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# The Effect of Particulate Matter Reduction by Indoor Air Filter Use on Respiratory Symptoms and Lung Function: A Systematic Review and Meta-analysis

**Hyung Jun Park**,[1] **Ho Young Lee**,[2] **Chong Hyun Suh**,[3] **Ho Cheol Kim**,[1] **Hwan Cheol Kim**,[4] **Young-Jun Park**,[5] **Sei Won Lee**[1*]

[1]Department of Pulmonary and Critical Care Medicine, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea
[2]Division of Pulmonary Allergy and Critical Care Medicine, Department of Internal Medicine, Busan Paik Hospital, Inje University College of Medicine, Busan, Korea
[3]Department of Radiology and Research Institute of Radiology, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea
[4]Department of Occupational and Environmental Medicine, College of Medicine, Inha University, Incheon, Korea
[5]Korea Research Institute of Bioscience and Biotechnology, Daejeon, Korea

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**Correspondence to**
**Sei Won Lee, MD, PhD**
Department of Pulmonary and Critical Care Medicine, Asan Medical Center, University of Ulsan College of Medicine, 88 Olympic-ro 43-gil, Songpa-gu, Seoul 05505, Korea.
Tel: +82-2-3010-3990
Fax: +82-2-3010-6968
E-mail: seiwon@amc.seoul.kr

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**ORCID iDs**
Hyung Jun Park
https://orcid.org/0000-0002-5523-5144
Ho Young Lee
https://orcid.org/0000-0001-7976-3753
Chong Hyun Suh
https://orcid.org/0000-0002-4737-0530
Ho Cheol Kim
https://orcid.org/0000-0002-3154-4858
Hwan Cheol Kim
https://orcid.org/0000-0002-3635-1297
Young-Jun Park
https://orcid.org/0000-0002-9958-3976
Sei Won Lee
https://orcid.org/0000-0003-4814-6730

## ABSTRACT

**Purpose:** Exposure to particulate matter (PM) is a key public health issue, but effective intervention has not yet been established. A systematic literature review and meta-analysis has been conducted to assess the relationship between the use of air filters, one of the most commonly studied interventions, and respiratory outcomes in patients with chronic respiratory diseases.
**Methods:** We systematically reviewed intervention studies on PM using PubMed, EMBASE, and Cochrane databases up to September 2019. Studies that included data on PM concentration changes and respiratory symptoms or lung function in patients with respiratory diseases were eligible for inclusion. Effect estimates were quantified separately using the random-effects model.
**Results:** Six studies were included in the quantitative analysis. Air filter use reduced indoor PM2.5 by 11.45 μg/m$^3$ (95% confidence interval [CI], 6.88, 16.01 μg/m$^3$). Air filter use was not associated with improvements in respiratory symptoms in 5 of the 6 studies or significant changes in the predicted forced expiratory volume in one second (FEV1) (mean change, −1.77%; 95% CI, −8.25%, 4.71%). Air filter use was associated with improved peak expiratory flow rate by 5.86 (95% CI, 3.5, 8.19 of standardized difference).
**Conclusions:** The findings of this systematic review suggest that air filters may reduce indoor PM and increase peak expiratory rate in asthmatic patients. However, most studies showed no significant effects of air filters on respiratory symptoms or FEV1. Further studies in regions with high-density PM may provide additional information on this issue.
**Trial Registration:** PROSPERO Identifier: CRD42020156258

**Keywords:** Particulate matter; air pollution, indoor; air filters; pulmonary disease, chronic obstructive; asthma; forced expiratory volume; peak expiratory flow rate

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**Disclosure**

There are no financial or other issues that might lead to conflict of interest.

## INTRODUCTION

Exposure to particulate matter (PM) is a leading environmental concern that has been associated with an increased risk of still-birth, respiratory disease, cardiovascular disease, and even mortality.[1-4] The dose-response relationship and biological plausibility were evaluated in many prospective cohort studies.[5] However, despite some improvements in developed regions, the global population-weighted ambient PM2.5 concentration continues to increase annually, mainly due to the contribution of developing countries, particularly East Asia.[6]

As an increased concentration of PM (PM2.5-PM10) is considered to aggravate respiratory diseases by decreasing lung function[7] and exacerbating respiratory symptoms,[8] effective interventions are required. A nationwide reduction in PM2.5 concentration was shown to be associated with reduced mortality risk.[9,10] At an individual level of indoor exposure PM2.5, most studies evaluated the use of air filters. Morishita *et al.*[11] demonstrated that indoor air filtration may improve cardiovascular health outcomes. High-efficiency particulate air (HEPA) filters can trap >99% of ambient particles with a diameter > 0.3 μm, as well as reduce indoor PM mass and number by > 50%.[12] Sublett *et al.*[13] performed a systemic review of studies published up to 2010, focusing on the effect of air filters on allergic disease; however, health outcomes were not consistent and the study did not consider the concentration of PM. Some studies also showed that air filters can have a beneficial effect on respiratory symptoms in patients with asthma.[14,15] The impact of PM is prominent in patients with chronic respiratory diseases, such as chronic obstructive pulmonary disease (COPD) and asthma.[16]

Many recent studies evaluated the effect of interventions on PM concentration, particularly the use of air filters on respiratory outcomes. However, a meta-analysis of interventions to reduce PM in patients with respiratory diseases has not previously been performed. Here, we performed a systematic review and meta-analysis to determine the effect of reducing PM through the use of air filters in patients with chronic respiratory diseases.

## MATERIALS AND METHODS

### Search strategy and selection criteria

A systematic search of the PubMed, EMBASE, and Cochrane databases was performed to identify studies on the health effects of interventions to reduce PM published prior to September 27, 2019. The search strategy included the following combinations of keywords: ("particulate matter" OR "PM10" OR "PM2.5" OR "Asian dust" OR "micro dust" OR "yellow dust" OR "coarse particle" OR "ultrafine particle" OR "indoor" OR "outdoor") OR "NOT ("mite") AND ("air conditioner" OR "air filter" OR "air cleaner" OR "HVAC") AND ("pulmonary disease, chronic obstructive" OR "lung disease, interstitial" OR "idiopathic pulmonary fibrosis" OR "cryptogenic organizing pneumonia" OR "asthma" OR "bronchiectasis"). Synonyms for PM and air filter were included using Medical Subject Heading (MeSH) terms and EMBASE subject headings (Emtree). Detailed information on our search strategy is provided in **Supplementary Data S1**. The search was limited to studies published in English.

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist was used to report the findings in this meta-analysis (**Supplementary Table S1**).[17] According to the PRISMA guidelines, article titles and abstracts were extracted by a single researcher (C.H.S.)


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and reviewed independently by 2 researchers (H.J.P., H.Y.L.) to include intervention studies. The full text was evaluated, and the inclusion criteria were applied; any disagreement was resolved by another researcher (S.W.L.). Studies were included if they met the following criteria: 1) they reported a change in PM concentration after the intervention; 2) the study types were restricted to randomized controlled trials and randomized cross-over studies; 3) air filters were able to filter more than 99% of particles greater than 0.3 μm; 4) they were published in a peer-reviewed journal in English; and 5) they were conducted in patients diagnosed with chronic respiratory diseases including asthma, COPD, interstitial lung disease and bronchiectasis. Quality assessment of the studies was performed by 2 researchers (H.J.P., H.Y.L.) (**Supplementary Table S2**). When the same trial was identified in duplicate, the study with the more recent, updated, complete report was included.

## Data extraction

The study design, mean age, sample size, follow-up period, PM concentration, location, blinding method, type and number of air filters, spirometry results, and clinical outcomes were extracted from each study. All of the estimates were calculated by Comprehensive Meta-Analysis, version 3 (Biostat, Englewood, NJ, USA). Data were extracted from the tables and figures of the studies included. If the estimates of a study were presented in figures without specific descriptions in the text, the investigators were conducted to obtain the relevant estimates. If no response was received after 3 emails, the articles were excluded from the quantitative analysis.

