

# Effect of HEPA Filtration Air Purifiers on Blood Pressure



## A Pragmatic Randomized Crossover Trial

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### ABSTRACT

**BACKGROUND** Particulate matter (PM) pollution is a leading cause of cardiovascular risk and illness, including elevated blood pressure (BP).

**OBJECTIVES** The purpose of this study was to test the efficacy of in-home air purifiers to reduce BP for adults living adjacent to highways.

**METHODS** We conducted a pragmatic randomized crossover trial of the effect of high-efficiency particulate arrestance (HEPA) vs sham filtration on BP. Residences were randomized to start with 1 month of HEPA filtration or 1 month of sham filtration. A 1-month wash out period with no filtration was followed by 1 month of the alternate filtration. Participant questionnaire data and BP were collected 4 times, at the start and end of each filtration period. PM concentrations were measured in a subset of residences. Linear mixed models were used to compare the mean change in BP between the HEPA and sham filtration periods. Models were adjusted for time invariant and time-varying covariates.

**RESULTS** A total of 154 participants were analyzed. The mean age was 41.1 years, 59.7% were women, 68.2% were non-Hispanic White, and a majority were of higher socioeconomic status. The mean baseline brachial systolic blood pressure (SBP)/diastolic BP was 118.8/76.5 mm Hg. HEPA filtration significantly reduced PM in comparison to both indoor sham and outdoor levels. Participants' SBP at the start of the intervention period moderated the efficacy of the intervention ( $P = 0.03$ ). Participants who had elevated brachial SBP ( $\geq 120$  mm Hg) had a significant 2.8-mm Hg mean reduction in SBP after HEPA filtration ( $P = 0.03$ ) and a 0.2-mm Hg mean increase in SBP after sham filtration ( $P = 0.85$ ). The net result was a significant 3.0-mm Hg mean difference in favor of HEPA filtration ( $P = 0.04$ ). There was no significant benefit on diastolic BP or for participants with normal SBP ( $< 120$  mm Hg).

**CONCLUSIONS** The use of in-home HEPA air purifiers resulted in clinically important reductions in SBP for people with elevated SBP in environments with relatively low PM<sub>2.5</sub> concentrations. (JACC. 2025;86:577-589)  
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The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors' institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the [Author Center](#).

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**ABBREVIATIONS  
AND ACRONYMS**

- BP** = blood pressure
- DBP** = diastolic blood pressure
- HEPA** = high-efficiency particulate arrestance
- PM** = particulate matter
- PM<sub>2.5</sub>** = particulate matter <2.5 μm in diameter
- PNC** = particle number count, a measure of ultrafine particles
- PSS** = perceived stress scale
- SBP** = systolic blood pressure
- UFP** = ultrafine particles

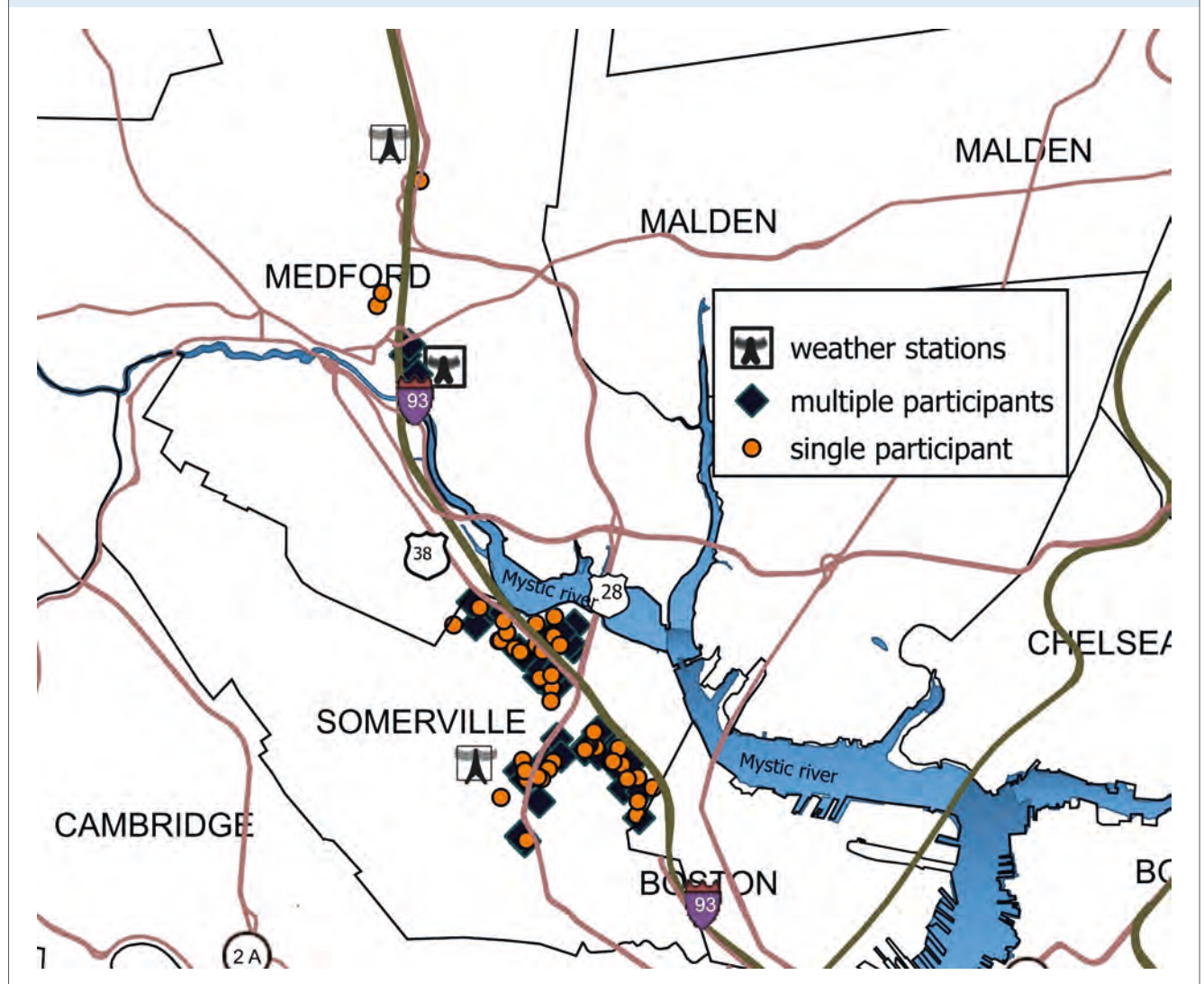
People living in housing adjacent (<200 m) to highways with large traffic volumes (>100,000 vehicle trips per day) are exposed to locally elevated particulate matter (PM) emanating from tailpipes, as well as tire and brake wear.<sup>1-5</sup> PM<sub>2.5</sub> (particulate matter with aerodynamic diameter <2.5 μm) and ultrafine particles (UFP) (<0.1 μm) readily permeate homes that do not have a tight building envelope or mechanical ventilation equipped with high efficiency filtration and recirculation.<sup>6,7</sup> Growing evidence shows associations of exposure to PM with indicators of cardiovascular health risk.<sup>8-10</sup>

