BMI, and blood pressure were presented using means, standard deviations, and ranges. Categorical variables, including gender, were summarized using frequencies and percentages. These descriptive statistics provided an overview of the sample distribution and baseline characteristics.

Correlation Analysis

correlation analysis was used to assess the relationship between body mass index and systolic blood pressure. This method was chosen to evaluate the strength and direction of linear association between the two continuous variables. A significance level of $p < 0.05$ was considered statistically

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significant. The correlation coefficient (r) was interpreted to determine whether the association was weak, moderate, or strong.

Multiple Linear Regression Analysis

A multiple linear regression model was applied to examine the independent associations of BMI, age, and gender with systolic blood pressure. This approach allowed for adjustment of potential confounding variables and provided estimates of the individual contribution of each predictor while holding other variables constant.

The results of the regression analysis were reported using regression coefficients (β), standard errors (SE), t-values, and corresponding p-values. Model performance and explanatory power were assessed using the coefficient of determination (R^2) and adjusted R^2 values, which indicate the proportion of variance in systolic blood pressure explained by the predictors.

Univariate Linear Regression Analysis

To further explore the independent effect of each predictor variable, separate univariate linear regression analyses were conducted for BMI, age, and gender. Each model evaluated the association between a single independent variable and the outcome (systolic blood pressure) without adjustment for other covariates.

This step provided a clearer understanding of the crude relationships between predictors and the outcome variable. Regression coefficients were interpreted as the change in systolic blood pressure associated with one-unit change in the predictor variable.

Binary Logistic Regression Analysis

In addition to linear regression models, a multivariable binary logistic regression analysis was performed to assess the association between BMI, age, and gender with a categorical outcome

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variable. This model estimated the odds ratios (ORs) for each predictor while controlling for the effects of the other variables in the model.

The results were presented as odds ratios with 95% confidence intervals and corresponding p-values. An odds ratio greater than 1 indicated increased odds of the outcome, while an odds ratio less than 1 suggested reduced odds. Statistical significance was determined at the conventional threshold of $p < 0.05$.

Statistical Significance and Interpretation

For all statistical tests, a p-value of less than 0.05 was considered statistically significant. Both effect sizes and significance levels were reported to ensure proper interpretation of findings. Where applicable, confidence intervals were also provided to indicate the precision of estimates.

Ethical Considerations

The study utilized publicly available NHANES data, which are fully de-identified and anonymized to protect participant confidentiality. Since the dataset does not contain personal identifiers, ethical approval was not required for this secondary data analysis. The study adhered to ethical standards for the use of publicly accessible health survey data and followed established guidelines for responsible data handling and reporting.

Results

A total of 5,805 adults aged 20 years and older were included in this analysis, with 2,619 males (45.1%) and 3,186 females (54.9%). The mean age of participants was **53.85 years**, and the mean BMI was **29.73 kg/m²**. The average systolic and diastolic blood pressures were **122.87 mmHg** and **74.76 mmHg**, respectively.

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Correlation Analysis

BMI showed a weak but statistically significant positive correlation with systolic blood pressure ($r = 0.027$, $p = 0.037$), indicating that higher BMI is associated with slightly elevated systolic BP among adults.

Multiple Linear Regression

A multiple linear regression model was conducted to examine the relationship between BMI, age, gender, and systolic blood pressure. The model was statistically significant ($F = 375.5$, df = 3, 5801, $p < 2.2e\text{-}16$) and explained about 16% of the variance in systolic BP ($R^2 = 0.1626$, Adjusted $R^2 = 0.1622$).

- **BMI** was positively associated with systolic blood pressure ($\beta = 0.087$, SE = 0.030, $t = 2.864$, $p = 0.004$), suggesting that each 1 unit increase in BMI was associated with a 0.087 mmHg increase in systolic BP after controlling for age and gender.
- **Age** was strongly associated with systolic BP ($\beta = 0.404$, SE = 0.013, $t = 31.913$, $p < 0.001$), indicating that systolic BP increased by 0.404 mmHg for every additional year of age.
- **Gender** was significantly associated ($\beta = -4.21$, SE = 0.435, $t = -9.674$, $p < 0.001$), with females having, on average, 4.21 mmHg lower systolic BP than males.

