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The Effects of Home Particulate Air Filtration on Blood Pressure: A Systematic Review

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Abstract

Air pollution is a major contributor to cardiovascular morbidity and mortality. Fine particulate air pollution ($PM_{2.5}$) may be a modifiable risk factor for hypertension. The benefits of in-home air filtration on systolic blood pressure and diastolic blood pressure are unclear. To examine the effects of in-home personal air cleaner use on fine particulate exposure and blood pressure, we queried PubMed, Web of Science, Cochrane Central Register, Inspec, and EBSCO GreenFILE databases for relevant clinical trials. Included studies were limited to non-smoking participants in smoke-free homes with active or sham filtration on indoor fine particulate concentrations and changes in systolic and diastolic blood pressure. Of 330 articles identified, ten trials enrolling 604 participants met inclusion criteria were considered. Over a median 13.5 days, there was a significant reduction of mean systolic blood pressure by nearly 4 mmHg (−3.94 mmHg; 95% CI [−7.00,−0.89]; p = 0.01), but a non-significant difference in mean DBP (−0.95mmHg; 95% CI: [−2.81, 0.91]; p=0.32). Subgroup analyses indicated no heterogeneity of effect by age, level of particulate exposure, or study duration. Given the variation in study design, additional study is warranted to confirm and better quantify the observed benefits in systolic blood pressure found with personal air cleaner use.

Graphical Abstract

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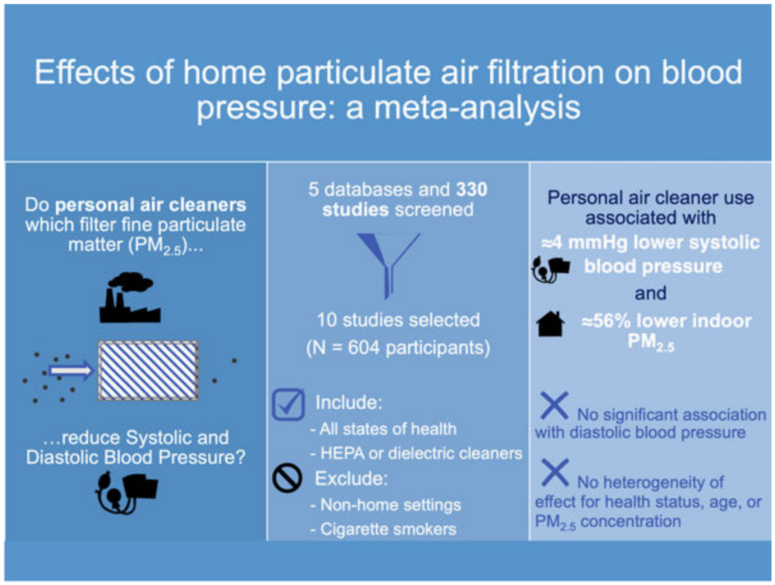

Summary

This is the first meta-analysis to assess the effect of personal air cleaner use on reduction of indoor $PM_{2.5}$ and reduction of blood pressure. Our findings indicate that, across ten trials enrolling 604 participants, personal air cleaners are associated with a significant decrease in systolic blood pressure.

Keywords

Fine particulate matter; PM2.5; Personal air cleaner; Air filtration; Systolic blood pressure; Home intervention

INTRODUCTION

Background:

Ambient air pollution is linked with poor health outcomes and is a major contributor to the global burden of disease. Fine particulate matter less than 2.5 μm in diameter ($PM_{2.5}$) is strongly associated with cardiovascular morbidity and mortality. In 2016, ambient and household air pollution were together responsible for an estimated 6.1 million deaths globally, the majority of which were due to cardiovascular disease (CVD).[1–3] Short-term $PM_{2.5}$ exposure (hours to weeks) increases the likelihood of adverse cardiovascular events, including myocardial infarction, stroke, and heart failure, and longer-term exposure magnifies that risk. One pathway through which long-term PM exposures may contribute to CVD is by potentiating chronic cardiovascular risk factors, including hypertension.[4] Hypertension is a well-established risk factor for CVD.[5] Given that individuals spend roughly 80–90% of their time indoors,[6,7] improving the indoor environment may be an effective CVD prevention strategy. Outside and indoor $PM_{2.5}$ levels are correlated, particularly at high levels of PM 2.5 exposure, and the indoor environment contributes substantially to human pollutant exposure.[8–11] High-efficiency indoor air filters, or "personal air cleaners" (PACs), have been proposed as an intervention to decrease indoor $PM_{2.5}$ exposure. Although some trials have demonstrated improvements in systolic and diastolic blood pressure (SBP and DBP, respectively) with indoor air filtration,[12,13] evidence remains mixed overall.[14–16] Therefore, to evaluate the utility of indoor air filtration on SBP and DBP, we conducted a systematic review and meta-analysis of published trials evaluating effects of in-home PACs on: 1) indoor particulate matter concentrations; and, 2) systolic and diastolic blood pressure in non-smoking adults.

METHODS

The authors declare that all supporting data are available within the article and its online supplementary files.

Search strategy

We conducted a systematic search of the literature in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria[17]. The search Strategy was developed in consultation with an experienced Medical Librarian (TR) and run by co-author (DW). The search was performed on July 9 2019, and updated on July 23, 2019. We queried the following databases: PUBMED, Web of Science Core Collection, Inspec, EBSCO GreenFILE, and Cochrane Central Register of Controlled Trials (which includes published and unpublished records from ClinicalTrials.gov and the WHO's International Clinical Trials Registry Platform). The search was not limited by language or publication date. An example of the PubMed Search Strategy is included as an appendix to this article.

Study Inclusion & Exclusion Criteria

We included studies that met all of the following criteria: (1) were randomized controlled trials in humans; (2) evaluated PACs, including high efficiency particulate air (HEPA) filters and electrostatic precipitators; 3) compared indoor $PM_{2.5}$ during air filtration versus no air filtration (defined as active vs sham filtration); (4) compared blood pressure during active versus sham filtration; (5) took place in a home or residential setting; and, (6) were published in English. One included study reported only levels of Particle Number Concentration (PNC, a measure of ultrafine particles with diameter < 100 nm) in the absence of $PM_{2.5}$ measurements. Given the large quantity of particulate matter delivered by a single cigarette,[18] we excluded studies that enrolled current cigarette smokers, or that were performed in cigarette smoking households.

Article selection

Two authors (DW and JN) screened all articles, independently and in duplicate. Based on the title and abstract, eligible articles were selected if they fulfilled all inclusion and exclusion criteria. If a title and abstract did not provide sufficient detail for a determination, the article was included and progressed to a further round of screening. All selected articles underwent a more rigorous second round of screening, involving a full-text review and assessment of eligibility. At this stage, the reviewers recorded a rationale to justify the exclusion of any article. Discrepancies between the reviewers (DW and JN) were resolved through verbal discussion and consensus (n=2). All final articles were determined to meet all eligibility criteria.

Data extraction

Data were extracted manually and stored in a dedicated spreadsheet. The following study-level data points were extracted: participant characteristics (sex, age, medical history, medications, intervention duration), pre- and post-intervention levels of $PM_{2.5}$ (or PNC if $PM_{2.5}$ was not reported), SBP and DBP at baseline and post-intervention, setting and location of air filtration, mode of intervention, and "sham" or control air filtration. If a washout period occurred between intervention and control conditions its duration was recorded.

Outcomes

The primary health outcomes assessed were changes in SBP or DBP in association with PAC use.

Statistical Analysis

The effects of PAC on BP reduction and their 95% confidence intervals (CIs) were estimated using random-effects meta-analysis of study-level data. Heterogeneity in the study estimates were assessed using I^2 statistics. Publication bias was assessed by visual inspection of funnel plots, and with Egger's statistic.[19] A sensitivity analysis was performed excluding studies with longer duration to determine consistency of the general findings. Statistical analyses were performed in Review Manager (RevMan) version 5.3 (Cochrane Community) and R version 3.5.2 (R Project for Statistical Computing).