For the case-crossover study,[18] there was no way to compare it to RCTs such as the description of the first period result or any details. So, the study was not included in the quantitative analysis. In addition, when conducting the plan for extracting, we were unsure as to which statistical metrics were used for evaluating symptoms; thus, we did not limit the symptom metrics associated with asthma.

## Risk of bias

The risk of bias in the randomized controlled trials was assessed using the revised Cochrane risk of bias tool for randomized trials 2.0.[19] The tool included the response option of "definitely or probably yes" (assigned as a low risk of bias), or "definitely or probably no" (assigned as a high risk of bias). The items consisted of 5 components: randomization process, deviation from intended interventions, missing outcomes data, measurement of the outcome, and selection of the reported result. Considering the possibility of bias arising from deviation from the intended intervention in randomized cross-over trials, additional consideration for the carry-over effect (from the previous experimental condition) was used in the risk-of-bias tool 2.0.

## Statistical analysis

All statistical analyses were carried out using Comprehensive Meta-Analysis, version 3. The metrics of the analysis for the primary outcome were as follows: reductions in PM (effect measure: difference in means), changes in predicted forced expiratory volume in 1 second (FEV1; effect measure: differences in mean values), and changes in predicted or raw peak expiratory flow rate (PEF or PEFR: standardized difference in mean). As the symptom score was analyzed with different statistical metrics in each study, we performed a qualitative analysis for changes in symptoms.

Heterogeneity among studies was estimated using the $I^2$-based Cochrane Q test. Heterogeneity was quantified as very low, low, moderate, and high, with upper limits of 25%,

50% and 75% for $I^2$, respectively.[20] A sensitivity analysis was performed after the exclusion of trials with a high risk of bias and different populations. For the studies without a description of the correlation between pre- and post-intervention, a correlation of 0.5 was assumed for the conservative approach.[20] To assess publication bias, funnel plots and Egger's weighted linear regression results were reviewed visually.[21] Where statistically significant publication bias was present, the "trim and fill" approach was employed to obtain an unbiased summary effect estimate.[22] Given that Egger's test may be underpowered in meta-analyses with a low number of studies,[23] the trim and fill approach was also applied for analyses with statistically insignificant publication bias to ensure the validity of our results.

## RESULTS

### Study selection and characteristics

A flow diagram of the evaluation process is shown in **Fig. 1**. The literature search yielded a total of 2,109 related articles; 229 duplicates were removed. Among the remaining 1,880 articles, 1,803 were excluded following a review of titles and abstracts. Full-text screening led to the exclusion of 70 studies that included an inappropriate population (n = 5), non-randomized studies (n = 18), interventions other than air filter (n = 30), no respiratory outcomes (n = 8), or abstracts alone (n = 9). Afterward, 7 studies were included in the qualitative analysis.

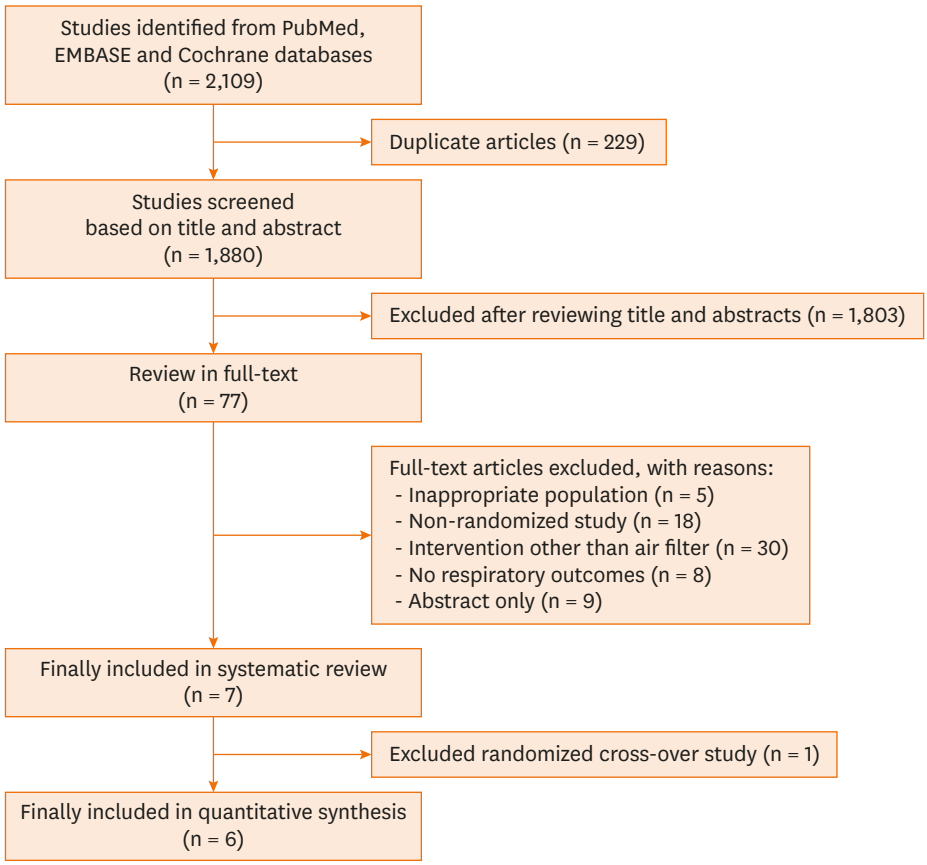


**Fig. 1.** PRISMA flow diagram.

Six of the studies included were randomized controlled trials conducted on asthmatic patients,[14,15,24-27] and one was a randomized cross-over study conducted on COPD patients.[18] Six studies were conducted in the US[14,15,24-27] and one was conducted in China.[18] The characteristics of the studies are described in **Table 1**. The severity of asthma was described with different measures such as lung function (FEV1, PEF), symptoms score, or grading system according to the GINA guideline.[28] In 3 studies,[15,24,26] patients with moderate-to-severe asthma comprised more than 50% of the whole participants, while other studies included patients with any range of symptoms of asthma (**Table 2**).

**Table 1.** Characteristics of the included studies on the effect of air filter use on respiratory disease

| References | Study design | Age | No. | Follow-up | Population | PM2.5* concentration | Baseline predicted FEV1† | Intervention/ comparison | Location | Place/ No. of air filter |
|---|---|---|---|---|---|---|---|---|---|---|
| Jhun *et al.*[27] | Randomized controlled trial | 8.1 | 25 | 26 | Asthma | 6.2 μg/m$^3$ | No data | Air filter/ sham filter | Northeastern USA | Classroom/4 (hallway: 1, classroom: 3) |
| Park *et al.*[14] | Randomized controlled trial | 12.3 | 16 | 12 | Asthma | 7.42 μg/m$^3$ | NA | Air filter/ sham filter | Fresco, CA, USA | House/2 (living: 1, bed room: 1) |
| Noonan *et al.*[15] | Randomized controlled trial | 12.3 | 92 | 2 | Asthma | 17.1 μg/m$^3$ | 87.2% ± 18.1%/ 88.3% ± 24.9% | Air filter/ no filter | Montana, Idaho, and Alaska, USA | House/2 (living: 1, bed room: 1) |
| Eggleston *et al.*[25] | Randomized controlled trial | 8.4 | 100 | 52 | Asthma | 38.0 μg/m$^3$ | 101% ± 20%/ 100% ± 21% | Air filter/ no filter | Baltimore, MD, USA | House/1 (bed room) |
| Butz *et al.*[24] | Randomized controlled trial | 9.1 | 123 | 26 | Asthma | 39.5 μg/m$^3$ | NA | Air filter/ no filter (with education) | Baltimore, MD, USA | House/2 (living: 1, bed room: 1) |
| Lanphear *et al.*[26] | Randomized controlled trial | 8.6 | 225 | 52 | Asthma | 4.0 × 10$^6$/ft$^3$ (No. of particles) | NA | Air filter/ sham filter | Cincinnati, OH, USA | House/2 (living: 1, bed room: 1) |
| Shao *et al.*[18] | Randomized cross-over | 66.4 | 20 | 2 | COPD | 60.0 μg/m$^3$ | 66.90% ± 31.10%/ 74.04% ± 28.90% | Air filter/ sham filter | Beijing, China | House/2 (living: 1, bed room: 1) |

PM, particulate matter; FEV1, forced expiratory volume in one second; COPD, chronic obstructive pulmonary disease; NA, not applicable.
*Baseline concentration of PM2.5 at randomization. †Predicted FEV1 is described with mean and standard deviation of intervention group/control group.