Elevated blood pressure (BP) and hypertension have been shown to be associated with both exposure to traffic-related PM and cardiovascular diseases.<sup>11-13</sup>

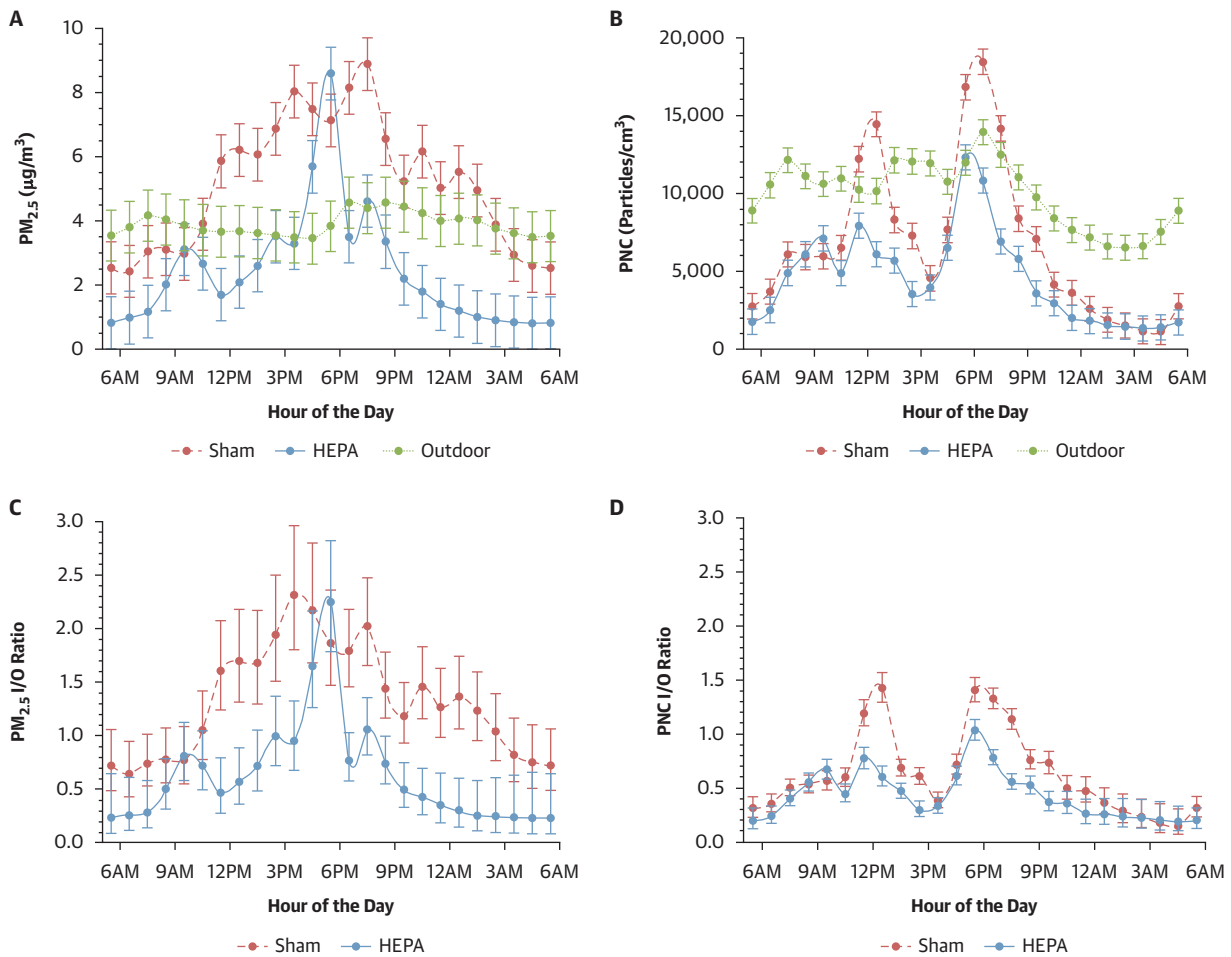
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Epidemiologic evidence has shown an increasing risk of stroke, heart attack, and death with increasing BP.<sup>14</sup> Even in middle-aged and older individuals with normal BP, increases of a few mm Hg in systolic blood pressure (SBP) and diastolic blood pressure (DBP) are strongly related to a higher risk of vascular and overall mortality. This relationship remains consistent without evidence of a threshold, continuing down to at least 115/75 mm Hg. An increase of 2 mm Hg in SBP translates into a 7%

**FIGURE 1** Map Showing Location of Participants' Homes, Relative to Highways, and Weather Underground Outdoor Weather Stations in the Randomized Crossover Trial



**FIGURE 2** Pattern of Indoor (Sham vs HEPA) and Outdoor PM<sub>2.5</sub> and PNC Concentrations Over a 24-Hour Period



(A) Particulate matter <2.5 µm in diameter (PM<sub>2.5</sub>) concentrations; (B) particle number count (PNC) concentrations; (C) indoor/outdoor (I/O) PM<sub>2.5</sub> concentration ratios; (D) indoor/outdoor PNC concentration ratios. Hourly arithmetic means with 95% CIs, where each hour represents the mean of all recorded measurements within that period of time. HEPA = high-efficiency particulate arrestance.

increased risk of death from ischemic heart disease and a 10% increased risk of death from stroke.<sup>14</sup>