Binary Logistic Regression Analysis: A multivariable logistic regression approach was used to evaluate the relationship of BMI, age, and gender with the outcome. The findings indicated that age had a statistically significant effect on the likelihood of the outcome (OR = 1.07, $p < 0.001$), suggesting an **increase** in odds with increasing age. In contrast, BMI (OR = 1.00, $p = 0.418$) and gender (OR = 1.01, $p = 0.873$) did not show statistically significant associations. Odds ratios along with their corresponding significance levels were reported.

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univariate linear regression analyses:

The univariate linear regression analyses exploring the individual associations of Body Mass Index (BMI), Age, and Gender with the outcome variable.

- **BMI**: A significant positive association was observed (β=0.45, $p < 0.001$), indicating that for every unit increase in BMI, the outcome variable increases by approximately 0.45 units.
- **Age**: Age also showed a significant positive association (β=0.42, $p < 0.001$). Each additional year of age corresponds to a 0.42-unit increase in the outcome.
- **Gender**: Gender was a significant predictor (β=-3.94, $p < 0.001$). Compared to the reference group (presumably males), female participants scored, on average, 3.94 units lower on the outcome measure

Table 1: Descriptive Statistics of Participants by Gender

Gender	N	MEAN_AGE	SD_AGE	MEAN_BMI	SD_BMI	MEAN_SBP	SD_SBP	MEAN_DBP	SD_DBP
Female	3,186	53.62712	17.0298	30.12784	7.732161	120.9131	18.78648	74.20794	10.83548
Male	2,619	54.12829	17.1671	29.24639	6.337008	125.2490	16.6656	975.43452	11.06017

The table_1 shows that males and females have similar average ages, but males have slightly higher mean systolic and diastolic blood pressure compared to females. In contrast, females show a higher average BMI than males, while the variability in all measured variables is relatively comparable across both groups.

Table 2: Multiple Linear Regression of Mean SBP on BMI, Age, and Gender

Term	Estimate	STD Error	T value	P value
(Intercept)	96.656	1.173	82.383	0.000
BMI	0.087	0.030	2.864	0.004

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Age	0.404	0.013	31.913	0.000
Gender (Male)	4.210	0.435	9.674	0.000

The Table-2 show that BMI, age, and gender are all significantly associated with systolic blood pressure (SBP). Specifically, SBP increases with higher BMI and age, and males have significantly higher SBP compared to females after adjusting for other variables.

Table 3: UNIVARIATE LINEAR REGRESSION

Variable	*Term*	*Estimate*	*STD Error*	*Statistics*	*P value*
BMI	*(Intercept)*	106.3696799	0.795210167	133.762978	<0.001
BMI	*BMI*	0.4480236	0.027180885	16.483038	<0.001
AGE	*(Intercept)*	100.1193572	0.395798953	252.955048	<0.001
AGE	*AGE*	0.4217266	0.007856919	53.675825	<0.001
GENDER	*(Intercept)*	121.2113669	395.938496	395.938496	<0.001
GENDER	*FEMALE*	-3.9364885	-9.429618	-9.429618	<0.001

The Table-3 results indicate that BMI, age, and gender are all significantly associated with systolic blood pressure (SBP). SBP increases with both BMI and age, while females have significantly lower SBP compared to males.

Table 4: Binary logistics

Term	Estimate	Conf low	Conf high
(Intercept)	0.002904929	0.001782352	0.004664738
BMI	1.004558055	0.993459980	1.015598646
AGE	1.068913778	1.063389920	1.074684862
Gender (female)	1.012366002	0.870780553	1.177434911