**Table 2.** Changes in symptoms after air filter use

| References | Asthma severity | Outcome measures | Duration | Outcome (mean, 95% CI) |
|---|---|---|---|---|
| Jhun *et al.*[27] | Any symptoms of asthma | Daytime symptoms<br>Nighttime symptoms<br>Interfere with the child's activity | 0, 3, 6, 9, 12 months | 3 months: 0.78 (0.28 to 2.12)<br>6 months: 0.69 (0.19 to 2.48)<br>9 months: 0.74 (0.26 to 2.12)<br>12 months: 1.09 (0.28 to 4.32) |
| Park *et al.*[14] | Any symptoms of asthma | Asthma control test score | 0, 6, 12 weeks | 6 weeks: 8.29 (6.15 to 10.4)<br>12 weeks: 9.55 (7.65 to 11.45) |
| Eggleston *et al.*[25] | Any symptoms of asthma | Daytime symptoms<br>Symptoms with exercise<br>Nighttime symptoms<br>Interfere with the child's activity | 0, 3, 6, 9, 12 months | 3 months: 1.04 (0.85 to 1.27)<br>6 months: 0.771 (0.62 to 0.96)<br>9 months: 0.785 (0.61 to 1.01)<br>12 months: 0.952 (0.76 to 1.19) |
| Noonan *et al.*[15] | Moderate-to-severe > 50% of the participants | PAQLQ<br>Overall<br>Symptoms<br>Limitation of activity<br>Emotion | 0, 2 weeks | 2 weeks:<br>Overall: −0.04 (−0.48 to 0.40)<br>Symptoms: −0.04 (−0.48 to 0.40)<br>Limitation: −0.24 (−0.71 to 0.24)<br>Emotion: −0.04 (−0.44 to 0.39) |
| Butz *et al.*[24] | Moderate-to-severe > 50% of the participants | Free of symptom days:<br>Daytime symptoms<br>Nocturnal symptoms<br>Slowed-activity | 0, 6 months | 6 weeks:<br>Daytime: 1.3 (−0.13 to 2.73)<br>Nocturnal: 1.24 (−0.73 to 3.21)<br>Slowed-activity: 1.99 (0.09 to 3.89) |
| Lanphear *et al.*[26] | Moderate-to-severe > 50% of the participants | Shortness of breath<br>Tightness in chest<br>Wheeze<br>Difficulty sleeping | 0, 3, 6, 9, 12 months | 3 months: 1.04 (0.67 to 1.59)<br>6 months: 1.1 (0.62 to 1.90)<br>9 months: 1.31 (0.79 to 2.21)<br>12 months: 0.81 (0.47 to 1.44) |

CI, confidence interval; PAQLQ, pediatric asthma quality of life questionnaire.

The design and population of the COPD study[18] was quite different from other asthma studies, [14,15,24-27] and not included in the quantitative analysis for lung function. We could not find studies on interstitial lung disease or bronchiectasis that met the inclusion criteria.

The mean concentration of baseline indoor PM2.5 ranged from 6.2 to 60.0 μg/m³ (**Table 1**). Most of the filters were deployed in households, and 6 studies[14,15,18,24,26] deployed 2 air filters and one study[25] deployed one air filter. The other study deployed 4 air filters in classrooms.[27]

## Effect of air filters on PM

The studies had different baseline PM concentrations and sequestrating effect of air filters. Therefore, the pooled estimate was calculated with an absolute difference in means. Five of the studies[14,15,24,26,27] employed HEPA filter which can eliminate PM2.5 more than 99.9% and 2 did not describe a filter model (**Supplementary Table S3**).[18,25] All of the included studies reported that the use of air filters resulted in a significant reduction in PM2.5 (**Fig. 2**). When studies were categorized according to a baseline PM2.5 concentration, they showed that the higher the baseline concentration, the greater the PM2.5 reduction, except for 1 study that used a different unit of PM.[26] Due to the variation in baseline PM concentration, the random-effects model was applied. The model yielded a pooled estimate of absolute difference in PM2.5 of −11.45 μg/m³ (95% confidence interval [CI], −16.02, −6.88 μg/m³) with the use of an air filter. Because of differences in the baseline concentration of PM, a high level of heterogeneity ($I^2$ = 96.63%) was observed among the studies included. When we divided the studies into lightly polluted and heavily polluted areas according to the baseline PM concentration, effect estimates were −5.58 μg/m³ (−10.07, −1.09) in lightly polluted areas and −18.8 μg/m³ (−28.1, −9.67) in heavily polluted areas (**Supplementary Fig. S1**).

Two studies showed the cleaning effect of air filters on $PM_{10}$.[24,25] A random-effects model yielded a pooled estimate of the absolute difference in $PM_{10}$ of −14.91 μg/m³ (95% CI, −24.35, −5.46 μg/m³) with the use of air filters. These 2 studies showed similar baseline $PM_{10}$ concentrations with moderate heterogeneity ($I^2$ = 36.9%; **Fig. 2**).

## Effect of air filter use on respiratory symptoms

Six studies evaluated changes in symptoms after air filter use (**Table 2**).[14,15,24-27] The symptom measures were not consistent among the studies, with some using percentage

| Study name | Size of PM | Statistics for each study | | |
|---|---|---|---|---|
| | | Difference in means | Lower limit | Upper limit |
| Eggleston *et al.* (2005)[25] | PM10 | −21.000 | −33.734 | −8.266 |
| Butz *et al.* (2011)[24] | PM10 | −11.100 | −19.772 | −2.428 |
| | | −14.907 | −24.346 | −5.467 |
| Jhun *et al.* (2017)[27] | PM2.5 | −2.400 | −3.103 | −1.697 |
| Park *et al.* (2017)[15] | PM2.5 | −3.080 | −4.243 | −1.917 |
| Noonan *et al.* (2017)[14] | PM2.5 | −11.457 | −13.144 | −9.770 |
| Eggleston *et al.* (2005)[25] | PM2.5 | −14.000 | −25.371 | −2.629 |
| Butz *et al.* (2011)[24] | PM2.5 | −23.400 | −34.195 | −12.605 |
| Shao *et al.* (2017)[18] | PM2.5 | −36.000 | −46.394 | −25.606 |
| | | −11.452 | −16.022 | −6.882 |

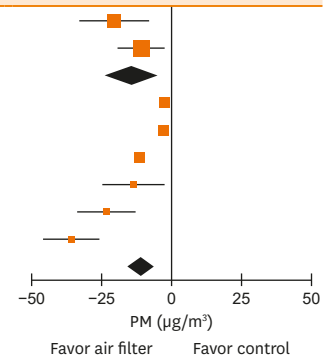


**Fig. 2.** Pooled effect estimates on the reduction of PM according to air filter use. The forest plot shows the reduction of PM in the included studies. The studies are sorted according to the baseline concentration of $PM_{2.5}$. PM, particulate matter; CI, confidence interval.

of symptomatic patients and others using asthma control questionnaire (ACT or pediatric asthma quality of life questionnaire). Duration of air filter use ranged from 2 weeks to 12 months. Among the studies with more than 6 months of observation,[25-27] there was no significant trend toward high effect size with longer use of air filter. One study that measured symptoms with the ACT score showed a significant effect of air filter with PM2.5 reduction of only 3 μg/m$^3$, the other 5 studies did not show significant symptomatic improvements with air filter use (**Table 2**).[15,24-27] In addition to a study by Park *et al.*,[14] Eggleston *et al.*[25] also showed a trend of air filters having significant beneficial effects at 6 months. Other studies did not show significant reductions in asthma symptoms.