RESULTS

Database Search Strategy

A systematic search of the literature was conducted on July 9 2019, and updated on July 23, 2019. The search retrieved 330 total database records, of which 29 duplicates were removed. Unique studies (n = 301) were initially screened by title and abstract. At this stage, 272 articles were deemed ineligible for failing to meet the inclusion criteria, and one ongoing study[20] was excluded due to lack of published data (Figure 1). The remaining 29 articles underwent a full-text review. One study was discarded for including participants who smoked or lived in smoking homes[16]. Ultimately, we identified 10 studies, enrolling a total of 604 participants, meeting inclusion criteria.[14,15,21–28]

Studies' baseline $PM_{2.5}$ concentrations were categorized using WHO criteria as summarized in Table 1. Two studies[14,21] reported low air pollution exposure levels as defined by WHO air pollution standards [29] (baseline $PM_{2.5}$ <10 μg/m^3); four studies [24,26–28] enrolled participants at "high" levels of exposure, or between WHO recommended levels and WHO Interim Target-1 (IT-1) (baseline $PM_{2.5}$ between 10–35 μg/m^3); and three studies[22,23,25] enrolled participants at "extreme" levels of exposure, or above WHO IT-1 levels (baseline $PM_{2.5}$ >35 μg/m^3).[29] One study was classified as indeterminate, as $PM_{2.5}$ was not quantified. Four studies enrolled only healthy college-aged subjects;[22,24–26] four studies enrolled older adults age > 50 years (many with cardiopulmonary risk factors, medical comorbidities, or receiving vasoactive medications); [14,21,23,28] and two studies enrolled healthy participants and did not limit enrollment based on age.[15,27] Characteristics of the ten included studies are summarized in Table 2. Methods of blood pressure measurement are further synthesized in Supplementary Table S1.

Outcomes of Air Filtration on $PM_{2.5}$ and Blood Pressure:

For 9 out of 10 included studies, the median ± standard deviation (S.D.) study duration was 9 ± 14.1 days. One longer-term study was included that randomized subjects to one year of sham or air filtration intervention.[27] Among all trials, PAC use yielded an absolute $PM_{2.5}$ reduction of 20.9 μg/m^3 (S.D. ± 18.2 μg/m^3), and a relative reduction of 55.9% (S.D. ± 17.0%). Across all 10 trials, the use of PACs was associated with a mean SBP reduction of nearly 4 mmHg (−3.94 mmHg; 95% CI [−7.00,−0.89]; p = 0.01), no evidence of a difference in mean DBP (−0.95mmHg; 95% CI: [−2.81, 0.91]; p=0.32), Figure 2. Sensitivity analyses (results not shown) showed consistency with these findings when analysis was restricted to studies designed with SBP as a primary outcome, or which only used ABPM results alone. In a separate sensitivity analysis excluding the one longer-term study of air filtration intervention,[30] similar effects were observed on SBP (−3.02mmHg; 95% CI: [−5.90, −0.14]; p = 0.04) and DBP (p=0.96). The finding of SBP reduction with home air filtration was consistent by health status at baseline (no comorbidities vs. chronic comorbidities or risk factors), P interaction = 0.36 (Supplementary Figure S1). Subgroup analyses revealed no heterogeneity of effect when participants were stratified by age (Supplementary Figure S2a), level of $PM_{2.5}$ exposure (Supplementary Figure S2b), or study duration (data not shown). Due to lack of observed effect for mean reduction in DBP in the primary analysis, subgroup analyses were not performed for effect on DBP.

Results of Bias Assessment

Using the Cochrane Collaboration Risk of Bias criteria, 8 of 10 studies were classified as having low risk of bias, and 2 of 10 studies as having unclear risk of bias (Supplementary Table S2). Egger's test did not provide evidence of publication bias among studies assessing the impact of air filtration interventions on SBP (p = 0.74) or DBP (p=0.65). Funnel plots were not markedly asymmetric for either SBP or DBP. Methodologic heterogeneity was present for both SBP (I^2 = 68%) and DBP (I^2 = 57%).

