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ORIGINAL ARTICLE

Air Pollution and Home Blood Pressure: The 2021 Athens Wildfires

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Abstract

Introduction Fine particulate matter with an aerodynamic diameter < 2.5 µm ($PM_{2.5}$) in the ambient air has been associated with increased blood pressure (BP) levels and new-onset hypertension. However, the association of BP with a sudden upsurge of $PM_{2.5}$ in extreme conditions has not yet been demonstrated.
Aim To evaluate the association between $PM_{2.5}$ pollutants the week before, during, and the week after the 2021 wildfires in Athens (Greece) and home BP measurements.
Methods Home BP measurements were performed, and the readings were transferred to the doctor's office through a telemonitoring system on the patient's Smartphone
application. Data from a calibrated, sensor-based $PM_{2.5}$ monitoring network assessed $PM_{2.5}$ exposure.
Results $PM_{2.5}$ pollutants demonstrated a gradual surge while the particle concentration was not different in the selected air pollution measurement stations. A total of 20 consecutive patients with controlled hypertension, mean age 61 ± 9 years, were included in the analysis. For one unit in µg/m^3 increase of $PM_{2.5}$ particle concentration, an average of 2.1 mmHg increment in systolic BP was observed after adjustment for confounders (P = 0.023).
Conclusions Our findings raise the hypothesis that short-term exposure to raised $PM_{2.5}$ concentrations in the air appears to be associated with increases in systolic home BP." Telemonitoring systems of home BP recordings may provide important information for the clinical management of hypertensive patients, at least in conditions of major environmental disturbances, such as wildfires.

Keywords Air pollution · Particulate matter · Hypertension · Telemonitoring

1 Introduction

Ambient air pollution has been ranked as a leading modifiable mortality risk factor and recognized as a component of disability at a global level [1]. In addition, recent studies have evaluated the effect of short and long-term exposure to air pollutants on blood pressure (BP) [2–4]. More specifically, short-term exposure to particulate matter < 2.5 µg ($PM_{2.5}$) above 10 µg/m^3 was associated with a 1–3 mmHg increase in systolic and diastolic BP over the days following exposure [1]. In addition, long-term exposure has been associated with sustained BP elevation and new-onset hypertension development [5]. However, no study has determined the association between pollutant $PM_{2.5}$ and out-of-office BP levels.

Consequently, this longitudinal study evaluated the variation of systolic and diastolic BP levels assessed by home BP measurement (HBP) at different levels of $PM_{2.5}$

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concentration. We hypothesized that home systolic or diastolic BP would increase when individuals are exposed to higher $PM_{2.5}$ concentrations. We used air pollution and home BP data to test our hypothesis before, during, and after a major environmental disturbance (i.e., the 2021 wildfires) occurred in Athens (Greece).

2 Methods

2.1 Study participants

One-center hypertensive individuals under antihypertensive treatment with available HBP monitoring data were selected. For at least three months before the present study initiation (i.e., a week before, during the period of wildfires, and the week after), a telemonitoring service was used to trace BP changes and optimize BP control. The diagnosis of hypertension in all selected patients was made using office and ambulatory blood pressure (ABP) measurements right before the HBP telemonitoring period. HBP measurements were under close surveillance using a telemonitoring-based service (PCC Hellas iPAX©, MDStation™), making available the BP readings data in the hypertension center. All patients had well-controlled BP before entering the study. Participants gave their written permission for their data to be accessed and analyzed anonymously. Patients unable to self-monitor their BP, those treated exclusively by lifestyle changes, or those not taking their medication according to the prescribed schedule were excluded. The HBP telemonitoring started on April 2021 and continued for six months. A graphical display of HBP measurements was sent for every monitoring week, followed by a review of BP readings by the center. A total of, 1455 HBP measurements were obtained from 20 participants for the week before, during, and after the wildfires.