## Effect of air filter use on lung function

Four studies analyzed changes in FEV1 after air filter use.[15,18,25,27] In quantitative analysis, 3 studies conducted meta-analysis,[15,25,27] except for the COPD study.[18] For changes in predicted FEV1, a random-effects model yielded a pooled estimate of −1.71% (95% CI, −8.25%, 4.71%; **Fig. 3**). The $I^2$ was 49.4, indicating a moderate degree of heterogeneity among the studies. To evaluate publication bias, Egger's regression test was performed and a *P* value of 0.90 was calculated. When evaluating according to the period of air filter use, short use (<6 months) of air filter showed FEV1 change of 0.92 (−5.27, 7.12) and long use (12 months) of air filter showed FEV1 change of −2.42 (−7.13, 2.29) (**Supplementary Fig. S2**). There was no positive effect with longer air filter use. One study in COPD patients did not show significant improvement in FEV1 for 2 weeks (**Fig. 3**).[18]

Three studies analyzed changes in PEF after air filter use; 2 studies[15,27] used raw changes in PEF and 1 study[15] used predicted PEF. The pooled effect size of the 2 studies was 5.86 (3.53, 8.20) of standardized mean difference and $I^2$ was 52.3, indicating a moderate degree of heterogeneity (**Fig. 4**). The study that used predicted PEF did not show significant changes in PEF.

## Quality assessment and sensitivity analysis

Three studies were judged to have a low risk of bias[15,26,27] and one raised some concerns (**Fig. 5**).[18] The risks of bias in the studies included are described in **Supplementary Fig. S3**. Three studies compared between groups with air filter intervention and those without any kind of intervention using air purification devices,[14,24,25] and had a high risk of bias for respiratory symptoms (**Fig. 5**). One study had a high risk of bias for lung function,[25] and the lung function showed no significant changes after excluding this study (**Supplementary Fig. S2**).

| Study or subgroup | Statistics for each study | | | *P*-value |
|---|---|---|---|---|
| | Difference in means | Lower limit | Upper limit | |
| Asthma | | | | |
| Jhun *et al.* (2017)[27] | 3.250 | −4.558 | 11.058 | 0.415 |
| Noonan *et al.* (2017)[14] | −0.710 | −8.800 | 7.380 | 0.863 |
| Eggleston *et al.* (2005)[25] | −8.000 | −16.043 | 0.043 | 0.051 |
| | −1.771 | −8.252 | 4.710 | 0.592 |
| COPD | | | | |
| Shao *et al.* (2017)[18] | −3.180 | −7.934 | 1.574 | 0.190 |
| | −3.180 | −7.934 | 1.574 | 0.190 |

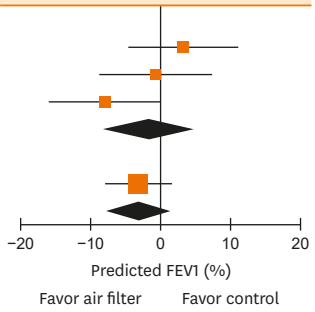


**Fig. 3.** Effect of air filter use on FEV1. The studies are sorted according to the baseline concentration of PM. FEV1, forced expiratory volume in one second; PM, particulate matter; COPD, chronic obstructive pulmonary disease; CI, confidence interval.

| Study or subgroup | Statistics for each study | | | *P*-value |
|---|---|---|---|---|
| | Std diff in means | Lower limit | Upper limit | |
| PEF | | | | |
| Park *et al.* (2017)[15] | 7.230 | 4.620 | 9.840 | 0.000 |
| Jhun *et al.* (2017)[27] | 4.828 | 2.889 | 6.766 | 0.000 |
| | 5.863 | 3.532 | 8.195 | 0.000 |
| Predicted PEF | | | | |
| Noonan *et al.* (2017)[14] | 0.133 | −0.276 | 0.543 | 0.523 |
| | 0.133 | −0.276 | 0.543 | 0.523 |

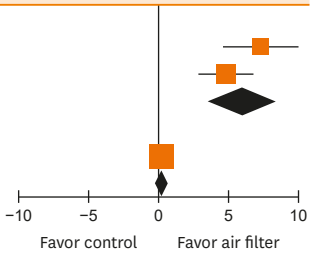


**Fig. 4.** Effect of air filter use on PEF rate. The studies are grouped according to the metric used (i.e., raw value of PEF vs. predicted PEF).
PEF, peak expiratory flow.

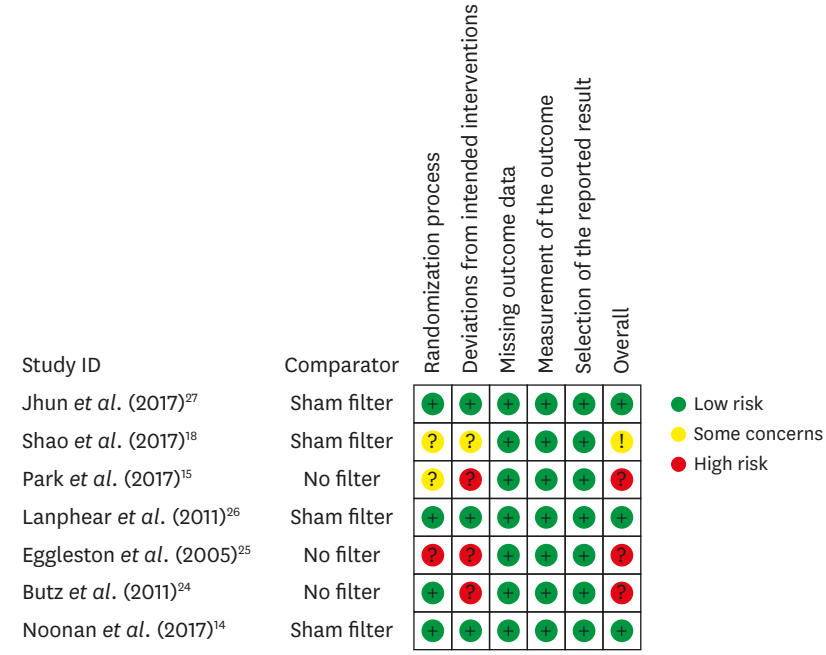


**Fig. 5.** Summary of the risk of bias on respiratory symptoms.

## DISCUSSION

In this qualitative and quantitative review, the literature was systematically evaluated to determine the effect of air filter use on respiratory outcomes in patients with chronic respiratory diseases. The results demonstrated that air filter use significantly reduced indoor PM2.5 and that higher baseline PM concentration was associated with greater PM reductions. Although PM reduction may improve the PEF rate, there were no significant effects on respiratory symptoms or predicted FEV1. No study about other respiratory diseases, such as interstitial lung disease or bronchiectasis, was founded in our searching strategy.

Although 2 studies showed significant changes in respiratory symptoms with air filter use,[14,25] the remaining showed no statistically significant improvements. Previous meta-analyses have shown that short-term exposure to PM2.5 could aggravate respiratory symptoms and reduce

PEF in patients with COPD[8] or asthma.[8,29] The odds ratio of the respiratory symptoms was 1.22-1.57 with a 50 μg/m$^3$ increase in PM2.5, depending on the model used.[8] The baseline concentration of PM2.5 (6.2-39.5 μg/m$^3$) was relatively low in the studies evaluated here,[14,15,24-27] and the pooled change in PM2.5 was −5.58 to −18.8 μg/m$^3$ as for lightly to heavily polluted areas. The minimal degree of reduction in PM due to low baseline concentration may have influenced the results and led to a lack of statistical significance. The measure of respiratory symptoms was different between studies[14,15,25-27] from cough to emotional function. The previous systematic review used cough and wheeze as the measure of respiratory symptoms.[8] However, for the estimates of respiratory symptoms as asthma status (symptoms of day and night, limitation of activity) in this review, there is no significant change in respiratory symptoms by air filter use.