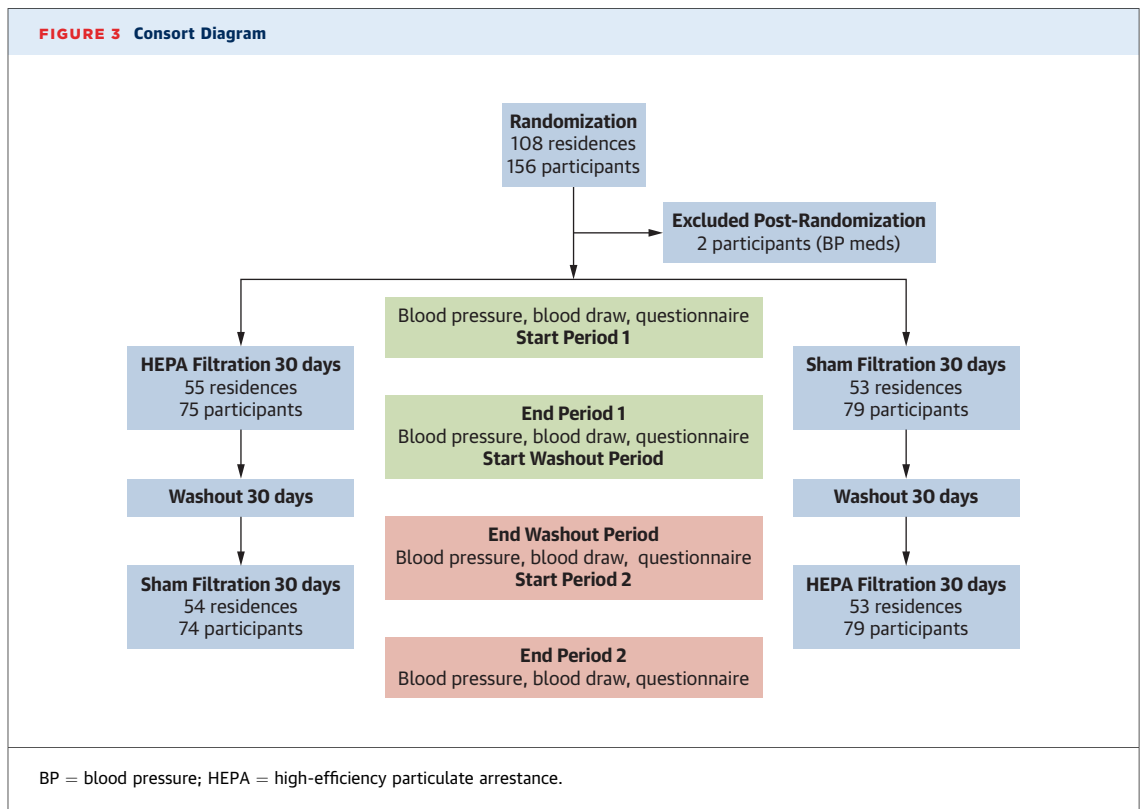
Results from controlled trials of antihypertensive drugs show that decreases in BP lead to decreased rates of cardiovascular deaths and stroke in populations with all levels of risk from other factors, such as elevated low-density lipoprotein cholesterol and smoking.<sup>15,16</sup> In contrast, evidence is much more limited for the benefits on BP by reducing exposure to PM. In a controlled exposure randomized crossover trial that directly supports the research we report here, we showed a dose-response relationship between near highway PM and SBP. Further, the relationship was stronger among participants whose baseline SBP was ≥120 mm Hg.<sup>17</sup>

Here we report the efficacy results from an in-home pragmatic randomized crossover trial of air purifiers in residences close to major highways. This research is a continuation of more than 15 years of research and community engagement about traffic-related pollution. Our study was responsive to near highway community requests to test protective measures.<sup>18</sup> Given that 24% of the U.S. population lives near high-volume roadways, the need to find protective measures extends far beyond our study areas.<sup>1</sup>

## METHODS

### STUDY DESIGN, RECRUITMENT, AND RANDOMIZATION.

The study methods have been previously published<sup>19</sup>



and registered on ClinicalTrials.gov ([NCT04279249](https://clinicaltrials.gov/ct2/show/study/NCT04279249)). In brief, recruitment was conducted door-to-door, as well as by word-of-mouth outreach over 4 years (2020-2024). Participants were enrolled during the cooler months (September through April) when the levels of traffic-generated PM tend to be higher. Participant inclusion criteria were as follows: 30 years of age or older, living full time at the residence, cognitive capacity to respond to questionnaires, and speaking English or Spanish. Exclusion criteria were as follows: smoking, using vapes or allowing smoking/vaping in the home, history of heart attack/stroke/major cardiovascular outcome, recent cancer requiring surgery and/or chemo/radiation treatment, active COVID infection, not receiving the COVID vaccine, taking antihypertensive or anti-inflammatory medications, occupational exposure to traffic pollution, or presence of significant combustion sources other than cooking inside the home (eg, regular burning of incense). Because no restrictions were imposed on participants' daily activities, they lived their usual lives throughout the trial's duration.

All participant residences were within 200 m of at least 1 high-traffic volume highway (I-93 and Rt-38) in eastern Massachusetts, USA ([Figure 1](#)). Residences were randomized to start with 1 month

of high-efficiency particulate arrestance (HEPA) filtration or 1 month of sham filtration. There was a 1-month wash out period with no filtration followed by 1 month of the alternate filtration. Participant questionnaire data and BP were collected 4 times, at the start and end of each filtration period. The trial received approval from the UConn Health Institutional Review Board Human Subjects Protection Program, and all participants provided written informed consent.

**AIR PURIFIERS AND PARTICIPANT BLINDING.** We used freestanding, custom made HealthMate air purifiers manufactured by Austin Air. The units had only HEPA filters without a carbon or zeolite coating layer because we sought to filter out only PM, for which evidence of cardiovascular effects is strong, and not gases, for which such evidence is weak. The filter was made of 5.5 m<sup>2</sup> of medical-grade material. The manufacturer states the filter's removal efficiency for particles <0.3 and <0.1 μm to be >99% and 95%, respectively and that they are rated for use in spaces up to ~140 m<sup>2</sup>. We installed air purifiers with clean filters in the bedroom and living room (or both bedrooms for homes with 2 participants using separate bedrooms). We encouraged, but did not require, participants to keep doors and windows shut as much as possible.

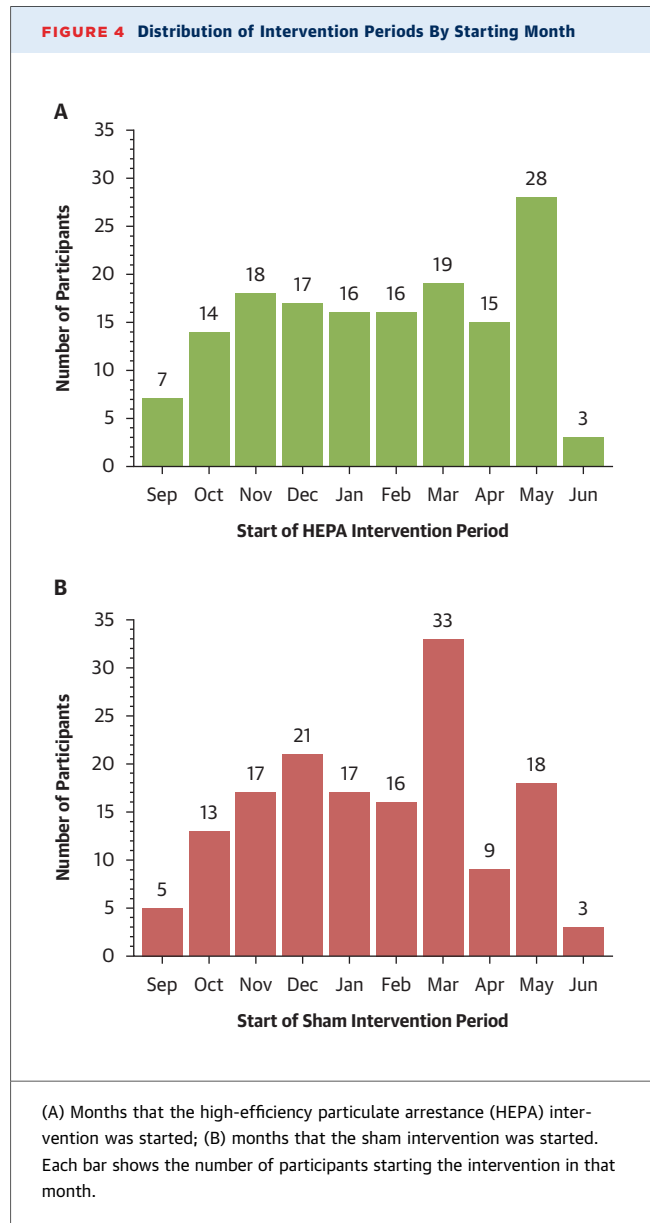
The sham filtration consisted of the same units with the filter removed, and therefore, the outward appearance of the unit did not differ between HEPA and sham filtration. The HealthMate units operated at ~60 dB with HEPA filters, about the same noise level as window-mounted air conditioners. The sham units operated at ~58 dB. There was no appreciable difference in the draft or airflow rate (air velocity at the vent was ~11 ft/s). Success of blinding was assessed by asking the participant at the end of each intervention period, “During the last month, which kind of filter do you think you had? (Actual HEPA, No filter, Don’t Know).” The James’ Blinding Index was used to quantify the level of blinding, ranging from 0 (complete unblinding) to 1 (complete blinding).<sup>20,21</sup> A trial is considered to be well-blinded if the lower limit of the 2-sided CI is >0.5.

