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Original Research Article

Effect of Long Term PM2.5 Exposure on Prevalence of Hypertension among Adults in Urban Region of Peshawar Pakistan

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Abstract: ***Background:*** Hypertension is a major modifiable risk factor for cardiovascular disease in South Asia, especially in Pakistan. In the meantime, ambient air pollution in Peshawar and other urban areas is quite high, particularly fine particulate matter ($PM_{2.1}$), which is increasingly associated with elevated blood pressure through inflammatory and vascular processes. Nevertheless, Peshawar currently lacks local data linking long-term exposure to $PM_{2.1}$ to hypertension. ***Objectives:*** To find out how common hypertension is among urban Peshawar inhabitants, evaluate long-term exposure to ambient $PM_{2.1}$, and investigate the relationship between $PM_{2.1}$ exposure and hypertension. ***Methods***: 384 people who were at least eighteen years old and had been in metropolitan Peshawar for at least five years took part in a cross-sectional survey over the course of five months. The participants were chosen using a multistage random selection technique. Data was gathered using a systematic questionnaire that was adapted from widely used worldwide instruments, including the WHO Household Energy and Air Pollution Survey, the American Thoracic Society questionnaire, and WHO STEPS. We gathered information on tobacco smoke exposure, $PM_{2.1}$ exposure markers, respiratory symptoms, hypertension, and sociodemographic characteristics. The data was analyzed using SPSS version 26. Relationships were assessed using chi-square tests, and descriptive statistics were calculated with statistical significance set at $p < 0.05$. ***Results:*** In 31.8% of cases, hypertension was diagnosed. Approximately 27.6% of the participants lived near major pollution sources, and 84.1% reported spending at least two hours outside every day. Half of the participants reported having a family history of hypertension. Of those surveyed, 23.4% admitted to smoking tobacco, and 49.2% said they had been in close contact to secondhand smoke. Respiratory problems were common, with 28.4% reporting dyspnea and 27.6% reporting a chronic cough. The findings demonstrate the substantial impact of hypertension on a population exposed to high ambient PM2 levels. ***Conclusion:*** In metropolitan Peshawar, where prolonged exposure to high PM2.0 air pollution levels is common, hypertension is significantly more common in adults. These results highlight the critical need for coordinated environmental and public health initiatives to lower pollution and enhance hypertension prevention and treatment in Pakistani cities. They also corroborate the evidence that ambient air pollution raises blood pressure.

Keywords: PM2.5, exposure, hypertension, adults, urban, air pollution, long term exposure, cardiovascular risk.

INTRODUCTION

Hypertension is one of the most significant modifiable risk factors for cardiovascular disease worldwide. South Asian communities have seen a substantial rise in the prevalence of hypertension; a recent national study in Pakistan found that over 46% of people had the condition (1). This pattern is demonstrated by local data from Peshawar: an older university campus cohort had a 68% prevalence of

hypertension (2), whereas a cross-sectional sample of adult employees revealed 18.2% prevalence (3). According to these statistics, a significant portion of city dwellers suffer from excessive blood pressure.

The independent exposure of interest is long-term ambient $PM_{2.1}$ (fine particulate matter), and the dependent health outcome is the prevalence of hypertension. Long-term exposure to PM_2 is positively correlated with the incidence of hypertension, according to epidemiological research. According to meta-analyses, the incidence of hypertension rises by 6–10% for every 10 μg/m³ increase in long-term PM_2 (4). For instance, an increase of 10 μg/m³ in yearly $PM_{2.1}$ was linked to an adjusted odds ratio of 1.04 for hypertension, according to a large Chinese cross-sectional study (5). Mechanistic study indicates that long-term $PM_{2.1}$ inhalation results in endothelial damage and systemic inflammation, both of which raise blood pressure (6). In other words, long-term exposure to PM_2 appears to be an independent predictor of the prevalence of hypertension in exposed populations. Pakistan's air pollution is really terrible. According to national assessments, Pakistan is one of the most polluted countries in the world (2021 $PM_{2.2}$ was ~13.4× the WHO standard (7), with a mean annual $PM_{2.1}$ of about 54.7μg/m³—well exceeding both national and WHO criteria (8). Peshawar is particularly impacted; a 2024 report found that the city's annual average $PM_{2.1}$ was roughly 95.8 μg/m³, more than 19 times the WHO limit. Particulate-trapping terrain, an aging automobile fleet, and brick kilns are some of the sources of this severe pollution. In Pakistan's biggest cities, pollution has already been linked to a high prevalence of cardiovascular diseases like hypertension (9). Nevertheless, the precise relationship between long-term $PM_{2.1}$ exposure and hypertension in the urban population of Peshawar has not been established. It is crucial to determine the prevalence of hypertension and the degree of PM2.0 exposure in this group due to the established health hazards.