The previous meta-analysis was a panel study to evaluate the effect of short-term exposure to PM (a few days) on respiratory outcomes.[8] Two studies evaluated the effect of long-term (several decades) exposure to PM on respiratory symptoms.[30,31] The current study evaluates the effect of PM reduction in various periods (less than 6 weeks to 12 months). In the subgroup analysis of different duration, there was no tendency toward or significant difference in respiratory symptoms with longer use of air filter.

Edginton *et al.*[32] reviewed the effect of PM on FEV1 in healthy adults. Short-term exposure (over several days) resulted in FEV1 changes of −7.02 mL with a PM2.5 increase of 10 μg/m$^3$. Gauderman *et al.*[33] evaluated the effect of PM on lung development in adolescents over an 8-year period and showed that high PM2.5 concentration could reduce lung growth as measured by FEV1 and forced vital capacity. In another study, long-term exposure to PM2.5 reduced FEV1 by 0.24% each year.[34] However, our data did not show that reductions in PM were associated with improvements in FEV1 and that the duration of air filter use did not provide additional benefits for FEV1 as well. These results may be due to the shorter use of air filters than in an observational study[32] and the less potent reduction in the concentration of PM.

One personal exposure study showed that increases in PM2.5 and $PM_{10}$ were associated with decreases in PEFR of 2 days after exposure in asthmatic patients.[35] Also, a panel study demonstrated that decreases in PM during the 2008 Olympics in Beijing were associated with increases in PEF.[36] Our current study showed that PEF may be increased in the air filter use group. As the PEF predicted cannot be pooled with the raw PEF value, the pooled estimate was conducted only on raw PEF. Although the included studies estimating PEF had small numbers of participants, the effect sizes of the 2 studies were rather large.[14,27] One study raised some concerns on the effect of PEF by reporting no significant effect of a larger population or greater reduction of PM in the PEF predicted.[15] Therefore, the effect of air filter on PEF should be validated with well-designed and well-conducted studies in the future.

Other interventions, such as facial mask, omega-3 and vitamin D, can ameliorate the adverse effect of PM. Wearing a facial mask is an easy way to avoid exposure to PM, and Langrish *et al.*[37] demonstrated that the use of facial masks lowered systolic blood pressure in healthy subjects exposed to PM. During the study period, the concentration of PM2.5 was 86-140 ug/m$^3$ in Beijing. Other studies also support the cardiovascular effects of facial mask use to avoid PM, including decreased systolic blood pressure, increased heart rate variability, and reduced ST segment depression,[18,37,38] even when considering the confounding effect of traffic noise.[39] However, the observation periods of the studies were just a few weeks and none of the studies showed the effect on respiratory outcomes such as lung functions and symptoms. In a review article, omega-3 oil was shown to have an anti-inflammation effect and reduced

asthma symptoms.[40] Brigham *et al.*[41] demonstrated a correlation between omega-3 intake and PM2.5, and showed a marginal effect in reducing respiratory symptoms in children with asthma. Vitamin D is also reported to help control asthma.[40] Bose *et al.*[42] demonstrated that a decreased concentration of vitamin D in obese children with asthma is associated with aggravated symptoms following a 10 unit increase in PM2.5. However, these were observational studies and no other studies of vitamin D or omega-3 oil as interventions are available. Therefore, we realized after brief literature search that a tool other than air filter could not be analyzed as an intervention for PM.

This study has some limitations. First, all studies included in this quantitative analysis were conducted in the USA, where PM concentration is relatively low. It is possible that studies conducted in the areas of high PM concentration may have shown a greater effect with air filter use. Secondly, half of the studies[15,24,25] may have deviated from the intended intervention by using an open-label design that allows for the possibility of a placebo effect; therefore, the evidence level of each study may be low. In sensitivity analysis that excluded the studies at high risk of bias, the effect of air filter use on symptoms or PEFR was not evident. Thirdly, the measure of asthma symptoms was not consistent, and quantitative analysis was therefore not possible. However, the inconsistency of effect direction can be enough evidence that a small reduction in PM is not helpful in sufficiently reducing asthma symptoms.

Despite these limitations, our study has several strengths. To our knowledge, this is the first meta-analysis of the effect of intervention on respiratory outcomes associated with reduced indoor PM in patients with respiratory diseases. Heterogeneity in our analyses was addressed by stratifying the studies included according to baseline PM concentration, type of air filter implementation, duration of air filter use, and study design.

In conclusion, the use of indoor air filters was associated with reductions in indoor PM concentration, which may have conferred beneficial effects on PEF in asthmatic patients. However, the use of air filters was not associated with significant improvements in symptoms or FEV1. Further studies in heavily polluted areas are needed to confirm the positive effects of air filters.

## ACKNOWLEDGMENTS

This study was supported by Research of Korea Centers for Disease Control and Prevention (2019ER671100), and grants from the KRIBB Research Initiative Program (Young-Jun Park).

## SUPPLEMENTARY MATERIALS

**Supplementary Data S1**
Search strategy

Click here to view

**Supplementary Table S1**
PRISMA report

Click here to view

**Supplementary Table S2**

Risk of bias of revised Cochrane risk of bias tool for randomized trial 2.0

Click here to view

**Supplementary Table S3**

Air cleaners used in each study

Click here to view

**Supplementary Fig. S1**

Forest plot of the effect of air filters on PM reduction according to baseline concentration.

Click here to view

**Supplementary Fig. S2**

Forest plot of the effect of air filters on FEV1 according to the duration of follow-up.

Click here to view

**Supplementary Fig. S3**

Bar graph presenting the risk of each bias item as percentages across all included studies.

Click here to view

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**Supplementary Data S1.** Search strategy

**PubMed search**

#1. particulate matter[MeSH Terms]

#2. indoor

#3. outdoor

#4. PM2.5

#5. PM10

#6. asian dust

#7. micro dust

#8. yellow dust

#9. coarse particle

#10. ultrafine particle

#11. mite

#12. (#1 OR #2 OR #3 OR #4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10) NOT #11

#13. pulmonary disease, chronic obstructive[MeSH Terms]

#14. “chronic obstructive lung disease”

#15. lung disease, interstitial[MeSH Terms]

#16. idiopathic pulmonary fibrosis[MeSH Terms]

#17. cryptogenic organizing pneumonia[MeSH Terms]

#18. asthma[MeSH Terms]

#19. bronchiectasis[MeSH Terms]

#20. “cryptogenic organizing pneumonia”

#21. “bronchiectasis”

#22. “interstitial lung disease”

#23. “asthma”

#24. #13 OR #14 OR #15 OR #16 OR #17 OR #18 OR #19 OR #20 OR #21 OR #22 OR #23

#25. air conditioner

#26. air filters[MeSH Terms]

#27. air cleaner

#28. intervention

#29. air filt*

#30. #25 OR #26 OR #27 OR #28 OR #29

#31. #12 AND #24 AND #30

**EMBASE search**

#1. 'air filter'/exp/mj

#2. 'hepa filter'/mj

#3. 'air cleaning system'/exp/mj

#4. (air AND filtration)

#5. intervention

#6. hvac

#7. 'heating, ventilation, air-conditioning system'

#8. 'air conditioner'

#9. #1 OR #2 OR #3 OR #4 OR #5 OR #6 OR #7 OR #8

#10. 'chronic obstructive lung disease'/exp/mj

#11. 'interstitial lung disease'/mj

#12. 'fibrosing alveolitis'/exp/mj

#13. 'bronchiectasis'/exp/mj

#14. 'bronchiolitis obliterans organizing pneumonia'/exp/mj

#15. 'asthma'/exp/mj

#16. ‘asthma’

#17. “bronchiolitis obliterans organizing pneumonia”

#18. “bronchiectasis”

#19. “fibrosing AND alveolitis”