For 45 participants, we installed HOBO Plug Load Data Loggers (UX120-018, Onset Corp) between the electrical outlet and the filter power cord to continuously record electricity use. We previously reported that air purifiers were running ~99% of the time during the preceding 30 days.<sup>22</sup>

**QUESTIONNAIRES.** Questionnaires were administered at entry into the trial and at each of the 3 subsequent home visits. Participants were asked about exposure to secondhand smoke, exposure to combustion sources, recent life events, social stress, health status, time-activity for recent workdays and weekends (see [Supplemental Material](#) for details), opening of windows, noise exposure, and use of the air purifiers.

**BP MEASUREMENTS.** Home visits occurred in the morning on weekdays. At each visit, the participant’s BP was measured using a portable SphygmoCorXCEL instrument made by ATCOR with cuffs scaled to arm size.<sup>23</sup> The cuff was placed on the left arm 2 to 3 inches above the elbow. During the BP measurement, the participant was seated for 5 minutes then put their arm on a flat surface at heart level, was instructed to not talk, to keep their feet flat on the ground, and remain still. Three consecutive readings were taken with an interval of 1 minute. We excluded the first of the 3 and averaged the second and third measurements for analyses. The instrument was calibrated twice by the manufacturer during the trial period. Blood draws were taken after BP measurements to avoid inducing stress.

**ENVIRONMENTAL MONITORING.** Air purifiers are well established to reduce PM in homes,<sup>24</sup> and therefore we conducted air monitoring in a subset of homes to assess the fidelity of the filtration units. Monitoring in each home was for approximately



1 week during HEPA and 1 week during sham filtration. Simultaneous indoor and outdoor measurements of PM<sub>2.5</sub> were recorded in 19 homes and UFPs (measured as particle number count [PNC]) were recorded in 8 homes. The PM<sub>2.5</sub> level was recorded every minute with Modulair-PM or Modulair sensors. The PNC was recorded every second using condensation particle counters (either Model 3783, TSI; 7-3,000 nm or Model 9403 Advanced Mixing Condensation Particle Counter, Brechtel Mfg, Inc; 6-1,000 nm). Outdoor temperature was obtained from the closest Weather Underground stations (Figure 1) for the date and time of each BP measurement.

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**TABLE 1** Characteristics of Participants at the Start of the Intervention Period

	HEPA (n = 153)	Sham (n = 152)
Randomized to sequence		
HEPA then sham filtration	74 (48.4)	73 (48.0)
Sham then HEPA filtration	79 (51.6)	79 (52.0)
Age, y	41.1 ± 9.9	41.0 ± 9.8
Age category		
<40 y	84 (54.9)	85 (55.9)
≥40 y	69 (45.1)	67 (44.1)
Sex		
Male	62 (40.5)	61 (40.1)
Female	91 (59.5)	91 (59.9)
Ethnicity and race		
Hispanic	29 (19.0)	28 (18.4)
White, non-Hispanic	104 (68.0)	104 (68.4)
Black, non-Hispanic	8 (5.2)	8 (5.3)
Asian, non-Hispanic	12 (7.8)	12 (7.9)
Highest level of education		
Grade or high school	17 (11.1)	16 (10.5)
Some college	17 (11.1)	17 (11.2)
College or university degree	43 (28.1)	43 (28.3)
Graduate degree	76 (49.7)	76 (50.0)
Work status		
Unemployed	26 (17.0)	26 (17.1)
Part time	19 (12.4)	18 (11.8)
Full time	108 (70.6)	108 (71.1)
Total annual household income		
<\$48,000	11 (7.2)	11 (7.2)
\$48,000-\$84,999	19 (12.4)	18 (11.8)
≥\$85,000	95 (62.1)	96 (63.2)
Declined to answer	28 (18.3)	27 (17.8)
Weight status		
Healthy	66 (43.1)	66 (43.4)
Overweight	45 (29.4)	45 (29.6)
Obesity	42 (27.5)	41 (27.0)
Time spent inside home, h/d	18.7 ± 3.6	18.6 ± 3.6
Perceived Stress Scale (PSS-4)	3.4 ± 3.0	3.3 ± 3.0
Brachial SBP, mm Hg	119.1 ± 13.1	118.6 ± 11.9
Brachial DBP, mm Hg	76.8 ± 9.4	76.3 ± 8.6
Start of intervention period		
March 15 through June 8 and September 8 through October 20 (warmer)	66 (43.1)	53 (34.9)
October 21 through March 14 (cooler)	87 (56.9)	99 (65.1)
Outdoor temperature, °F	44.3 ± 11.8	40.9 ± 12.1

Values are n (%) or mean ± SD.  
DBP = diastolic blood pressure; HEPA = high-efficiency particulate arrestance; SBP = systolic blood pressure.

**STATISTICAL ANALYSIS.** The trial planned to enroll 207 participants from 172 residences to detect a 2.5-mm Hg SBP mean difference between the HEPA and sham filtration periods with 80% power at a 2-sided 5% significance level (paired Student's *t*-test with a paired-change SD of 11 mm Hg and 20% of residences with 2 participants), which included 10%

loss of data caused by participant dropouts or missing paired SBP measurements.<sup>19</sup>

Linear mixed models were used to compare the mean change in BPs between the HEPA and sham filtration periods. For each participant, change in BP was calculated as the difference between the start and end of each intervention period measurements. The models included a random intercept to account for the within-participant correlation of repeated BP measurements, and sequence and period effects. The participant's age, sex, and corresponding BP measurement at the start of each intervention period were included as covariates in the model. We also included the number of hours per day spent indoors at home a week before the BP measurement, outdoor temperature and Perceived Stress Scale (PSS-4) score at the time of the BP measurement. Because it was previously observed that participants' SBP at trial entry (<120 mm Hg vs ≥120 mm Hg) moderated SBP outcome,<sup>17</sup> a cross-product term was included in the model to assess its significance. The cross-product term consisted of the intervention (HEPA vs sham) and the dichotomized SBP at the start of the intervention period (<120 mm Hg vs ≥120 mm Hg). Aside from its use in our previous trial,<sup>17</sup> the American College of Cardiology and the American Heart Association consider an SBP <120 mm Hg as being normal/nonelevated whereas an SBP ≥120 mm Hg is considered to be elevated.<sup>25</sup> Moreover, the cut point of 120 mm Hg is clinically important as there is growing evidence in the literature that SBPs above this level increase the risk of cardiovascular disease outcomes.<sup>26</sup> Finally, a sensitivity analysis using 5 SBP cut points below 120 mm Hg and 5 SBP cut points above 120 mm Hg was conducted to assess the relationship between the choice of cut point and the effectiveness of the HEPA intervention.