DISCUSSION

To our knowledge, this is the first meta-analysis to evaluate the effect of in-home PACs on blood pressure. Among ten randomized control trials (RCTs) enrolling over 600 non-smoking participants, the use of PACs over a median 13.5 day duration was associated with a nearly 4 mmHg reduction in SBP, and no evidence of an effect on DBP. This observation was consistent across categories of cardiopulmonary risk factors, medication categories, age, or levels of $PM_{2.5}$ exposure, suggesting the results of our meta-analysis are similar across different population subgroups. The findings of this meta analysis are notable, as even a small decrease in the distribution of blood pressure in a population may significantly reduce cardiovascular morbidity and mortality. For example, it is estimated that shifting the distribution of SBP in a population downward by 5 mmHg could reduce mortality from stroke by 14%, coronary heart disease by 9%, and all-cause mortality by 7%.[31] Thus, although modest, a short-term decrease in SBP of 4mmHg through the use of PACs may have important health benefits if sustainable over the long-term.

While we included studies with a wide range of participants and categories of exposure, studies that included current cigarette smokers as participants were excluded. The quantity of $PM_{2.5}$ delivered by cigarette smoke vastly exceeds environmental $PM_{2.5}$ concentrations; therefore, we concluded that the effects of particles and gases produced by smoking may confound any potential benefits from home air filtration.[18] Importantly, our finding of a significant reduction in SBP was observed despite inclusion of participants with hypertension, diabetes, and vasoactive medication regimens, suggesting that short-term health effects of in-home air filtration may be widely applicable.

PACs are a low-cost and simple intervention to lower $PM_{2.5}$ exposure. Individuals in post-industrial societies spend disproportionate amounts of time indoors, and indoor $PM_{2.5}$ often significantly exceeds outdoor concentrations.[32] The mechanisms through which $PM_{2.5}$ increases blood pressure are not well elucidated. Evidence from human and animal controlled exposure studies suggests that $PM_{2.5}$ raises blood pressure through 1) increasing inflammation and oxidative stress; 2) impairing endothelial function or; 3) increasing sympathetic activation, while decreasing parasympathetic tone.[33] Putative changes in sympathetic and parasympathetic tone may be one pathway for the differential effects of in-home air filtration on SBP compared with DBP observed in this analysis. Further analysis of the study presented Li 2017 showed an association between indoor air filtration and reduction in circulating stress hormones, markers of inflammation, and metabolic activity. These findings suggests that PM2.5 likely influences autonomic signaling to affect HPA axis activation and, subsequently, blood pressure.[25]

Limitations:

Our study is limited by the relatively small number of published RCTs investigating the effects of home air filtration on blood pressure in non-smokers. We also observed heterogeneity in study characteristics, including intervention duration, participant age and risk factors, composition and concentration of air pollution, proportion of time participants spent in the home, and indoor filtration method. Additionally, only one study (Morishita, 2018) quantified personal-level $PM_{2.5}$ exposure in addition to absolute indoor $PM_{2.5}$ concentrations, and many studies restricted participants' mobility outside the home. Both these factors limit our ability isolated the effect of air filtration interventions on actual exposure reduction in a "real-world" setting. However, sensitivity analysis on the aforementioned parameters demonstrated consistency of effect of indoor air filtration for reductions in SBP. Also, one large study (Chuang, 2017) was very influential in the analysis, but when excluding that study a significant reduction of SBP was still observed (p=0.04). Our analysis found no significant effect on DBP, and it is unclear if this lack of effect on DBP is due to limitations in power, study design or a true biological effect.

Furthermore, only a portion of included trials were designed with blood pressure as a primary outcome; and among these, most were powered to detect changes in SBP specifically (as opposed to DBP). It is probable that several studies were not adequately powered to detect significant reduction of SBP and especially DBP. We also recognize that variations in the method of blood pressure assessment may be confounding in this relationship; Supplementary Table S2 shows these parameters in further detail.

Finally, the majority of included studies assess only the immediate impact of short-term (≤2 weeks) air filtration interventions. It is unknown whether these effects are sustained following termination of the intervention. Finally, we can only speculate on the effects of longer-term interventions on blood pressure and reduction in cardiovascular risk.