#20. “interstitial AND lung AND disease”

#21. #10 OR #11 OR #12 OR #13 OR #14 OR #15 OR #16 OR #17 OR #18 OR #19 OR #20

#22. 'particulate matter'/exp/mj

#23. 'suspended particulate matter'/mj

#24. 'pm2.5'

#25. 'pm10'

#26. 'asian dust'

#27. 'indoor'

#28. 'outdoor'

#29. 'yellow dust'

#30. 'coarse particle'

#31. 'ultrafine particle'

#32. 'mite'

#33. (#22 OR #23 OR #24 OR #25 OR #26 OR #27 OR #28 OR #29 OR #30 OR #31) NOT #32

#34. #9 AND #21 AND #33

**Cochrane search**

#1 MeSH descriptor: [Pulmonary Disease, Chronic Obstructive] explode all trees

#2 MeSH descriptor: [Lung Diseases, Interstitial] explode all trees

#3 MeSH descriptor: [Idiopathic Pulmonary Fibrosis] explode all trees

#4 MeSH descriptor: [Cryptogenic Organizing Pneumonia] explode all trees

#5 MeSH descriptor: [Asthma] explode all trees

#6 MeSH descriptor: [Bronchiectasis] explode all trees

#7. “Interstitial lung disease”

#8. “Cryptogenic organizing pneumonia”

#9. “Asthma”

#10. “Bronchiectasis”

#11. “Chronic obstructive lung disease”

#12. #1 OR #2 OR #3 OR #4 OR #5 OR #6 OR #7 OR #8 OR #9 OR #10 OR #11

#13. MeSH descriptor: [Air Filters] explode all trees

#14. ‘air conditioner’

#15. ‘air cleaner’

#16. ‘air filtration’

#17. ‘HVAC’

#18. ‘heating, ventilation, air-conditioning system’

#19. ‘HEPA filter’

#20. #13 OR #14 OR #15 OR #16 OR #17 OR #18 OR #19

#21. MeSH descriptor: [Particulate Matter] explode all trees

#22. ‘PM2.5’

#23. ‘PM10’

#24. ‘asian dust’

#25. ‘indoor’

#26. ‘outdoor’

#27. ‘yellow dust’

#28. ‘microdust’

#29. ‘coarse particle’

#30. ‘ultrafine particle’

#31. ‘mite’

#32. (#21 OR #22 OR #23 OR #24 OR #25 OR #26 OR #27 OR #28 OR #29 OR #30) NOT #31

#33. #12 AND #20 AND #32

**Supplementary Table S1.** PRISMA report

| # | Item | Guidance | On page # | Author Comments |
|---|---|---|---|---|
| **Title** | | | | |
| 1 | Title | Identify the report as a systematic review, or systematic review and meta-analysis, as appropriate. | 1 | The title identifies the report both as a systematic review and meta-analysis. |
| **Abstract** | | | | |
| 2 | Structured summary | Provide a structured summary including, as applicable:<br>• Background;<br>• Objectives;<br>• Data sources;<br>• Study eligibility criteria, participants, and interventions;<br>• Study appraisal and synthesis methods;<br>• Results;<br>• Limitations; conclusions and implications of key findings;<br>• Systematic review registration number. | 3 | A structured abstract is provided based on the PRISMA guidelines, as:<br>-Background (background + objectives)<br>-Methods (data sources + study criteria + study appraisal & synthesis methods)<br>-Results<br>-Conclusions (Limitations; conclusions and implications of key findings;<br>- Systematic review registration number. |
| **Introduction** | | | | |
| 3 | Rationale | Describe the rationale for the review in the context of what is already known. | 4 | |
| 4 | Objectives | Provide an explicit Population-Intervention-Comparator-Outcome-Study Design (PICOS) or Population-Exposure-Comparator-Outcome-Study Design (PECOS) statement as appropriate, detailing the following in relation to the research questions being asked:<br>• Participants<br>• Interventions / Exposures (as appropriate)<br>• Comparisons<br>• Outcomes<br>• Study design | 4 | Our PICO statement includes<br>- **P**articipants: Patients with chronic respiratory disease (asthma, COPD, bronchiectasis, ILD)<br>-**E**xposures: particulate matter<br>-**I**ntervention: air filter, air mask, omega-3, vitamin<br>-**O**utcome: respiratory symptoms, $FEV_1$<br>- **S**tudy design: randomized control trial, randomized case-crossover |
| **Methods** | | | | |
| 5 | Protocol and registration | Indicate if a review protocol exists, if and where it can be accessed (e.g. web address), and registration information including registration number (if available). | 5 | PROSPERO registration is under reviewed. ID 156258 |

| | | | | |
|---|---|---|---|---|
| 6 | Eligibility criteria | Specify study characteristics (e.g. PICOS/PECOS, length of exposure) and report characteristics (e.g. years considered, language, publication status) used as criteria for eligibility, giving rationale. | 5 | We included intervention studies that examined reduction of PM and respiratory outcomes or spriomteric results which were only published in a peer-reviewed journal. The criteria are described in the first and second paragraph of the method. |
| 7 | Information sources | Describe all information sources (e.g. databases with dates of coverage, contact with study authors to identify additional studies) in the search, and date last searched. | 5 | We searched in PubMed, EMBASE, Cochrane database; and screened the studies references for additional studies. |
| 8 | Search | Present full electronic search strategy for at least one database, including any limits used, such that it could be repeated. | 5 | We used keywords in the first paragraph of the methods. Detailed strategy was described in Supplementary Data S1. |
| 9 | Study selection | State the process for selecting studies (i.e., screening, eligibility, included in systematic review, and, if applicable, included in the meta-analysis). | 5 | Described in method ***Search strategy and selection criteria*** section |
| 10 | Data collection process | Describe method of data extraction from reports (e.g., piloted forms, independently, in duplicate) and any processes for obtaining and confirming data from investigators. | 5 | Described in method ***Search strategy and selection criteria*** section |
| 11 | Data items | List and define all variables for which data were sought (e.g., PICOS/PECOS, funding sources) and any assumptions and simplifications made. | 5-6 | Described in method Data extraction section |
| 12 | Risk of bias in individual studies | Describe methods used for assessing risk of bias of individual studies (including specification of whether this was done at the study or outcome level), and how this information is to be used in any data synthesis. | 5 | Risk of bias is evaluated based on Cochrane risk of bias tool for randomized trials 2.0. In case of randomized cross-over trial, additional consideration was analysed separately. |
| 13 | Summary measures | State the principal summary measures (e.g., risk ratio, difference in means). | 6-7 | Effect measurement<br>Reduced PM: difference in means<br>Change of symptoms: odds ratio<br>Changed FEV1: difference in means |
| 14 | Synthesis of results | Describe the methods of handling data and combining results of studies, if done, including measures of consistency (e.g., $I^2$) for each meta-analysis. | 7 | "statistical analysis" provide a full description. We measured heterogeneity by $I^2$ based on Cochrane Q test. Although we used random-effects model for the difference in reduced PM of each studies. |