Linear mixed models were also used to analyze the monitoring data. As both PM<sub>2.5</sub> and PNC levels were recorded multiple times per day over an entire week in the homes, the models included 2 random intercepts to account for the nesting of measurements. The models included outdoor daily temperature as a covariate and a cross-product term to compare the difference in levels between HEPA and sham filtration at each hour of the day. The monitoring results are summarized in terms of arithmetic means with 95% CIs. An exploratory analysis was conducted to assess the moderating effects of spending time indoors at home on BP outcome from the time activity questionnaire. All statistical analyses were carried out using SAS 9.4 (SAS Institute Inc), and results with *P* values <0.05 were deemed statistically significant.

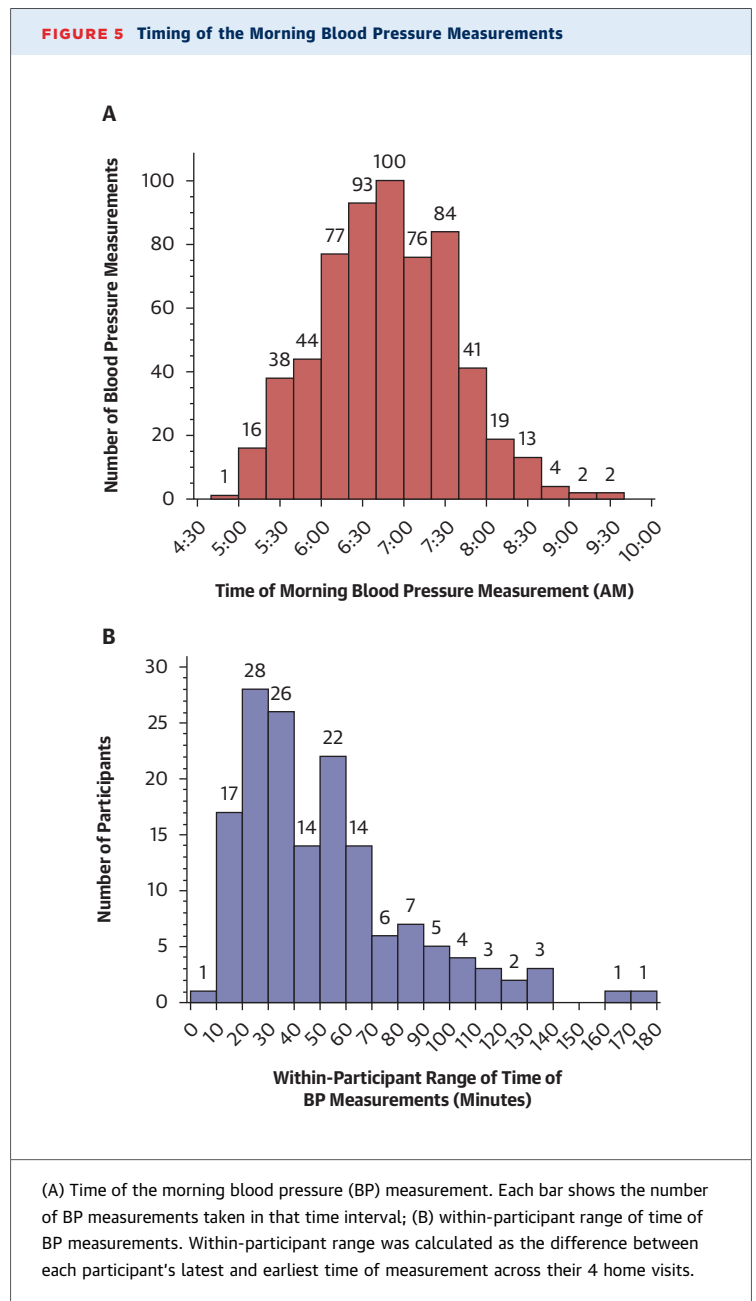
**RESULTS**

**OUTDOOR AND INDOOR PM DURING HEPA AND SHAM FILTRATION PERIODS.** Figure 2 summarizes the pattern of PM<sub>2.5</sub> and PNC concentrations over a 24-hour period. In comparison to outdoor and indoor sham filtration, mean PM<sub>2.5</sub> concentration was significantly reduced by HEPA filtration ( $P < 0.001$ ) (Figures 2A and 2C); the arithmetic mean PM<sub>2.5</sub> concentrations over a 24-hour period were 3.9, 5.2, and 2.5 μg/m<sup>3</sup> for outdoor, indoor sham, and HEPA filtration, respectively. Mean indoor PNC concentrations were also significantly reduced by HEPA filtration ( $P < 0.001$ ), with greater reductions with HEPA filtration during noontime and evening cooking hours (Figures 2B and 2D); the arithmetic mean PNC concentrations over a 24-hour period were 10,052, 6,925, and 4,706 particles/cm<sup>3</sup> for outdoor, indoor sham, and HEPA filtration, respectively. As both PM<sub>2.5</sub> and PNC concentrations decreased overnight, this suggests that indoor pollutant levels were at lower concentrations at the time of the participants' BP measurements.

**BP OUTCOMES.** Of the 201 individuals screened, 156 (77.6%) were enrolled into the trial. Upon a post-randomization review of participants' medical history, 2 participants were identified to have been on antihypertensive medications and were excluded. Therefore, the final sample size for the analyses consisted of 154 participants from 108 residences (Figure 3). Despite enrolling fewer participants than originally planned, the analysis sample size of 154 participants had 77% power to detect a 2.5-mm Hg SBP mean difference, using the trial-based paired-change SD of 11.4 mm Hg.

Of the 154 participants in the analysis, 3 (1.9%) did not have all 4 BP measurements: 1 participant moved out of state and did not have the third and fourth BP measurements; 1 participant had a missing second BP measurement because of instrument malfunction; and 1 participant did not have the fourth BP measurement because they moved. Therefore, of the 308 possible pairs of measurements (ie, pair = start and end of each intervention period), 3 pairs were excluded because of missing data. As a result, 153 participants received 30 days of HEPA filtration and 152 received 30 days of sham filtration. The James' Blinding Index equaled 0.87 (95% CI: 0.83-0.90) after the first intervention period and equaled 0.83 (95% CI: 0.78-0.89) after the second intervention period. Because both CIs do not include 0.5, the trial was well-blinded.

**FIGURE 5** Timing of the Morning Blood Pressure Measurements



The months in which participants started their intervention period were similar between HEPA and sham filtration (Figure 4), thus minimizing the effects of seasonal variability of PM, despite more participants starting with HEPA filtration in the warmer month of May and more participants starting with sham filtration in the cooler month of March. This imbalance may partially explain the significant difference in outdoor temperatures between the HEPA and sham groups at the start of the intervention period (44.3 °F vs 40.9 °F;  $P = 0.01$ ) (Table 1).