PERSPECTIVES

Although improving outdoor air quality is the first priority against ambient air pollution health impacts, this meta-analysis found that in-home air filtration significantly reduced indoor exposures to $PM_{2.5}$ air pollution and SBP. PACs, a low-cost and generally accessible intervention, may represent an effective cardioprotective intervention for physicians to recommend to populations especially at risk. However, further investigation is needed to identify the optimal populations, durations and conditions for sustained use of indoor air filtration as a potential novel strategy to reduce cardiovascular risk.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Novelty and Significance

What is new?

- To our knowledge, this is the first meta-analysis to examine the effect of personal air cleaners on blood pressure.
- Personal air cleaner use is associated with a significant decrease in systolic blood pressure.
- No change in diastolic blood pressure associated with personal air cleaner use was observed.

What is relevant?

- Indoor exposure to fine particulate matter may be a modifiable risk factor for hypertension.

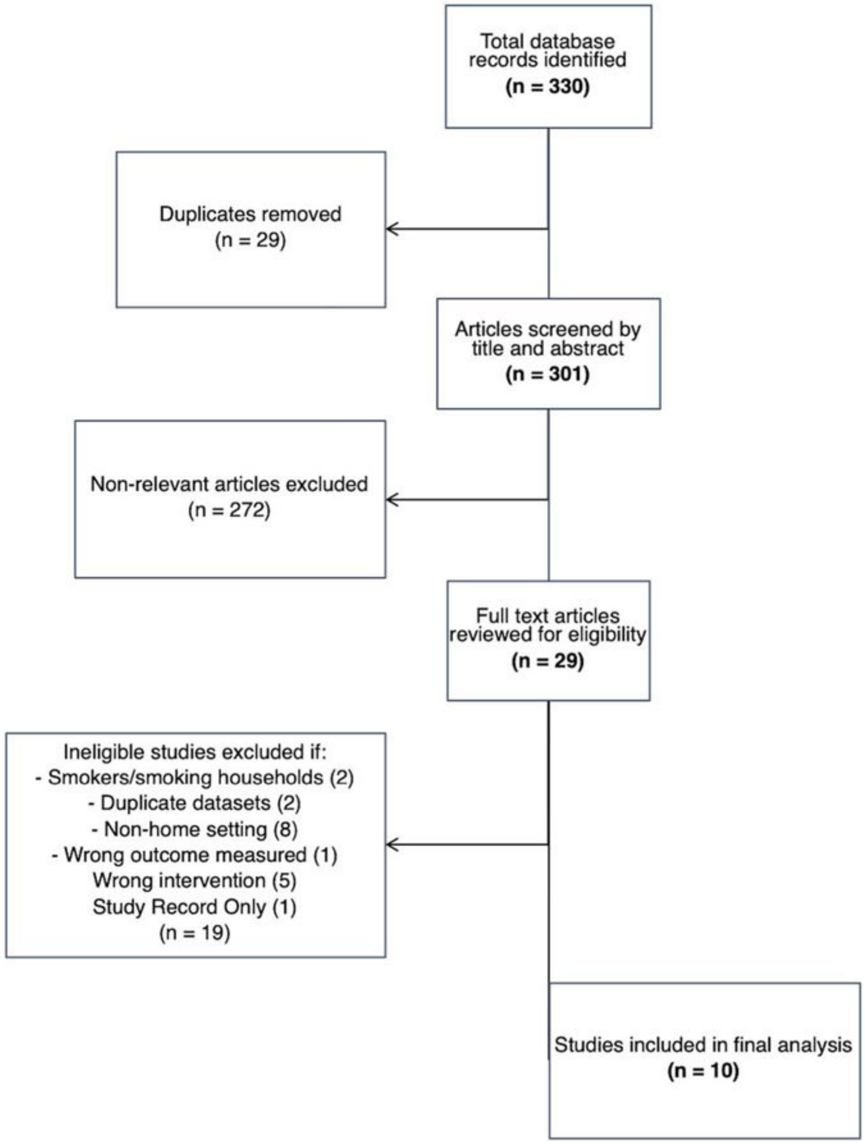

Figure 1.
Flow Diagram Illustrating the Stages of the Literature Search

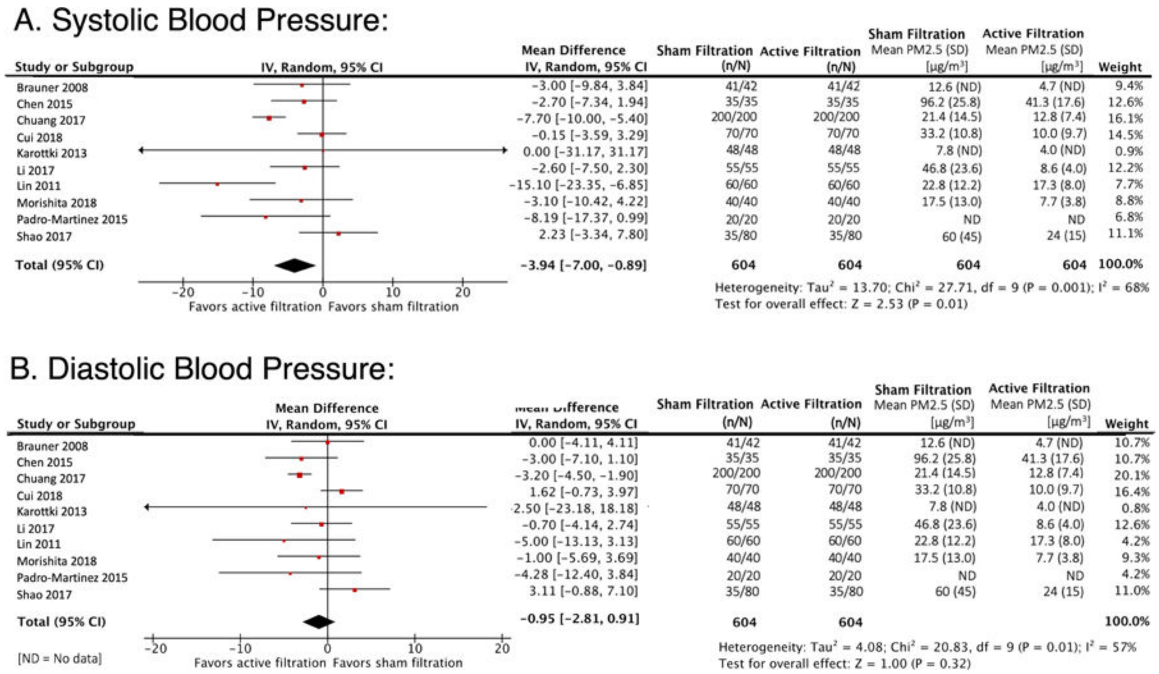

Figure 2.

Meta-Analysis of the Effects of Air Filtration on SBP and DBP

Meta-analysis of the effects of indoor air filtration on blood pressure. The mean difference estimates are shown for A) Systolic blood pressure (SBP) and B) Diastolic blood pressure (DBP).

ND = No Data.

Table 1:

Criteria for Categorizing Study Air Pollution Levels

$PM_{2.5}$ Exposure	$PM_{2.5}$ Range
Low	<10 μg/m^3
High	10–35 μg/m^3
Extreme	> 35 μg/m^3
Indeterminant	Not Reported

For each study, air pollution levels were categorized as “low”, “high”, “extreme,” or “indeterminate” based on participants’ baseline $PM_{2.5}$ exposure levels. The WHO air quality guidelines were used to define PM2.5 range levels for each category, as shown above. Studies that did not report $PM_{2.5}$ levels but instead reported other measures of air pollution such as particle number concentration (PNC) were classified as indeterminant.