| | | | | |
|---|---|---|---|---|
| 15 | Risk of bias across studies | Specify any assessment of risk of bias that may affect the cumulative evidence (e.g., publication bias, selective reporting within studies). | 7 | Publication bias was assessed though funnel plot and Egger's weighted linear regression results. Unreported results of the studies were collected by emailing with the authors. |
| 16 | Additional analyses | Describe methods of additional analyses (e.g., sensitivity or subgroup analyses, meta-regression), if done, indicating which were pre-specified. | 7 | Sensitivity analysis were performed for studies excluding high risk of bias. |
| **Results** | | | | |
| 17 | Study selection | Give numbers of studies screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, illustrated with a PRISMA flow diagram. | 7 | "Study selection and characteristics", including PRISMA flow diagram (Figure 1) |
| 18 | Study characteristics | For each study, present in a summary table the characteristics for which data were extracted (e.g., study size, PICOS/PECOS, follow-up period) and provide the citations. | 7-8 | The key parameter of the included studies are summarized Table 1. |
| 19 | Risk of bias within studies | Present data on risk of bias of each study and, if available, any outcome level assessment (see item 12). | 9-10 | "Quality assessment and sensitivity analysis" including summarized risk of bias (Figure 5, Supplementary Fig. S3) |
| 20 | Results of individual studies | For all outcomes considered (benefits or harms), present, for each study: (a) simple summary data for each intervention group (b) effect estimates and confidence intervals, ideally with a forest plot (unless such a plot would be misleading) | 7 | Th outcome of each studies were summarized in Table 1, supplementary Table 1. The forest plot was in Supplementary Figs. S1, S2. |
| 21 | Synthesis of results | Present results of each meta-analysis done, including confidence intervals and measures of consistency. | 8-9 | "Effect of air filter use on respiratory symptoms and lung function" showed the meta-analysis results. |
| 22 | Risk of bias across studies | Present results of any assessment of risk of bias across studies (see Item 15). | 8-10 | Publication bias was described following each meta-analysis results. We used egger's regression test and trim and fill method. |
| 23 | Additional analysis | Give results of additional analyses, if done (e.g., sensitivity or subgroup analyses, meta-regression [see Item 16]). | 8-10 | Subgroup analysis were performed by the period of using air filter (Supplementary Figs. S1, S2)<br>Sensitivity analysis were performed after excluding studies with high risk of bias. But there was no change. (sensitivity analysis) |
| **Discussion** | | | | |
| 24 | Summary of evidence | Summarize the main findings including the strength of evidence for each main outcome; consider their relevance to key groups (e.g., researchers, users, and policy makers). | 11-12 | The main findings are discussed in the first part of the Discussion session. |

| | | | | |
|---|---|---|---|---|
| 25 | Limitations | Discuss limitations at study and outcome level (e.g., risk of bias), and at review-level (e.g., incomplete retrieval of identified research, reporting bias). | 13 | The limitation was described in Discussion session. |
| 26 | Conclusions | Provide a general interpretation of the results in the context of other evidence, and implications for future research. | 13 | Described in the last paragraph of discussion. |
| **Funding** | | | | |
| 27 | Funding | Describe sources of funding for the systematic review and other support (e.g., supply of data); role of funders for the systematic review. | 13 | Described in "Conflict of interest" |

Modified PRISMA report adapted from: Moher D, Liberati A, Tetzlaff J, Altman DG; The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Med 2009;6:e1000097. DOI: 10.1371/journal.pmed1000097. (changes are minor, with text edits to accommodate the subject matter of the journal and formatting to fit page).

PICOS, Population-Intervention-Comparator-Outcome-Study Design; PECOS, Population-Exposure-Comparator-Outcome-Study Design; COPD, chronic obstructive pulmonary disease; ILD, Interstitial lung disease; FEV1, forced expiratory volume in one second; PM, particulate matter.

**Supplementary Table S2.** Risk of bias of revised Cochrane risk of bias tool for randomized trial 2.0

| **Unique ID** | 1 | **Study ID** | Jhun 2017 | **Assessor** | HJ Park, H Lee |
|---|---|---|---|---|---|
| **Ref or Label** | | **Aim** | assignment to intervention (the 'intention-to-treat' effect) | | |
| **Experimental** | Air filter | **Comparator** | Sham filter | **Source** | |
| **Outcome** | asthma symptoms/FEV1 | **Results** | | **Weight** | 1 |
| **Domain** | **Signalling question** | | | **Response** | **Comments** |
| **Bias arising from the randomization process** | 1.1 Was the allocation sequence random? | | | Y | Eighteen classrooms (for the 25 participants) were randomized in a 1:1 ratio by school to receive High Efficiency Particulate Air (HEPA) cleaners.<br><br>The children, teachers, and school officials were blinded to the status (active vs. sham) of the air cleaners in each classroom. |
| | 1.2 Was the allocation sequence concealed until participants were enrolled and assigned to interventions? | | | Y | |
| | 1.3 Did baseline differences between intervention groups suggest a problem with the randomization process? | | | N | Children in the treatment and control groups had similar<br><br>sociodemographic and health characteristics |
| | **Risk of bias judgement** | | | **Low** | |
| **Bias due to deviations from intended interventions** | 2.1.Were participants aware of their assigned intervention during the trial? | | | N | The children, teachers, and school officials were blinded to the status (active vs. sham) of the air cleaners in each classroom. |
| | 2.2.Were carers and people delivering the interventions aware of participants' assigned intervention during the trial? | | | N | |
| | 2.3. If Y/PY/NI to 2.1 or 2.2: Were there deviations from the intended intervention that arose because of the experimental context? | | | NA | |
| | 2.4 If Y/PY to 2.3: Were these deviations likely to have affected the | | | NA | |

| | | | |
|---|---|---|---|
| | outcome? | | |
| | 2.5. If Y/PY/NI to 2.4: Were these deviations from intended intervention balanced between groups? | NA | |
| | 2.6 Was an appropriate analysis used to estimate the effect of assignment to intervention? | Y | |
| | 2.7 If N/PN/NI to 2.6: Was there potential for a substantial impact (on the result) of the failure to analyse participants in the group to which they were randomized? | NA | |
| | **Risk of bias judgement** | **Low** | |
| **Bias due to missing outcome data** | 3.1 Were data for this outcome available for all, or nearly all, participants randomized? | PN | |
| | 3.2 If N/PN/NI to 3.1: Is there evidence that result was not biased by missing outcome data? | PN | |
| | 3.3 If N/PN to 3.2: Could missingness in the outcome depend on its true value? | PN | |
| | 3.4 If Y/PY/NI to 3.3: Is it likely that missingness in the outcome depended on its true value? | NA | |
| | **Risk of bias judgement** | **Low** | |
| **Bias in measurement of the outcome** | 4.1 Was the method of measuring the outcome inappropriate? | N | |
| | 4.2 Could measurement or ascertainment of the outcome have differed between intervention groups? | N | |
| | 4.3 Were outcome assessors aware of the intervention received by study participants? | Y | |
| | 4.4 If Y/PY/NI to 4.3: Could assessment of the outcome have been influenced by knowledge of intervention received? | N | |
| | 4.5 If Y/PY/NI to 4.4: Is it likely that assessment of the outcome was influenced by knowledge of intervention received? | NA | |
| | **Risk of bias judgement** | **Low** | |

| | | | |
|---|---|---|---|
| **Bias in selection of the reported result** | 5.1 Were the data that produced this result analysed in accordance with a pre-specified analysis plan that was finalized before unblinded outcome data were available for analysis? | Y | |
| | 5.2 ... multiple eligible outcome measurements (e.g. scales, definitions, time points) within the outcome domain? | N | |
| | 5.3 ... multiple eligible analyses of the data? | N | |
| | **Risk of bias judgement** | **Low** | |
| **Overall bias** | **Risk of bias judgement** | **Low** | |

| | | | | | |
|---|---|---|---|---|---|
| **Unique ID** | 2 | **Study ID** | Shao 2017 | **Assessor** | HJ Park, H Lee |
| **Ref or Label** | | **Aim** | assignment to intervention (the 'intention-to-treat' effect) | | |
| **Experimental** | Air filter | **Comparator** | Sham filter | **Source** | Journal article(s) with results of the trial |
| **Outcome** | FEV1 | **Results** | | **Weight** | 1 |
| **Domain** | **Signalling question** | | | **Response** | **Comments** |
| **Bias arising from the randomization process** | 1.1 Was the allocation sequence random? | | | Y | BIAPSY is a randomized cross-over intervention trial to investigate if the deployment of mobile air filtration units in private households can lead to reductions in indoor air pollution and to improve health.<br><br>No comment for blindness |
| | 1.2 Was the allocation sequence concealed until participants were enrolled and assigned to interventions? | | | NI | |
| | 1.3 Did baseline differences between intervention groups suggest a problem with the randomization process? | | | N | cross over study |
| | **Risk of bias judgement** | | | **Some concerns** | |
| **Bias due to** | 2.1.Were participants aware of their assigned intervention during the | | | N | |