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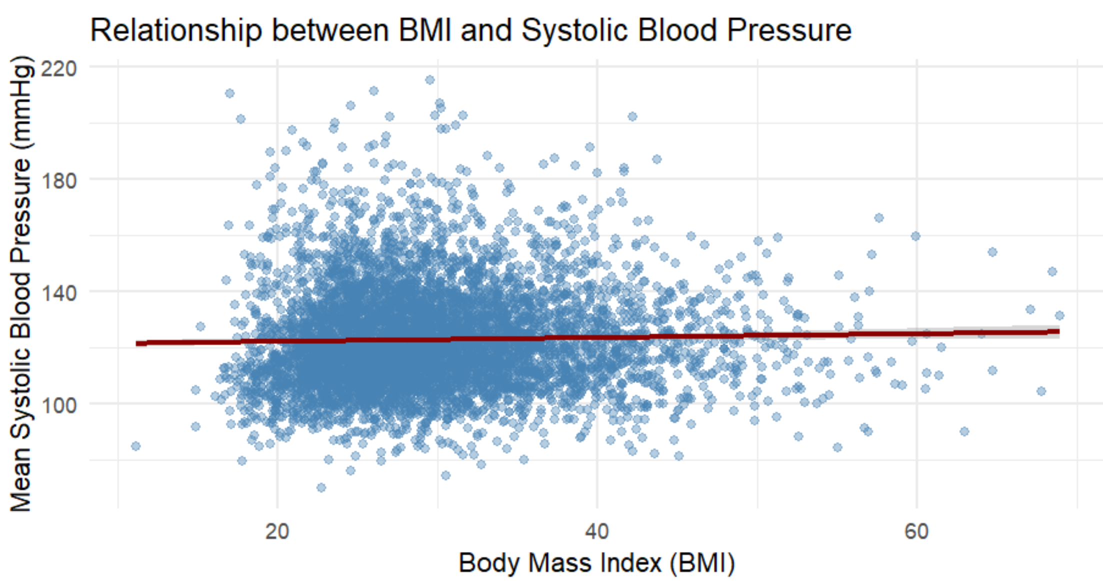
The Table_4 results show that age is a significant predictor of the outcome, where increasing age is associated with higher odds (OR = 1.069, 95% CI: 1.063–1.075). In contrast, BMI and gender do not show a statistically significant association, as their confidence intervals include 1, suggesting no clear effect of BMI or being female on the outcome in this model.



This figure (Figure 01) shows a positive relationship between BMI and systolic blood pressure, with higher BMI values associated with slightly higher systolic BP

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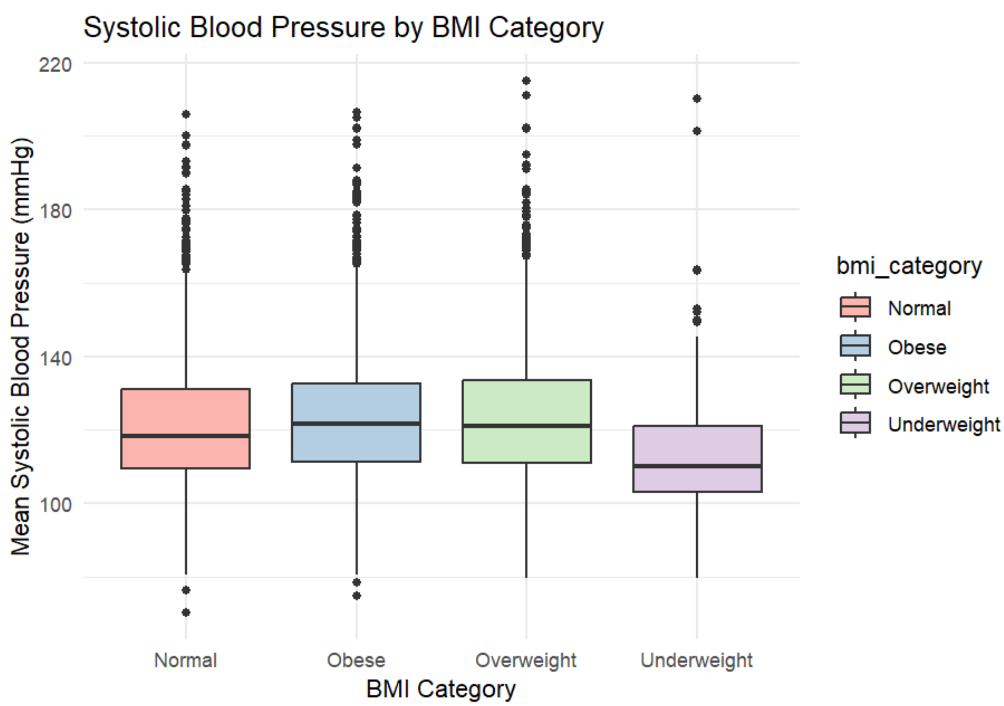

The boxplot (Figure 2) displays systolic blood pressure across BMI categories. Median systolic BP increases progressively from the Underweight and Normal groups to the Overweight and Obese groups, highlighting that higher BMI is generally associated with higher blood pressure.

