Postprint: Effects of Indoor Air Particulate Matter Reduction on Cardiovascular and Respiratory Physiological Parameters in Older Adults

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Date: 2022-11-22T00:00:00+00:00

Abstract

Background: Exposure to indoor particulate matter pollution increases the morbidity and mortality of respiratory and cardiovascular diseases, particularly among the elderly in China.

Objective: This study aimed to investigate the effects of indoor particulate matter on cardiopulmonary-related physiological indicators in the elderly and whether short-term use of air purifiers could improve cardiopulmonary health in the elderly.

Methods: In 2020, a randomized, double-blind crossover trial was conducted among 24 healthy elderly individuals in a senior care center in Chongqing, China. Participants were randomly and equally divided into two groups, alternating between using real or sham air purifiers for 48 hours with a 2-week washout interval. We measured 14 biomarkers of inflammation, coagulation, and oxidative stress in the circulatory system. Lung function, blood pressure, heart rate, and FeNO were also measured. Linear mixed-effects models were applied to evaluate the effects of the intervention on health outcome variables. In sensitivity analysis, stratification by sex was performed to explore differences in protective effects of air purifier activation between males and females.

Results: After using air purifiers, particulate matter concentration in the elderly' s bedrooms decreased by approximately 70%. Particulate matter purification resulted in an 11.85% decrease in CRP, 12.52% decrease in fibrinogen, 15.57% decrease in MCP-1, 18.18% decrease in MPO, 16.92% decrease in PAI-1, 12.58% decrease in t-PA, 18.37% decrease in FeNO, and 5.84% decrease in HR in the elderly.

Conclusion: This intervention study demonstrates that indoor air purification is associated with reduced concentrations of systemic and local inflammatory and coagulation biomarkers. Air purification exerts stronger protective effects on

male elderly than on female elderly. Air purification may serve as a public health measure to improve circulatory and cardiopulmonary health in the elderly.

Full Text

Effects of Reducing Indoor Air Particles on Cardiovascular and Respiratory Physiological Indicators in the Elderly

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Funding: This work was supported by the Central University Basic Business Fee "Medical-Engineering Integration" Project "Pathogenic Mechanism of Indoor Environmental Risk Factor Coupling Exposure on COPD in the Elderly" (Grant No. 2019CDYGYB023) and the National Natural Science Foundation of China General Project "Analysis of Exposure Pathways and Accumulation Characteristics of Respiratory System Function in the Elderly under High Indoor Humidity Environment" (Grant No. 52078076).

Abstract

Background: Exposure to indoor air particulate matter pollution increases the incidence and mortality of respiratory and cardiovascular diseases, particularly among the elderly in China. **Objective:** This study investigated the effects of indoor air particulate matter on cardiopulmonary-related physiological indicators in elderly individuals and whether short-term use of air purifiers can improve cardiopulmonary health. **Methods:** In 2020, we conducted a randomized, double-blind crossover trial among 24 healthy elderly individuals at an aged-care center in Chongqing, China. Participants were randomly divided into two groups of equal size and alternated between using true or sham air purifiers for 48 hours, with a 2-week washout interval between interventions. We measured 14 biomarkers of inflammation, coagulation, and oxidative stress in the circulatory system, as well as lung function, blood pressure, heart rate, and fractional exhaled nitric oxide (FeNO). Linear mixed-effects models were applied to evaluate the intervention effects on health outcome variables. In sensitivity analyses, we stratified by sex to explore differences in the protective effects of air purification between older men and women. **Results:** Following

air purifier use, bedroom particulate matter concentrations decreased by approximately 70%. Air purification was associated with an 11.85% decrease in C-reactive protein (CRP), 12.52% decrease in fibrinogen, 15.57% decrease in monocyte chemoattractant protein-1 (MCP-1), 18.18% decrease in myeloperoxidase (MPO), 16.92% decrease in plasminogen activator inhibitor-1 (PAI-1), 12.58% decrease in tissue plasminogen activator (t-PA), 18.37% decrease in FeNO, and 5.84% decrease in heart rate. **Conclusion:** This intervention study demonstrated that indoor air purification is associated with reduced concentrations of systemic and local inflammatory and coagulation biomarkers. The protective effects of air purification were stronger in elderly men than in elderly women. Air purification may represent a public health intervention to improve circulatory and cardiopulmonary health in the elderly.