**TABLE 2 Changes in Blood Pressures From the Start of the Intervention Period**

	n <sub>HEPA</sub> , n <sub>Sham</sub>	HEPA	Sham	Difference	95% CI	P Value
<b>Brachial SBP</b>						
Overall	153, 152	-1.1 ± 0.7	-0.6 ± 0.7	-0.5 ± 0.9	-2.4 to 1.3	0.56
<120 mm Hg	88, 91	0.1 ± 1.1	-1.1 ± 1.0	1.2 ± 1.2	-1.2 to 3.6	0.33
≥120 mm Hg	65, 61	-2.8 ± 1.3	0.2 ± 1.3	-3.0 ± 1.5	-6.0 to -0.1	0.04
<b>Brachial DBP</b>						
Overall	153, 152	-0.4 ± 0.5	-0.5 ± 0.5	0.1 ± 0.6	-1.1 to 1.4	0.81
<80 mm Hg	100, 109	-0.5 ± 0.7	-0.8 ± 0.6	0.3 ± 0.8	-1.2 to 1.8	0.66
≥80 mm Hg	53, 43	-0.3 ± 1.0	0.1 ± 1.1	-0.4 ± 1.2	-2.7 to 2.0	0.76

Values are mean ± SE, unless otherwise indicated. Results were adjusted for participant's age, sex, and corresponding blood pressure measurement at the start of each intervention period. Results were also adjusted for number of h/d spent indoors at home 1 wk before the blood pressure measurement, and outdoor temperature and Perceived Stress Scale (PSS-4) score at the time of the blood pressure measurement.  
Abbreviations as in Table 1.

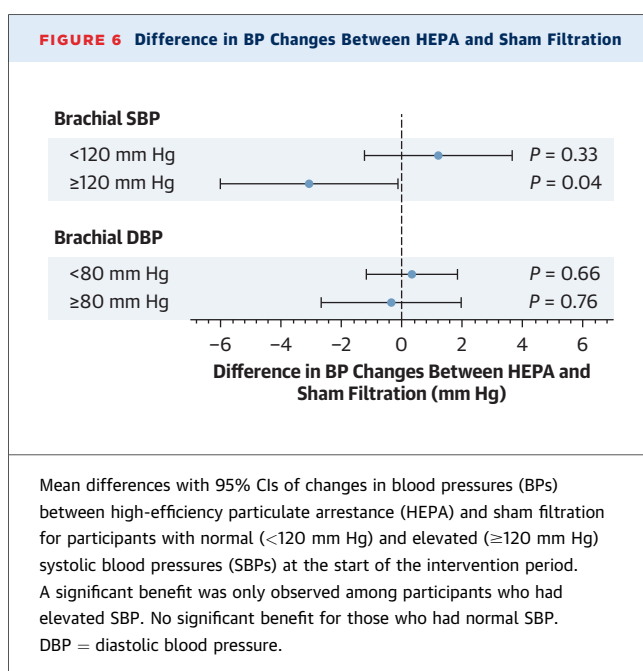
As so few participants had missing BP data, the comparison groups were balanced, including the sequence of intervention (Table 1). The mean age of the participants was 41.1 years (range 30 to 75 years), 59.7% were women, 68.2% were non-Hispanic White, 18.7% were Hispanic, 82.9% were working either part-time or full-time, and a majority were college educated and had household incomes >\$85,000 per year. The mean baseline brachial SBP/DBP was 118.8/76.5 mm Hg. The average outdoor temperature of 42.6 °F was consistent with enrolling participants during the colder months of the year.

Weekday morning BP measurements were taken between 4:47 AM and 9:35 AM, with a large majority (77.5%) of measurements taken between 6:00 AM and

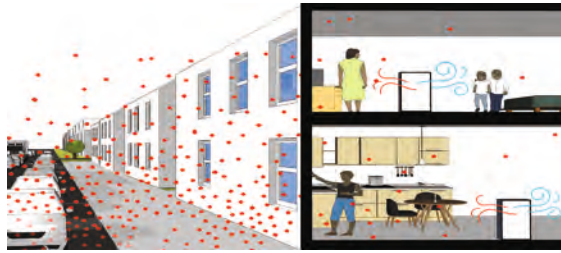
8:00 AM (Figure 5A). Consistency in the timing of the home visits minimized the variability of the measurement times (Figure 5B); 70.8% of participants had all their BP measurements within 1 hour of each other, 24.7% between 1 and 2 hours, and 4.5% between 2 and 3 hours.

The nonsignificant overall mean difference of 0.5 mm Hg between HEPA and sham filtration in reducing SBP is explained by the significant moderating effect of the participants' SBP at the start of the intervention period ( $P = 0.03$ ) (Table 2, Figure 6). Participants who had an elevated brachial SBP (ie, ≥120 mm Hg) at the start of the intervention period had a significant 2.8 mm Hg mean reduction in SBP ( $P = 0.03$ ) when they had HEPA filtration and a 0.2-mm Hg mean increase in SBP ( $P = 0.85$ ) when they had sham filtration. The net result was a significant 3.0 mm Hg mean difference in favor of HEPA filtration ( $P = 0.04$ ) (Central Illustration). In contrast, only small clinically unimportant reductions in DBP were observed and none reached statistical significance. Corresponding mean SBPs and DBPs are shown in Table 3 and Figure 7. The sensitivity analysis showed a relationship between SBP cut point and the effectiveness of the HEPA intervention (Figure 8). The benefit of HEPA filtration increased with higher starting SBP cut points and plateaued at 120 mm Hg. Individual changes in SBP during the HEPA and sham periods are displayed in Figure 9, stratified by SBP at the start of the intervention period baseline (SBP <120 mm Hg vs ≥120 mm Hg). A greater percentage of reductions in SBP was observed among participants who had elevated SBP at the start of the intervention period and had HEPA filtration (Figure 9C).

Results from the exploratory analysis are reported in the Supplemental Material. Although not statistically significant, the results suggest that participants who spent more time inside their home received



**CENTRAL ILLUSTRATION** Effect of High-Efficiency Particulate Arrestance Filtration Air Purifiers on Blood Pressure in Environments With Lower Levels of Particulate Matter



A Pragmatic Randomized Crossover Trial



Among participants with brachial systolic blood pressure  $\geq 120$  mm Hg



HEPA filtration reduced mean systolic blood pressure by 3 mm Hg in comparison to Sham Filtration

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HEPA = high-efficiency particulate arrestance.

greater benefit from HEPA filtration (Supplemental Table 1).

**DISCUSSION**

In this pragmatic randomized crossover trial of 154 participants, who had no restrictions on their daily activities, we observed a statistically significant and clinically important benefit of in-home HEPA air

filtration among those living near highways who had elevated SBP, but not for those who had normal SBP. Our trial suggests that benefits of air purifiers are possible even when  $PM_{2.5}$  concentrations are below regulatory limits.