2.2 Study procedures

2.2.1 HBP measurements and data transferring

Patients measured their HBP for four consecutive working days, twice in the morning before drug intake and twice in the evening, after 5 min of seated restat home with 1 min interval between the measurements. Readings are obtained at approximately the same time of the day, using a validated automatic BP monitoring (WatchBP Home, Microlife) with a tronco-conical cuff to obtain accurate BP readings, especially in obese individuals (devices with M–L size 22–42 cm (8.7–16.5 in.) are suitable for the majority of the patients. Before study initiation, the patient took BP readings at the office using the provided equipment under the doctor's supervision to become acquainted with the BP measuring technique. They were also instructed not to talk during or in between HBP measurements. During the telemonitoring HBP measurement period, BP data were transferred via Bluetooth from the monitor to the relevant application on each participant's Smartphone. In addition, the telemonitoring service automatically sent an electronic message to each participant's Smartphone, reminding them to take their medications according to the individualized prescription and requesting that a reply be sent back to the center. HBP measurements were collected daily from the telemedicine service, and the hypertension center personnel evaluated the average BP values weekly. Furthermore, the system's website automatically calculated the mean BP for every monitoring week and presented a graphical display of BP measurements for each patient. Telemonitoring system equipment was provided free of charge to all patients who agreed to report their HBP without intervention. Therefore, there was no financial gain for the authors or other individuals involved in the BP recording. Doctors at the hypertension center made all clinical decisions. Angiotensin receptor blockers or angiotensin-converting enzyme inhibitors were used for monotherapy treatment. A calcium channel blocker was used for combination treatments coupled with a renin-angiotensin system blocker. When necessary, hydrochlorothiazide was also administered as a part of combination therapy and was the first drug for down-titration of the ongoing treatment. Other antihypertensive drugs, such as β-blockers, were implemented when indicated. Although changes in the antihypertensive treatment regimen were performed to optimize BP control, this was not performed from the week preceding to the week following the wildfires. Patients were encouraged to adopt lifestyle changes throughout the study period. However, information about lifestyle changes during the study period is not available.

2.3 Exposure description

Repeated $PM_{2.5}$ particle concentration measurements were used the week before, during, and after the blazes in Attica (greater Athens area). The Attica region is located on the eastern edge of Central Greece. It covers about 3808 km^2, with 450 km^2 encompassed by the central Athens basin, with a population of 3.8 million (35% of the country's total population). Starting on August 3, 2021, and for the next 10 days, wildfires raged in northern and western areas of the Attica region, burning large areas of dense forest. According to the regional authority of Attica, the fire fronts extended to 20 and 30 km in western and northern Attica, respectively. Concurrently, a large-sale wildfire ravaged the central and northern part of the Euboea region, to the Northeast, with plumes transported to Athens even after the wildfires in Attica were under control. $PM_{2.5}$ concentrations for the study period (July 26–August 22, 2021) were obtained from the sensor network of the “Panhellenic Infrastructure for Atmospheric Composition and climate change” (PANACEA) which is a national integrated research infrastructure (RI) [6]. The PANACEA network uses the Purple Air PA-II monitors that incorporate twin Plantower PMS5003 sensors [7]. According to the procedures described previously [8], all devices were calibrated against reference-equivalent beta-attenuation $PM_{2.5}$ monitors at the Thissio supersite of the National Observatory of Athens. The PA-II monitors are known to track precisely the short-term temporal variability of $PM_{2.5}$. Following the application of the calibration models, they provide the magnitude of concentrations (except in the occurrence of extreme dust transport events, which were not observed during the study period). $PM_{2.5}$ was analyzed for 15 urban and suburban background locations, covering all six regional units within the central Athens basin and providing a fair representation of the exposed population during the events. The increased spatial coverage of the PANACEA network and the fact that concentrations are measured at background residential locations not directly influenced by local sources (e.g., traffic) can reduce the exposure misclassification error in the study design [9]. All $PM_{2.5}$ data were averaged hourly for use in the subsequent analysis (Supplementary Fig. 1).

Each patient was assigned using the zip (postal) residence code at study entry. Ambient air $PM_{2.5}$ pollutant data were obtained from the nearest to the residence’s monitoring station only. During the intense air pollution events, the authorities issued a recommendation for residents to restrict their outdoor activity in affected areas and avoid the ventilation of residences (e.g., through windows, doors, chimneys) to minimize outdoor and indoor exposure infiltration of particles.