Keywords: Cardiopulmonary health; The elderly; Particulate matter; Randomized double-blind crossover trial; Public health

Introduction

Numerous studies have shown that both short-term and long-term exposure to ambient particulate matter increases the incidence and mortality of respiratory and cardiovascular diseases [1, 2]. The underlying mechanisms for cardiovascular disease include pulmonary release of inflammatory and vasoactive molecules into the circulation, alterations in cardiac autonomic function, shifts in the balance between coagulation and fibrinolysis, endothelial and microvascular dysfunction, and progression of atherosclerosis with plaque destabilization [3, 4]. Elderly individuals exhibit heightened susceptibility to particulate matter pollution [5]. China is among the countries with the highest PM2.5 pollution levels worldwide, with urban residents spending an average of 87% of their time indoors—a percentage that is even higher for the elderly. Particulate matter can enter indoor environments through ventilation and infiltration, posing health risks to older adults [6]. Air purifiers represent an effective measure for reducing indoor particulate matter concentrations [7]. Therefore, determining the effectiveness of air purifiers in reducing indoor particulate matter in elderly residences and investigating the beneficial effects of indoor air purification on cardiopulmonary health in the elderly is of great importance. We conducted a randomized double-blind crossover trial at a nursing home in Chongqing to investigate the effects of short-term air purifier use on cardiopulmonary health in healthy elderly individuals by substantially reducing indoor particulate matter exposure. This study aimed to assess causal relationships, understand mechanistic endpoints, and provide a theoretical basis for establishing health building standards for the elderly.

1.1 Study Subjects and Experimental Design

This study was conducted in January 2020 at the Tian'ai Pavilion Elderly Apartment in Jiangbei District, Chongqing, China. We recruited 26 non-smoking elderly volunteers who were long-term residents of this facility through posted flyers and face-to-face conversations. All participants self-reported having no cardiopulmonary diseases or not being in an active phase of such conditions. Participants had lived in the nursing home for over one year and did not leave the facility during the study period. The 26 elderly participants resided in 18 rooms within the same building, with each room housing either one or two individuals. All rooms had identical structures consisting of a bedroom and bathroom, with no indoor sources of particulate matter pollution.

The study employed a randomized double-blind crossover intervention design to assess the acute effects of short-term indoor air filtration on health outcome variables. The 26 elderly participants were randomly divided into two groups (A and B) of 13 individuals each. Each participant underwent two experimental phases lasting 48 hours each, separated by a 12-day washout period. During the first phase, Group A used true air purifiers for 48 hours while Group B used sham purifiers (identical in appearance but with HEPA filters removed, providing no purification function). During the second phase, the interventions were switched between groups. Blood samples and morning urine were collected immediately after each intervention, and lung function, blood pressure, and heart rate were measured. Portable HEPA air purifiers (Model KJ001, Weiaikongpin) were used for indoor air purification, with a clean air delivery rate (CADR) of 436 m^3/h and airflow rate of 520 m^3/h. We required all participants to remain in their rooms with doors and windows closed during each 48-hour experimental period, with meals delivered to each room. All interventions began at 8:00 AM to avoid issues related to circadian variations. Both participants and researchers measuring health outcomes were blinded to the type of air purifier used. All participants provided written informed consent prior to participation. The study protocol was approved by the Life Science Ethics Review Committee of Central China Normal University (Approval No.: CCNU-IRB-2019-002).

1.2 Exposure Assessment

During each intervention period, indoor and outdoor particulate matter mass concentrations and temperature/humidity were measured in real-time using environmental monitors with a 1-minute time resolution. Particulate matter monitoring employed laser dust sensors (ZH03B), while temperature monitoring used polymer humidity-sensitive resistors and high-precision NTC temperature elements (MHTRD06). Indoor monitoring equipment was installed at least 1 meter away from air purifiers, with monitoring heights set between 0.6–1.0 meters to cover the breathing zone of elderly individuals who frequently lie down or sit. The 48-hour average concentration was used as the uniform exposure level for

1–2 participants in each room. Outdoor monitoring equipment was installed in a pavilion 10 meters from the residential building within the elderly apartment complex to represent outdoor particulate matter and temperature/humidity levels for all rooms.

1.3 Health Measurements

Before the experiment, we collected information on participants' age, sex, height, weight, and medical history. After each intervention, we collected 3 ml of venous blood (using EDTA tubes) and morning urine samples from all participants. Blood samples were separated to obtain plasma, and both plasma and urine were stored at -80°C. Using plasma and urine samples, we tested 15 circulating biomarkers: eight inflammatory markers (C-reactive protein [CRP], fibrinogen, P-selectin, monocyte chemoattractant protein-1 [MCP-1], interleukin-1β [IL-1β], interleukin-6 [IL-6], tumor necrosis factor-α [TNF-α], and myeloperoxidase [MPO]); four coagulation markers (soluble CD40 ligand [sCD40L], plasminogen activator inhibitor-1 [PAI-1], tissue plasminogen activator [t-PA], and D-dimer); and two oxidative stress markers (reactive oxygen species [ROS] and glutathione [GSH]). All biomarkers were measured using enzyme-linked immunosorbent assay (ELISA). Fractional exhaled nitric oxide (FeNO) levels were measured using a portable NIOX MINO device. Lung function parameters including forced expiratory volume in one second (FEV1), forced vital capacity (FVC), and peak expiratory flow (PEF) were measured using a spirometer. Blood pressure and heart rate were measured using an upper-arm electronic blood pressure monitor.