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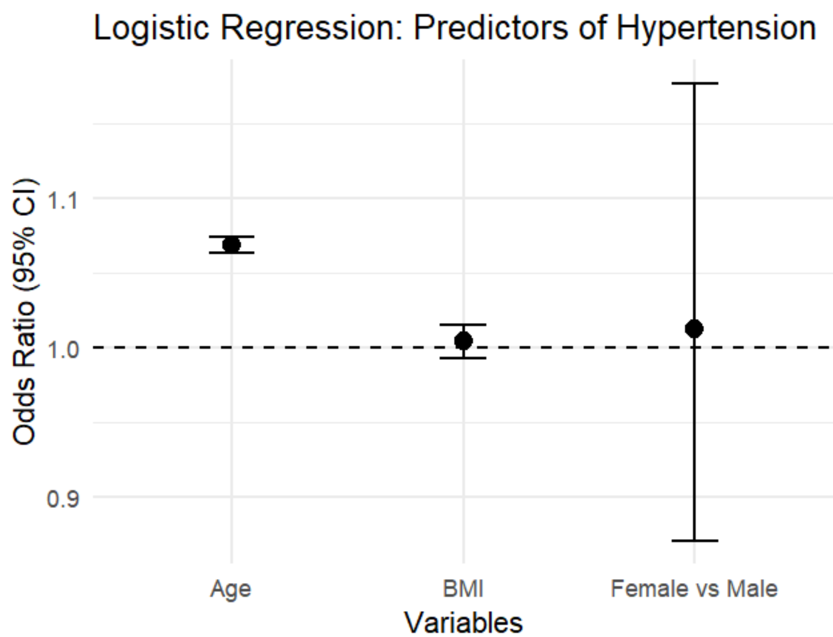

The Graph (Figure 03) demonstrate a positive linear relationship of systolic blood pressure with both BMI and age, indicating increasing blood pressure with higher values of these variables. In contrast, gender differences are evident, with females showing comparatively lower systolic blood pressure than males

Discussion:

Many studies in adults and children have shown that a person's blood pressure at one age can predict their future blood pressure. People who have higher blood pressure than others at one age generally continue to have higher blood pressure relative to their peers over time his tracking phenomenon highlights the long-term stability of blood pressure patterns across the life course and emphasizes the importance of early identification and intervention. Early-life blood pressure levels may set a trajectory that persists into adulthood, increasing the likelihood of hypertension and cardiovascular complications later in life. Therefore, monitoring blood pressure at earlier stages can provide valuable insights into long-term cardiovascular risk and help guide preventive strategies..[19].

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Body mass index (BMI) is the most commonly used measure to assess overweight and obesity in populations. It is calculated by dividing a person's weight in kilograms by the square of their height in meters. Numerous studies have shown that higher BMI is associated with increased blood pressure. Given that overweight and obesity contribute significantly to hypertension and related cardiovascular risks, understanding this relationship in U.S. adults is particularly important. BMI remains a practical and widely accepted indicator for identifying individuals at risk, especially in large-scale epidemiological studies. The relationship between BMI and blood pressure is often explained by physiological mechanisms such as increased blood volume, higher cardiac output, and structural changes in the vascular system that accompany excess body weight.[20].