2.4 Statistical analysis

Continuous variables are presented as means and standard deviations if normally distributed, otherwise as medians with their ranges, while categorical variables are frequencies and percentages. Air pollution was estimated as the average value from all stations before, during, and after wildfires. However, only the air pollution station nearest to each participant's residence was used to calculate $PM_{2.5}$ concentrations for the association of each period $PM_{2.5}$ concentration with the average BP during the same period. A Chi-square test was used to compare $PM_{2.5}$ values across the 3 different study periods, while a paired sample t-test was used to evaluate sequential changes in BP during the three study phases. Univariate regression analyses were used to determine the relationships of systolic or diastolic BP changes with independent variables, including $PM_{2.5}$ particle concentration changes. The multivariate models included significantly associated variables with BP changes in the univariate analysis. A P-value < 0.05 was considered in each analysis to indicate statistical significance for all binary comparisons. IBM SPSS Statistics for Windows, Version 23.0. (Armonk, NY: IBM Corp.) was used for all analyses.

3 Results

3.1 Patients and Stations

We included 20 hypertensive patients under antihypertensive treatment (mean age, 61 ± 9 years; 80% men; 23% current smokers). The clinical characteristics of the studied population are presented in Table 1. During the study period (from July 26th, 2021, to August 22th, 2021), no change in the ongoing antihypertensive treatment was made for any participants. The hourly reported $PM_{2.5}$ particle concentration was available from all 15 air pollution measurement stations in the Athens metropolitan area. In addition, the recordings from 10 stations nearest to each participant’s residence were used to contribute $PM_{2.5}$ particle data.

3.2 $PM_{2.5}$ Concentrations

$PM_{2.5}$ concentrations during the whole study period from all available stations are presented in Supplementary Fig. 1. In contrast, measures from the relevant 10 stations used in our analysis are presented in Supplemental Table S1 for the 3 different study periods. A significant change between the levels of $PM_{2.5}$ particle concentrations was noticed between the three study periods ($P < 0.001$ for all comparisons). However, the average $PM_{2.5}$ concentration was not different in the 10 selected air pollution measurement stations compared to all 15 stations situated in the entire greater area of Athens.

Table 1 Clinical characteristics of the participants

Variable	Estimate
Age, years	61 ± 9
Female sex, %	20%
Smokers, %	
Current	23
Past	23
Never	54
BMI, kg/m^2	29.47 ± 3
Systolic home BP, mmHg	125.5 ± 13.2
Diastolic home BP, mmHg	76.6 ± 7.6
Diabetes Mellitus, %	15
Dyslipidemia, %	46

BMI body mass index, *BP* blood pressure, *HBP* home blood pressure

3.3 Home BP measurements

On average, 3.3±0.8 daily BP measurements (total number, 1455) were available during the study period from all patients. As presented in Table 2, the average systolic BP was significantly higher during wildfires than the week before the study period. Diastolic BP after wildfires was significantly lower than

during the wildfire period, while diastolic BP during wildfires was higher than before and in the following week study period.

3.4 Relationship between blood pressure and $PM_{2.5}$ particle concentration

The univariate associations between systolic or diastolic BP change from before to during wildfires and different variables, including the change of $PM_{2.5}$ particle concentration for the same period, are presented in Supplemental Table S2. The change of $PM_{2.5}$ particle concentration from before wildfires to during wildfires was associated with systolic BP change ($P = 0.042$) during the same period. By contrast, no association between $PM_{2.5}$ concentrations and diastolic BP changes was noticed. As shown in Table 3, for one unit (μg/m^3) increase of $PM_{2.5}$ concentration, there was an average increment in systolic BP of 1.3 mmHg after adjustment for smoking status ($P = 0.026$).

4 Discussion

This study shows that during the Athens 2021 wildfires, hypertensive individuals with controlled hypertension displayed BP values that increased in absolute numbers following the rise in $PM_{2.5}$ levels in the center and suburbs of Athens. Although an average increase of 2.1 mmHg in systolic HBP was associated with a unit increase in $PM_{2.5}$ concentration during the wildfires compared to the week before, no linear association in diastolic HBP was noticed with increasing $PM_{2.5}$ concentrations. It is worth noting that the increase in systolic was observed despite patients having continued to take their medications as prescribed. In addition, BP levels gradually returned to baseline after the fires were controlled. Although anxiety or stress during the wildfire emergency could influence BP levels, monitoring of the mental health of the participants was out of the scope of our study.