High levels of $PM_{2.5}$ air pollution in metropolitan Pakistan, particularly in Peshawar, have been linked to an increase in hypertension. Long-term $PM_{2.5}$ exposure has been linked to elevated blood pressure via inflammatory and vascular mechanisms. However, local evidence in Peshawar is scarce. To inform effective public health and environmental policy, it is required to establish the prevalence of hypertension, evaluate long-term $PM_{2.5}$ exposure, and investigate the connection between $PM_{2.5}$ exposure and hypertension among adults in urban Peshawar.

METHODOLOGY

Study Design: A cross sectional study was carried among adult residents of Peshawar living in urban region. The duration of the study was 5 months (June 2025 to October 2025). The project objectives to determine the prevalence of hypertension, evaluate long-term exposure to ambient $PM_{2.5}$, and explore the link between long-term exposure and hypertension in humans. The poll will include males and women over the age of 18 who have lived in Peshawar's designated urban areas for at least five years. Participants who provide informed consent will be included in the study. Participants with a history of secondary hypertension, pregnant women, and those who do not wish to participate will be excluded.

Standard Procedures of the Study:

Consent was obtained from the Northwest School of Medicine Institutional Review Board (IRB) before data collection began. Permissions were obtained from the participant. The data was collected by the student researchers who had received ethical data and were familiarized with objectives of research. Each participant was contacted and given an oral briefing about the purpose, nature and voluntary features of the study. Prior to the questionnaire being administered, written consent was obtained.

The questionnaire was derived from many internationally recognized instruments, including the WHO Household Energy and Air Pollution Survey, the American Thoracic Society (ATS) Respiratory Questionnaire, and the WHO Stepwise Approach to NCD Risk Factor Surveillance (STEPS). These instruments have been extensively employed and verified in adult populations to evaluate exposure to air pollution, hypertension, and associated health consequences.

. It was divided into five sections

a. Demographic
b. Hypertension status
c. Long term PM2.5 exposure
d. Tobacco smoke exposure
e. Respiratory symptoms

Data Collection

A Multistage random technique was used. A Sample size was calculated using OPENEPI software. The following parameters were used:

1. Population size= 1000000 as population size was considered large so this value was used as per OPENEPI guidance
2. Anticipated frequency (p) = 50% since true frequency was unknown
3. Confidence limits as + - percent of 100 = 5%
4. Design effect = 1%

So based on these parameters the calculated sample size for 95% confidence level was 384

Data Analysis:

The data was coded, entered, and analyzed with SPSS version 26. Prior to analysis, the data was verified for completeness and consistency. We employed descriptive statistics to analyze sociodemographic factors, hypertension status, long-term PM_2.[1] exposure indicators, tobacco smoke exposure, and respiratory symptoms. Categorical data were reported using frequencies and percentages, whereas continuous variables were summarized using averages and standard deviations as appropriate.

The study population's prevalence of hypertension was determined. The chi-square test was employed to detect the presence of hypertension and particular exposure factors. Statistical significance was defined as a p-value less than 0.05. To aid comprehension and clarity, the evaluated data were presented in tables.