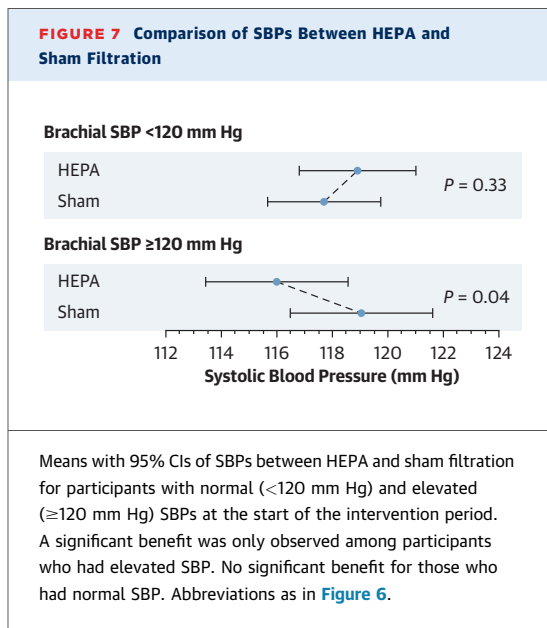
Putting our trial into perspective, Faridi et al<sup>27</sup> reviewed 17 air purifier trials with BP outcomes in 2023. All trials ranged in size from 20 to 70 participants, except 1 that had 200, representing the small

**TABLE 3** Blood Pressures at End of Intervention Period

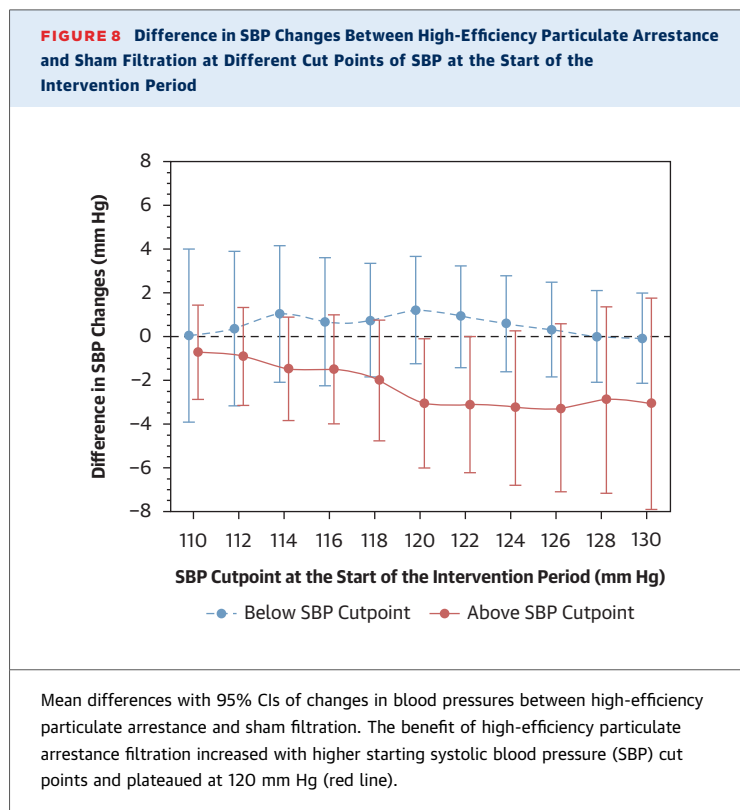
	$n_{HEPA}$ / $n_{Sham}$	HEPA	Sham	Difference	95% CI	P Value
<b>Brachial SBP</b>						
Overall	153 , 152	117.7 $\pm$ 0.7	118.2 $\pm$ 0.7	-0.5 $\pm$ 0.9	-2.4 to 1.3	0.56
<120 mm Hg	88 , 91	118.9 $\pm$ 1.1	117.7 $\pm$ 1.0	1.2 $\pm$ 1.2	-1.2 to 3.6	0.33
$\geq 120$ mm Hg	65 , 61	116.0 $\pm$ 1.3	119.0 $\pm$ 1.3	-3.0 $\pm$ 1.5	-6.0 to -0.1	0.04
<b>Brachial DBP</b>						
Overall	153 , 152	76.1 $\pm$ 0.5	76.0 $\pm$ 0.5	0.1 $\pm$ 0.6	-1.1 to 1.4	0.81
<80 mm Hg	100 , 109	76.1 $\pm$ 0.7	75.8 $\pm$ 0.6	0.3 $\pm$ 0.8	-1.2 to 1.8	0.66
$\geq 80$ mm Hg	53 , 43	76.2 $\pm$ 1.0	76.6 $\pm$ 1.1	-0.4 $\pm$ 1.2	-2.7 to 2.0	0.76

Values are mean  $\pm$  SE, unless otherwise indicated. Results were adjusted for participant's age, sex, and corresponding blood pressure measurement at the start of each intervention period. Results were also adjusted for number of h/d spent indoors at home 1 week before the blood pressure measurement, and outdoor temperature and Perceived Stress Scale (PSS-4) score at the time of the blood pressure measurement.

Abbreviations as in Table 1.



size of trials to date. Some of these trials also restricted participants' daily activities in unrealistic ways, such as limiting the number of hours outside of their residence and prohibiting indoor cooking. In a



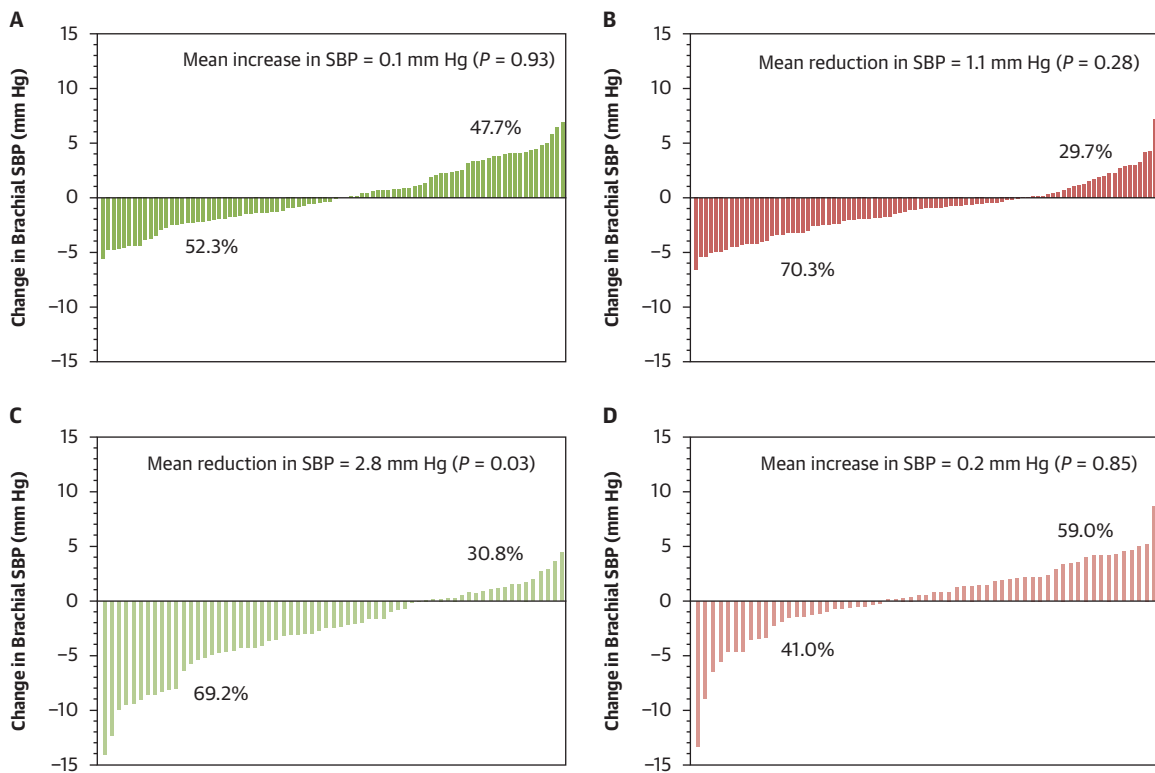
pooled analysis, Faridi et al<sup>27</sup> reported a reduction of just under 2.35 mm Hg in brachial SBP, similar to the reduction we report here for participants with elevated SBP. They found a much smaller reduction in DBP, <1 mm Hg, roughly consistent with our findings as well. In our previous controlled exposure randomized crossover trial, 77 participants were exposed to low, medium, and high traffic pollution for 2 hours on 3 consecutive Mondays. A 2.8-mm Hg mean increase in SBP was observed in the high exposure scenario.<sup>17</sup>