The association between the increase in $PM_{2.5}$ air pollutants and the rise in BP is well known and documented in previous studies [1, 3, 5]. A recent meta-analysis by Yang et al. reported that short-term exposure to some ambient air pollutants, including $PM_{2.5}$, showed a significant association with BP levels and development of hypertension [4]. This phenomenon between an elevation in systolic and diastolic BP was also observed in Chinese children exposed for a short period to $PM_{2.5}$ air pollutants over the ensuing few days [10]. In a review article, short-term changes in air pollution have also been associated with changes in BP, while a reduction in $PM_{2.5}$ levels results in a substantial BP-lowering [11].

Some studies have shown that ambient $PM_{2.5}$ pollution was associated with increased BP and higher cardiovascular morbidity and mortality [11–13]. Another Chinese community-based population study showed that $PM_{2.5}$ above 100 μg/m^3 was related to a significant increase in central aortic BP, suggesting that air pollution may determine BP levels that exceed the above given thresholds [14]. However, a recent post hoc analysis of the SPRINT trial reported that the cardiovascular benefit of intensive BP-lowering was greater in patients exposed to higher $PM_{2.5}$ [15]. In our study, abrupt increases in air pollution may contribute to lower BP control rates and mandate antihypertensive treatment potentiation.

Our paper does not consider $PM_{2.5}$ to be the sole air pollutant, but more a product off wildfire smoke. Among the air pollutants found in smoke, $PM_{2.5}$ is of the highest concern for human health. The exact mechanisms by which exposure to ambient air pollutants contributes to elevated BP values remain unclear. Increased $PM_{2.5}$ levels may elevate BP through triggering autonomic reflexes (via pulmonary receptors) or chemoreceptor dysfunction

Table 3 Multivariate regression analysis of systolic home blood pressure changes using as an independent variable the changes in $PM_{2.5}$ after adjustment for smoking status

Variable	Beta	B (95% CI)	P-value
Constant	–	−5.7 (−17.1, 5.7)	0.31
Smoking	0.51	4.5 (1.2, 7.8)	0.010
$PM_{2.5}$ change	0.43	1.3 (0.20, 2.4)	0.026

Table 2 Systolic and diastolic home blood pressure changes during the three different phases of the study

	Before	During	After	P-value
Systolic BP, mmHg	125.5 ± 13.2	129.9 ± 10.9	124.1 ± 9.2	0.012; < 0.001; 0.51
Diastolic BP, mmHg	76.6 ± 7.6	78.9 ± 7.3	74.5 ± 4.6	0.032; 0.001; 0.12

First reported P-value for the comparison between before and during wildfires; second reported P-value for during and after wildfires; third reported P-value for before and after wildfires. Paired samples t-test

[16]. Additional suggested mechanisms of BP increase in the same setting might be the enhancement of endothelial dysfunction partly mediated by higher levels of oxidative stress and systemic inflammatory biomarkers [16]. In our study, the absence of a significant relationship between diastolic BP and $PM_{2.5}$ concentration is difficult to explain. In a recent meta-analysis, short-term exposure to $PM_{2.5}$ was not associated with diastolic BP change at variance with systolic BP [17]. In the same vein [17], long-term exposure to $PM_{2.5}$ was associated with increased systolic and diastolic BP levels.

The results of our study could be generalized to settings around the world (e.g., wildfires in California and Australia) and may be helpful in hypertension management during large environmental disturbances. Regarding the limitations, although we used a complex but comprehensive air pollution station network to evaluate the concentration of $PM_{2.5}$ particles, only the measurements from proximal stations for each participant's residence were used in our analyses. Furthermore, a "control" population group of hypertensive patients with available BP measurements during the period of the wildfires, not living in the Athens region and consequently not exposed to the elevated $PM_{2.5}$ concentrations is not available. Despite our relatively small sample size, the detailed daily reporting of HBP minimizes the risk of extreme BP variations. Furthermore, HBP readings transmitted by telemonitoring for such assessments might expand the methodology for future ecological studies.

Despite from a small observation, our results also highlight the impact on the cardiovascular health of air pollutants, which is part of the bigger, serious issue of "climate crisis". More studies on the association of cardiovascular measures with measures of climate change are desirable.

5 Conclusion

HBP with combined telemonitoring systems may help hypertension control during long-standing extreme environmental disturbances, such as wildfires.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s40292-022-00547-0.

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Declarations

Conflict of interest The authors report no conflicts

Data availability One-center hypertensive individuals under antihypertensive treatment with available HBP monitoring data were selected.

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