Table 2:

Characteristics of Included Studies

Study ID	n	Population	Intervention		Outcomes	Baseline Air Pollution	Indoor Pollution Decrease (%)	
			Filter Type	Duration			PM2.5 µg/m^3	PNC #/cm^3
Brauner et al, 2008	41	Healthy elderly adults, 60–75 years Copenhagen, Denmark	HEPA Air purifier: Airshower; Airsonett AB, Ångelholm, Sweden	2 × 48h; no washout	- SBP, DBP - PM2.5 - PNC	Low	7.9 (63%)	6810 (61.7%)
Chen et al, 2015	35	Healthy college-aged (23±2 years) students Shanghai, China	Electret (model FAP04, 3M Filtrete, 3M Inc.)	2 × 48h; 14d washout	- SBP, DBP - PM2.5	Extreme	54.9 (57.1%)	ND
Chuang et al, 2017	200	Healthy homemakers (30–65 years, mean: 43.4 ± 7.6 years) Taipei, Taiwan	Electret (3M Filtrete, 3M Inc.)	2 × 12 months; no washout	- SBP, DBP - PM2.5	High	8.6µg (40%)	ND
Cui et al, 2018	70	Healthy young adults (22.0 ± 1.6 years) in dormitory housing, Shanghai, China	HEPA + activated carbon + polypropylene mesh Air purifier: Atmosphere®, Amway	2 × overnight; 14d washout	- SBP, DBP - PM2.5 - PNC	High	23.3 (72.4%)	3622 (59.2%)
Karottki et al, 2013	48	Adults (67 ± 6.5 years) living <350 meters from major roadways; 23% taking vasoactive drugs Copenhagen, Denmark	HEPA	2 × 14d; no washout	- SBP, DBP - PM2.5 - PNC	Low	3.8 (49%)	2317 (30.2%)
Li et al, 2017	55	Healthy college students (mean 20.2±1.3 years) in dormitory housing Shanghai, China	Electret (3M Filtrete, 3M Inc.)	2 × 9d; 12d washout	- SBP, DBP - PM2.5	Extreme	38.2 (81.6%) Personal exposure: 28.8 (54.2%)	ND
Lin et al, 2011	60	Healthy college students (median 25 ± 2.3 years) Taipei, Taiwan	Electret (3M Filtrete, 3M Inc,)	4 × 48h; 14d washout	- SBP, DBP - PM2.5	High	55.6 (23%)	ND
Morishita et al, 2018	40	Older residents of government-subsidized housing, most with chronic comorbidities (79% hypertensive, 25% diabetic) Detroit, USA	HEPA-type low efficiency filter (air purifier model HAPF30D-U2; Holmes) OR true HEPA (air purifier model HAPF300D-U2; Holmes)	3 × 3d; 7d washout	- SBP, DBP - PM2.5	High	9.8 (56%) Personal exposure: 6.4 (41%)	ND
Padro-Martinez et al, 2015	20	Middle-aged (≥40y; mean 53.9±9.2 years) publjc housing residents living <200m from an interstate highway. Abundant comorbidities (55% hypertensive). Somerville MA, USA	HEPA Air purifier: HEPAirX®, Air Innovations, Inc.	2 × 21d; no washout	- SBP, DBP - PNC		ND	4900 (47%)
Shao et al, 2017	35	Seniors with COPD (60%; mean 66.8±7.9 years) and non-COPD partners (40%; mean 65.9±6.9 years) Beijing, China	HEPA & activated carbon Air purifier: AC4374 and AC4016, Philips Lifestyle Ltd.	2 × 14d; no washout	- SBP, DBP - PM2.5	Extreme	36 (60%)	-

Characteristics of all included studies. Per the WHO air quality guidelines, “low” air pollution levels are here defined as $PM_{2.5}<10$ µm/m^3; “high” air pollution levels are defined as 10 µm/m^3 < $PM_{2.5}$ < 35 µm/m^3; and “extreme” air pollution levels are defined as $PM_{2.5}$ > 35 µm/m^3.

(Abbreviations: HEPA = High Efficiency Particulate Air; SBP = Systolic Blood Pressure; DBP = Diastolic Blood Pressure; PNC = Particle Number Concentration; ND = No Data)

* Outcomes recorded prior to and immediately after intervention