There have been a few clinical trials published since the systematic review. One, in Xi'an, China, was a randomized crossover trial of 38 healthy young adults.<sup>28</sup> They reported a reduction in SBP of about 3 mm Hg that was statistically significant. In another small sample of individuals with hypertension living in public housing in New York City, who were randomized between HEPA and sham, a nonsignificant reduction of about 3 mm Hg was reported.<sup>29</sup> A 1-year, randomized controlled, double-blind, parallel-group trial of air purifiers with 47 elderly residents living in Hong Kong found a statistically significant reduction in DBP of over 4 mm Hg. This trial also found a nonsignificant reduction in SBP of 2.49 mm Hg.<sup>30</sup>

The reduction in SBP that we report from the use of air purifiers has clinical importance and is likely caused by effects on the autonomic nervous system.<sup>31</sup> A meta-analysis of 61 prospective observational studies of adults with no previous vascular disease and usual BP estimated a 6% to 9% relative reduction in the risk of ischemic heart disease mortality for a 2- to 3-mm Hg reduction in SBP.<sup>14</sup> A second meta-analysis of 48 randomized clinical trials estimated a 4% to 6% relative reduction in the risk of developing major cardiovascular events (stroke, myocardial infarction, ischemic heart disease, or heart failure causing death or requiring hospitalization) among participants without previous cardiovascular disease for a 2- to 3-mm Hg reduction in SBP.<sup>32</sup> Another meta-analysis of 123 randomized clinical trials of BP-lowering treatment estimated a 5% to 7% relative reduction in the risk of developing major cardiovascular disease events for a 2- to 3-mm Hg reduction in SBP.<sup>33</sup>

**STUDY LIMITATIONS.** Despite the overall strength of our trial design and execution, there are some nuances and caveats that point to a need for further research. First, it is not clear to us why we saw a much more effective reduction for PM<sub>2.5</sub> than for PNC. One possibility, that we could not test while maintaining blinding, is that sham filtration reduced PNC concentrations more substantially than we had

**FIGURE 9** Individual Changes in SBP During the High-Efficiency Particulate Arrestance and Sham Filtration Periods



The results are stratified by normal systolic blood pressure (SBP) (<120 mm Hg) and elevated SBP ( $\geq$ 120 mm Hg) at the start of the intervention period: (A) normal SBP and high-efficiency particulate arrestance filtration; (B) normal SBP and sham filtration; (C) elevated SBP and high-efficiency particulate arrestance filtration; (D) elevated SBP and sham filtration. Bars below zero indicate a reduction in blood pressure and bars above zero indicate an increase in blood pressure. Percentages below zero are the proportion of participants who had a reduction in blood pressure and percentages above zero are the proportion of participants who had an increase in blood pressure. A greater percentage of larger reductions in brachial systolic blood pressure was observed among participants who had elevated SBP at the start of the intervention period and had high-efficiency particulate arrestance filtration (C).

expected. It is established that air movement leads to deposition of UFP on surfaces.<sup>34</sup> However, we saw little evidence of a reduction of BP over the sham periods.

Second, we were not able to assess the timeframe of air purifier effect on SBP. As BP was measured in the early morning, pollutant levels were at lower levels than midday and evening hours. This likely reduced the influence of indoor sources of pollutants, such as cooking, which was apparent in air monitoring data, usually in the evening. Assessing the benefits of air purifiers on BP across 24 hours would likely require either ambulatory or self-reported measurements which have not, to our knowledge, been included in any clinical trial of air purifiers published to date.

Third, although we controlled for outdoor temperature as a time varying confounder in the analyses, we did not control for indoor temperature because this was only available for a subset of residences. However, we have previously observed that indoor temperature varied far less than outdoor temperature and was not associated with meaningful changes in BP.<sup>35</sup>

Fourth, for our findings to translate from research to practical use, individuals would need to find the use of air filtration units desirable. We previously reported the reaction of participants in this trial having air purifiers in their homes.<sup>22</sup> Most participants set their air purifier to the medium, rather than high setting, to reduce its sound. The unit's size, airflow it generated, and energy consumption were also concerns for some participants.

Finally, our findings are limited in terms of generalizability. Besides the benefit being limited to people with SBP  $\geq 120$  mm Hg, our sample of participants were generally of higher socioeconomic status and predominantly of White race, despite extensive efforts to recruit more diverse participants. We found that individuals from lower socioeconomic status and racial/ethnic minority groups were much more likely to be taking antihypertensive medications, which was an exclusion criterion. As participation in the trial occurred during the cooler/warmer months of the year (September through June), the effectiveness of HEPA air filtration during the hot summer months (July and August) is unknown. Another trial, such as ours, is warranted to assess the benefits of air purifiers among individuals who are on antihypertensive medications, as well as an assessment in hotter climates.

## CONCLUSIONS

Our findings add to the growing literature that indicates that air purifiers have a clinically important beneficial effect on BP in near highway environments in a country with low PM<sub>2.5</sub> concentrations relative to many places globally. Our trial builds on prior research. First, it was substantially larger than most prior trials. Second, we controlled for 2 time-varying factors that we have not seen previously addressed.

Finally, unlike many prior studies, we did not restrict participants' daily activities.

Of particular interest, based on our results, there is a need to more carefully identify which subgroups of individuals benefit from the use of air purifiers. We believe it is a reasonable conclusion, given the lack of adverse effects, to recommend air purifier use for vulnerable populations, those with preexisting risk of cardiovascular disease such as elevated BP, and those who live within 200 m of high traffic highways or 100 m of high-traffic roads.

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**KEY WORDS** air purifiers, blood pressure, HEPA air filtration, highway traffic, particulate matter pollution, randomized crossover trial

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**APPENDIX** For supplemental material and a table, please see the online version of this paper.