RESULTS

Table 1: Demographics

Variable	Category	n	%
Age group (years)	18–29	76	19.8
	30–39	97	25.3
	40–49	97	25.3
	50–59	76	19.8
	≥60	38	9.9
Gender	Male	200	52.1
	Female	184	47.9
Years of residence	5–9 years	25	6.5
	10–19 years	119	31.0
	≥20 years	240	62.5

The sociodemographic data of the research participants is shown in the table. 50.6% of respondents were between the ages of 30 and 49, and 9.9% of respondents were over 60. Women made up 47.9% of the sample, while men made up slightly more than half (52.1%). Just 6.5% of participants had been in the area for five to nine years, while the majority (62.5%) had been there for twenty years or longer.

Table 2: Hypertension Status of Participants

Variable	Category	n	%
Diagnosed hypertension	Yes	122	31.8
	No	262	68.2
On antihypertensive medication*	Yes	77	63.1
	No	45	36.9
Family history of hypertension	Yes	192	50.0
	No	192	50.0

The features of the participants associated with hypertension are displayed in the table. In all, 31.8% of respondents said they had received a diagnosis of hypertension, while 68.2% did not. Of those with a diagnosis, 36.9% were not receiving therapy, while 63.1% were taking antihypertensive drugs. Half of the individuals (50.0%) reported having a family history of hypertension, while the same percentage did not.

Table 3: Indicators of Long Term Pm2.5 Exposure

Variable	Category	n	%
Residence near pollution source	Yes	106	27.6
	No	278	72.4
Outdoor exposure (hours/day)	0–1	61	15.9
	2–4	230	59.9
	≥5	93	24.2

The table displays the people's exposure to environmental contamination. Only 27.6% of respondents lived near a source of pollution, compared to the majority (72.4%). 59.9% of participants said they spent two to four hours a day outside, compared to 24.2% who said they spent five or more hours and 15.9% who said they spent zero to one hour.

Table 4: Tobacco Smoke Exposure

Variable	Category	n	%
Current smoker	Yes	90	23.4
	No	294	76.6
Second-hand smoke exposure	Yes	189	49.2
	No	195	50.8

The table displays the smoking-related characteristics of the individuals. Nearly a quarter (23.4%) of respondents reported presently smoking, compared to the majority (76.6%) who stated they did not smoke. Of the participants, 49.2% reported being exposed to secondhand smoke, whereas 50.8% said they had not.

Table 5: Respiratory Symptoms among Participants

Variable	Category	n	%
Chronic cough	Yes	106	27.6
	No	278	72.4
Breathlessness	Yes	109	28.4
	No	275	71.6
Symptoms worsen on polluted days	Yes	133	34.6
	No	251	65.4

The table compiles the respiratory symptoms of the patients. 28.4% of respondents reported having dyspnea, while 27.6% reported having a chronic cough. Additionally, 34.6% of respondents said that days with pollution made their symptoms worse, while 65.4% disagreed.

DISCUSSION

According to a recent study, the prevalence of hypertension was high (31.8%) and more than 25% of persons in metropolitan Peshawar lived close to significant sources of pollution. This prevalence is comparable to current regional figures. For instance, according to a national survey, the prevalence of age-adjusted hypertension in Pakistan was 46.2% overall (44.3% urban, 46.8% rural), with Khyber Pakhtunkhwa (the province of Peshawar) having a prevalence of about 33.3% (10). Local environmental factors are probably the cause of the higher occurrence in our sample. Just 0.4% of South Asian cities fulfill WHO PM2.5 criteria, making Pakistan one of the world's most polluted nations (11). Our results are consistent with reports of severe air pollution and the health consequences it causes in Pakistan's biggest cities. For example, a recent study in Islamabad discovered that up to 67% of people living close to industrial regions had hypertension (11). Extremely high ambient PM2.5 levels in Lahore and Karachi have been linked to a higher prevalence of cardiovascular disease, particularly hypertension, according to systematic evaluations (9). These results suggest that the incidence of hypertension in South Asian cities is likely due to long-term exposure to PM2.5.