1.4 Statistical Analysis Methods

Indoor and outdoor PM concentrations exhibited skewed distributions; therefore, the Wilcoxon signed-rank test was used to investigate differences in indoor PM concentrations between true and sham purification groups. Linear mixed-effects models were applied to examine the effects of indoor air purification on cardiopulmonary health indicators in the elderly. All health variables were skewed and were log-transformed prior to statistical analysis. In the models, indoor purification status was analyzed as a fixed effect, with all models including random intercepts for participants to account for correlations between repeated measurements. All models included age, sex, body mass index, indoor relative humidity, and indoor temperature as fixed-effect covariates. The Mann-Whitney U test was used to examine potential carryover effects from different intervention sequences. Additionally, we conducted sensitivity analyses stratified by sex to explore differences in the protective effects of air purification on physiological variables between older men and women. In sensitivity analyses, continuous indoor PM2.5 concentration measurements were used instead of the dichotomous air purification variable, with dependent variables identical

to those in the primary analysis. All statistical tests employed two-sided significance at $\alpha = 0.05$, and all analyses were performed using the "lme4" package (version 4.0.4) in R software.

Results

Initially, 26 elderly individuals were recruited for the trial, but two withdrew during the study. The final study population included 12 men and 12 women with a mean age of 82 ± 8 years and mean body mass index of 24.7 ± 3.8 kg/m^2. According to participant self-reports, they remained indoors throughout the intervention periods and spent the washout periods in the nursing home. All 24 participants completed blood pressure and heart rate measurements. Two participants refused blood draws and morning urine collection. Due to reduced lung function and vital capacity, two participants could not complete two full FeNO tests and lung function tests, another two completed only FeNO tests, and two completed only lung function tests. Therefore, the final analysis included paired blood pressure and heart rate data from 24 participants, paired FeNO and lung function test results from 20 participants, and paired blood and urine samples from 22 participants.

2.1 Particle Exposure

During the trial, mean outdoor concentrations of PM1.0, PM2.5, and PM10 were 37.8 g/m^3, 60.8 g/m^3, and 77.7 g/m^3, respectively. Mean indoor concentrations in the true purification group were 7.3 g/m^3, 12.7 g/m^3, and 16.0 g/m^3 for PM1.0, PM2.5, and PM10, respectively, while mean concentrations in the sham purification group were 27.3 g/m^3, 45.6 g/m^3, and 58.5 g/m^3. Significant differences in indoor particulate matter concentrations were observed between true and sham purification conditions in the elderly apartment, with air purifiers reducing indoor PM1.0, PM2.5, and PM10 concentrations by approximately 73%. Indoor temperature and humidity in the true and sham purification groups were 20.0°C, 53% and 19.8°C, 51%, respectively, with no significant differences.

2.2 Health Marker Responses to Indoor Air Purification

presents the geometric means and standard deviations for eight systemic inflammatory markers, four coagulation factors, blood pressure, heart rate, lung function, airway inflammation, and two oxidative stress biomarkers in the true and sham purification groups. Compared with the sham group, the true purification group showed lower levels of blood inflammatory and coagulation factors, though no such trend was observed for lung function or blood pressure.

The percentage changes and 95% confidence intervals (95% CI) for each health marker from linear mixed-effects models using true versus sham purification as a categorical variable are shown in . Indoor air purification resulted in significant reductions in three blood inflammatory markers, two coagulation factors, and heart rate. Compared with elderly individuals exposed to sham-purified air, those exposed to true-purified air showed significant reductions in fibrinogen (15.1%; 95% CI: -23.1% to -6.3%), MCP-1 (17.7%; 95% CI: -22.9% to -12.3%), and MPO (17.2%; 95% CI: -23.9% to -9.8%) among blood inflammatory factors; significant reductions in PAI-1 (14.9%; 95% CI: -21.1% to -8.2%) and t-PA (13.5%; 95% CI: -18.7% to -8.0%) among coagulation factors; and a significant 5.8% reduction in heart rate (95% CI: -10.6% to -0.8%). Except for FVC, the effects of indoor air purification on other health endpoints were consistent with the expected direction, and correlations between air purification and CRP, P-selectin, and D-dimer reached marginal significance ($p = 0.064$, 0.073, and 0.060, respectively). The sequence of true versus sham purification experienced by each participant was not associated with any health indicator (Mann-Whitney U test p-values ranged from 0.128 to 0.981).