Blood pressure has been shown to have a positive linear relationship with body mass index. Given the strong association between body weight and blood pressure, reductions in body weight are also associated with lower blood pressure. This highlights the importance of weight management as a key intervention strategy in controlling blood pressure and reducing cardiovascular risk. Lifestyle modifications, including dietary changes and increased physical activity, have been shown to effectively reduce both BMI and blood pressure. These findings reinforce the role of preventive strategies targeting obesity as an essential component of public health interventions. [21][22]

Several studies have shown that both systolic and diastolic blood pressure increase with age. In some populations, this age-related rise in blood pressure has been observed to be more pronounced in women than in men. These findings are consistent with broader epidemiological research indicating that blood pressure tends to increase progressively across adulthood in both males and females. Age-related changes in vascular structure and function, including arterial stiffness and reduced elasticity, contribute to this increase in blood pressure. Hormonal changes, particularly in women after menopause, may further influence these patterns, leading to variations in blood pressure trends between genders.[23]

In several studies, higher BMI has been associated with elevated systolic blood pressure, supporting previous research findings. Obesity and excess body weight are well-established risk factors for

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increased blood pressure, cardiovascular morbidity, and related health complications. BMI, as a widely used measure of nutritional status in adults, serves as a practical indicator for identifying individuals at greater risk of hypertension..The consistent association observed across multiple studies highlights the importance of addressing obesity as a modifiable risk factor. Public health policies aimed at reducing obesity prevalence may therefore have a significant impact on lowering the burden of hypertension and cardiovascular disease.[24]

Although body weight and body mass index (BMI) are commonly considered important determinants of blood pressure, evidence in adult populations remains inconsistent. In the present study, BMI was not significantly associated with blood pressure, indicating that additional factors may contribute to variations in blood pressure levels.This finding suggests that while BMI is an important indicator, it may not fully capture the complexity of factors influencing blood pressure. Other variables such as dietary habits, physical activity levels, genetic predisposition, and socioeconomic status may also play significant roles. Additionally, differences in study design, population characteristics, and measurement methods may contribute to inconsistencies observed across studies.[25]

A previous study reported that an increase in body weight of 4.5 kg was associated with a 4 mmHg increase in systolic blood pressure, which is consistent with our finding that higher BMI is associated with elevated SBP. This supports the biological plausibility of a link between body weight and blood pressure, even when statistical associations may appear modest. Small increases in blood pressure at the population level can translate into substantial increases in cardiovascular risk, underscoring the clinical importance of even modest associations.[26]

Obesity increases adipose tissue, which elevates vascular resistance and increases cardiac workload, ultimately contributing to higher blood pressure. It also activates the sympathetic nervous system, leading to peripheral vasoconstriction and increased arterial resistance, which may result in sustained elevation of blood pressure and development of hypertension. In addition, obesity is associated with hormonal and metabolic changes, including insulin resistance and inflammation,

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which further contribute to vascular dysfunction and increased blood pressure. These mechanisms collectively explain the complex relationship between obesity and hypertension.[27]

Age has been consistently shown to be positively associated with both systolic and diastolic blood pressure. The relationship between age and blood pressure has been reported as statistically significant in both males and females, and several studies suggest that this association may vary by gender.The findings of the present study are consistent with this evidence, as age emerged as the strongest predictor of systolic blood pressure. This reinforces the importance of age as a non-modifiable risk factor and highlights the need for age-specific prevention and management strategies to control blood pressure and reduce cardiovascular risk..[28][29][30]

Limitation:

This study has several limitations. The cross-sectional design prevents causal inferences, and some variables were self-reported, which may introduce bias. Blood pressure was measured during a single visit, which may not reflect long-term trends, and BMI does not account for body fat distribution or muscle mass. Additionally, unmeasured factors such as diet, physical activity, and genetics could influence the observed associations. Despite these limitations, the study provides valuable insights into factors associated with systolic blood pressure in U.S. adults.

Conclusion

This study investigated the relationship of body mass index (BMI), age, and gender with systolic blood pressure using NHANES 2021–2023 data. The findings indicate that age is the most influential factor associated with increased systolic blood pressure, showing a strong and consistent positive relationship across the analyses. BMI was also found to have a statistically significant association with systolic blood pressure, although the effect size was relatively small, suggesting a modest impact of body weight on blood pressure levels. Gender differences were evident, with

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females generally exhibiting lower systolic blood pressure compared to males after adjusting for other variables.

Overall, the results suggest that aging plays a major role in the elevation of systolic blood pressure, while BMI contributes to a lesser extent. Although the statistical models explained a moderate proportion of the variation in blood pressure, it is likely that other unmeasured lifestyle, genetic, and environmental factors also influence these outcomes. These findings highlight the importance of age-related monitoring and weight management in the prevention and control of hypertension among adults.

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