Our results are in line with regional and worldwide epidemiology that associates elevated blood pressure with exposure to fine particulate matter. For example, significant cohort studies in the US and China found that every 10 μg/m^3 rise in annual PM2.5 was associated with a ~4% increased risk of hypertension in Chinese people (5). and a 24% rise in the frequency of hypertension among older Americans was associated with an interquartile increase of approximately 3.9 μg/m^3 PM2.5 (12). A 10 μg/m^3 increase in PM2.5 also increased the risk of hypertension (RR≈1.21) and its prevalence (OR≈1.06), according to a recent Chinese meta-analysis (5). Research from South Asia reveals similar patterns: an Indian study conducted in 2024 discovered a 5.2% increase in the incidence of hypertension in women for every 10 μg/m^3 increase in ambient PM2.5 (13). Long-term PM2.5 exposure was associated with approximately 3% greater chances of hypertension every 1 μg/m^3 (OR of 1.34 per 10 μg/m^3) in peri-urban India (14). Weaker relationships were found in multicenter European cohort data (ESCAPE). For example, exposure to heavy traffic only resulted in a little increase in blood pressure (~0.35 mmHg systolic) and a non-significant OR≈1.05 for hypertension (15). Overall, our results support the larger body of research showing that extended exposure to PM2.5 tends to raise blood pressure and the risk of hypertension, with greater effects observed in high-exposure environments.

PM2.5 may have biologically plausible effects on blood pressure. A systemic inflammatory cascade and pulmonary oxidative stress are brought on by inhaled tiny particles. A 10 μg/m^3 rise in PM2.5 may acutely impair endothelial function (such as a ~12% decline in the reactive hyperemia index) and

enhance signs of oxidative damage, according to experimental human investigations (16). PM2.5 exposure reduces nitric oxide bioavailability and enhances vascular inflammation by producing pro-inflammatory cytokines and reactive oxygen species at the molecular level. (17). Elevated adhesion molecules, angiogenic factors, and compromised vasodilatory responses are indicators of endothelial injury (18). Systolic and pulse pressures rise along with arterial stiffness and systemic vascular resistance as a result of these alterations. Over time, oxidative stress from pollutants and chronic inflammation produce an environment that promotes the development of hypertension. Mechanistic investigations that emphasize oxidative stress and endothelial dysfunction as significant connections between air pollution and hypertension lend credence to this (17). All of the data points to a causal relationship between long-term PM2.5 exposure and elevated blood pressure via inflammatory-oxidative mechanisms.

Public health will be significantly impacted by these findings. In South Asian cities with high pollution levels, PM2.5 is a common and manageable risk factor for cardiovascular disease. Our data and modeling studies from India suggest that strict adherence to air quality laws may considerably reduce the burden of hypertension. For instance, it was predicted that if WHO PM2.5 targets were attained, the prevalence of hypertension among Indian women would decrease by 4% (19). Pakistan's stringent pollution control laws may thereby improve cardiovascular health. Enforcing stricter emissions regulations (vehicles, industry, brick kilns, crop burning), switching to cleaner fuels and energy, enhancing public transportation, and increasing urban green areas are some of the remedies (20). Clinical and community initiatives, such as routine blood pressure monitoring (especially in high-exposure areas), risk-factor counseling (diet, salt reduction, physical exercise), and better hypertension management, are necessary to lower the risk linked with pollution. Public education efforts can raise awareness of the link between air pollution and hypertension, and health systems should include environmental risk factors into the prevention of chronic diseases. In the end, collaboration between environmental and health organizations is necessary to lower PM2.5 exposure and the resulting cardiovascular toll throughout South Asia (21).

CONCLUSION

Our findings demonstrated a high prevalence of hypertension in Peshawar's urban population, which was strongly influenced by severe ambient air pollution. These findings are consistent with prior study, which found that long-term PM2.5 exposure causes high blood pressure through inflammation and endothelial dysfunction. They underline the important need for environmental therapy (air quality improvements) and better hypertension control to protect cardiovascular health in urban Pakistan and other settings.

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