We conducted sensitivity analyses stratified by sex to examine relationships between indoor air purification and physiological changes in the elderly, with results shown in [Figure 1: see original paper]. Indoor air purification significantly reduced CRP, fibrinogen, MCP-1, IL-1β, MPO, PAI-1, and t-PA in elderly men, and significantly reduced fibrinogen, MCP-1, MPO, PAI-1, t-PA, and heart rate in elderly women. The protective effects of air purification were stronger in elderly men compared to elderly women. For both sexes, fibrinogen, MCP-1, MPO, PAI-1, and t-PA were sensitive physiological indicators responsive to air purification.

[Figure 2: see original paper] presents the percentage change in each health indicator associated with a 10 g/m^3 increase in continuous indoor PM2.5 concentration. Consistent with the primary analysis, sensitivity analysis results also found that continuous exposure to indoor PM2.5 was positively associated with systemic inflammatory factors, coagulation factors, oxidative stress markers, cardiac function, and FeNO, but not significantly associated with lung function. Unlike the primary analysis, the sensitivity analysis revealed a significant correlation between indoor PM2.5 and D-dimer ($p = 0.028$), with D-dimer concentration increasing by 3.1% for each 10 g/m^3 increase in indoor PM2.5 concentration.

Discussion

Under sham purification conditions, indoor PM2.5 concentration in the elderly apartment was 45.6 g/m^3, exceeding the World Health Organization standard of 25 g/m^3. After air purifier use, indoor PM2.5 concentration decreased to 12.7 g/m^3, meeting WHO standards. Air purifiers can effectively reduce indoor par-

ticulate matter concentrations, thereby decreasing harm from inhalable particle exposure in the elderly. Short-term indoor air purification may confer cardiopulmonary benefits. In this study, we found modest but statistically significant decreases in four inflammatory markers (CRP, fibrinogen, MCP-1, MPO), two coagulation markers (PAI-1 and t-PA), and heart rate following PM reduction through air purification.

The relationship between air pollution and cardiovascular disease involves multiple pathophysiological pathways, including systemic inflammation and coagulation [8]. CRP measured by high-sensitivity assays is a reliable and independent predictor of cardiovascular events [9]. Previous studies investigating relationships between short-term and long-term PM exposure and CRP have found positive associations between PM exposure and CRP in some cross-sectional studies [10, 11]. In response to vascular injury or inflammation, the human body increases coagulation factors to enhance and complete thrombus formation, with fibrinogen playing a key role in this process [12, 13]. A study of 44 healthy adults in Tehran, Iran found significant differences in fibrinogen levels under different air pollution conditions, with the highest fibrinogen levels observed during dust storm conditions [14]. Another study of 40 healthy young adults also found a significant correlation between ambient PM2.5 concentration and fibrinogen levels [15]. These results are consistent with our findings, though our experimental conditions differed as they were conducted under normal atmospheric conditions where the primary PM source was outdoor traffic emissions rather than extreme weather events such as dust storms. A randomized double-blind intervention study of air purifiers among university students in Beijing, China conducted under daily atmospheric conditions found that air purification could reduce CRP and fibrinogen in young people, though not significantly [16]. In our study, 48 hours of indoor air purification caused significant changes in CRP and fibrinogen in elderly participants, likely due to age-related physiological decline that increases susceptibility to PM-induced cardiovascular damage. Therefore, the potential health benefits of air purification may be greater for the elderly than for the general population. The biological mechanisms linking inhalable particle exposure to venous thromboembolism have not been fully elucidated, though some studies suggest one possible mechanism involves hypercoagulability and enhanced thrombosis formation [17]. Our finding of significant reductions in PAI-1 and t-PA after air purification supports this hypothesis.

This study has several limitations. First, the study included only 24 participants from 16 rooms, which may have resulted in missing some potentially important but modest differences due to the relatively small sample size. Second, given the relatively small sample size and the examination of multiple health endpoints, our study should be considered exploratory.

Conclusion

This study demonstrated that air purifier use can significantly reduce indoor particulate matter concentrations in elderly apartments, with indoor PM2.5 concentrations decreasing by approximately 73%. Indoor air purification resulted in significant reductions in blood inflammatory markers (fibrinogen, MCP-1, MPO), coagulation markers (PAI-1 and t-PA), and heart rate. Stratified analysis revealed that indoor purification conferred greater benefits to elderly men than to elderly women. Indoor air purification also reduced oxidative stress markers in elderly men. Sensitivity analysis found a significant correlation between indoor PM2.5 and D-dimer, with D-dimer concentration increasing by 3.1% for each 10 g/m^3 increase in indoor PM2.5 concentration. The use of portable indoor air purifiers can reduce indoor particulate matter concentrations and significantly decrease inflammatory and coagulation factors in the elderly.

Conflict of Interest: None

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