| | | | |
|---|---|---|---|
| **deviations from intended interventions** | trial? | | |
| | 2.2.Were carers and people delivering the interventions aware of participants' assigned intervention during the trial? | N | |
| | 2.3. If Y/PY/NI to 2.1 or 2.2: Were there deviations from the intended intervention that arose because of the experimental context? | NA | |
| | 2.4 If Y/PY to 2.3: Were these deviations likely to have affected the outcome? | NA | |
| | 2.5. If Y/PY/NI to 2.4: Were these deviations from intended intervention balanced between groups? | NA | |
| | 2.6 Was an appropriate analysis used to estimate the effect of assignment to intervention? | Y | |
| | 2.7 If N/PN/NI to 2.6: Was there potential for a substantial impact (on the result) of the failure to analyse participants in the group to which they were randomized? | NA | |
| | **Risk of bias judgement** | **Some concerns** | This study did not consider the carry-over effect. If the patients used air filters for 2 weeks, they needed a wash-out period to diminish the effect of clean air. |
| **Bias due to missing outcome data** | 3.1 Were data for this outcome available for all, or nearly all, participants randomized? | Y | |
| | 3.2 If N/PN/NI to 3.1: Is there evidence that result was not biased by missing outcome data? | NA | |
| | 3.3 If N/PN to 3.2: Could missingness in the outcome depend on its true value? | NA | |
| | 3.4 If Y/PY/NI to 3.3: Is it likely that missingness in the outcome depended on its true value? | NA | |
| | **Risk of bias judgement** | **Low** | |
| **Bias in** | 4.1 Was the method of measuring the outcome inappropriate? | N | |
| | 4.2 Could measurement or ascertainment of the outcome have differed | N | |

| | | | |
|---|---|---|---|
| **measurement of the outcome** | between intervention groups? | | |
| | 4.3 Were outcome assessors aware of the intervention received by study participants? | PN | |
| | 4.4 If Y/PY/NI to 4.3: Could assessment of the outcome have been influenced by knowledge of intervention received? | NA | |
| | 4.5 If Y/PY/NI to 4.4: Is it likely that assessment of the outcome was influenced by knowledge of intervention received? | NA | |
| | **Risk of bias judgement** | **Low** | |
| **Bias in selection of the reported result** | 5.1 Were the data that produced this result analysed in accordance with a pre-specified analysis plan that was finalized before unblinded outcome data were available for analysis? | Y | |
| | 5.2 ... multiple eligible outcome measurements (e.g. scales, definitions, time points) within the outcome domain? | N | |
| | 5.3 ... multiple eligible analyses of the data? | N | |
| | **Risk of bias judgement** | **Low** | |
| **Overall bias** | **Risk of bias judgement** | **Some concerns** | |

| | | | | | |
|---|---|---|---|---|---|
| **Unique ID** | 3 | **Study ID** | Park 2017 | **Assessor** | HJ Park, H Lee |
| **Ref or Label** | | **Aim** | assignment to intervention (the 'intention-to-treat' effect) | | |
| **Experimental** | air filter | **Comparator** | no filter | **Source** | Journal article(s) with results of the trial |
| **Outcome** | asthma symptoms | **Results** | | **Weight** | 1 |

| **Domain** | **Signalling question** | **Response** | **Comments** |
|---|---|---|---|
| **Bias arising from the randomization process** | 1.1 Was the allocation sequence random? | N | The randomization was chosen by the investigators of the study |
| | 1.2 Was the allocation sequence concealed until participants were enrolled and assigned to interventions? | PY | |
| | 1.3 Did baseline differences between intervention groups suggest a problem with the randomization process? | N | |

| | Risk of bias judgement | Some concerns | |
|---|---|---|---|
| **Bias due to deviations from intended interventions** | 2.1.Were participants aware of their assigned intervention during the trial? | Y | |
| | 2.2.Were carers and people delivering the interventions aware of participants' assigned intervention during the trial? | Y | |
| | 2.3. If Y/PY/NI to 2.1 or 2.2: Were there deviations from the intended intervention that arose because of the experimental context? | PY | |
| | 2.4 If Y/PY to 2.3: Were these deviations likely to have affected the outcome? | PY | |
| | 2.5. If Y/PY/NI to 2.4: Were these deviations from intended intervention balanced between groups? | N | |
| | 2.6 Was an appropriate analysis used to estimate the effect of assignment to intervention? | PY | |
| | 2.7 If N/PN/NI to 2.6: Was there potential for a substantial impact (on the result) of the failure to analyse participants in the group to which they were randomized? | NA | |
| | **Risk of bias judgement** | **High** | |
| **Bias due to missing outcome data** | 3.1 Were data for this outcome available for all, or nearly all, participants randomized? | Y | |
| | 3.2 If N/PN/NI to 3.1: Is there evidence that result was not biased by missing outcome data? | NA | |
| | 3.3 If N/PN to 3.2: Could missingness in the outcome depend on its true value? | NA | |
| | 3.4 If Y/PY/NI to 3.3: Is it likely that missingness in the outcome depended on its true value? | NA | |
| | **Risk of bias judgement** | **Low** | |
| **Bias in** | 4.1 Was the method of measuring the outcome inappropriate? | N | |
| | 4.2 Could measurement or ascertainment of the outcome have differed | N | |

| | | | |
|---|---|---|---|
| **measurement of the outcome** | between intervention groups? | | |
| | 4.3 Were outcome assessors aware of the intervention received by study participants? | Y | |
| | 4.4 If Y/PY/NI to 4.3: Could assessment of the outcome have been influenced by knowledge of intervention received? | N | |
| | 4.5 If Y/PY/NI to 4.4: Is it likely that assessment of the outcome was influenced by knowledge of intervention received? | NA | |
| | **Risk of bias judgement** | **Low** | |
| **Bias in selection of the reported result** | 5.1 Were the data that produced this result analysed in accordance with a pre-specified analysis plan that was finalized before unblinded outcome data were available for analysis? | Y | |
| | 5.2 ... multiple eligible outcome measurements (e.g. scales, definitions, time points) within the outcome domain? | N | |
| | 5.3 ... multiple eligible analyses of the data? | N | |
| | **Risk of bias judgement** | **Low** | |
| **Overall bias** | **Risk of bias judgement** | **High** | |

| | | | | | |
|---|---|---|---|---|---|
| **Unique ID** | 4 | **Study ID** | Lanphear 2011 | **Assessor** | HJ Park, H Lee |
| **Ref or Label** | | **Aim** | assignment to intervention (the 'intention-to-treat' effect) | | |
| **Experimental** | air filter | **Comparator** | sham filter | **Source** | Journal article(s) with results of the trial |
| **Outcome** | asthma symptoms | **Results** | | **Weight** | 1 |

| **Domain** | **Signalling question** | **Response** | **Comments** |
|---|---|---|---|
| **Bias arising from the randomization process** | 1.1 Was the allocation sequence random? | Y | The Cincinnati Asthma Prevention Study was a randomized, double-blind |
| | 1.2 Was the allocation sequence concealed until participants were enrolled and assigned to interventions? | Y | |

| | | | |
|---|---|---|---|
| | | | Trial to test the effects of HEPA air cleaners<br><br>Children were assigned randomly to receive active HEPA air cleaners or inactive air cleaners. |
| | 1.3 Did baseline differences between intervention groups suggest a problem with the randomization process? | N | Allocation concealment was performed by using |
| | **Risk of bias judgement** | **Low** | |
| **Bias due to deviations from intended interventions** | 2.1.Were participants aware of their assigned intervention during the trial? | N | Double-blind<br><br>All of the investigators, research staff members, and participants were masked to group assignment until the end of the trial, except for the biostatistician (Dr Hornung), who was responsible for random permutation of the air cleaners<br>by using serial numbers. |
| | 2.2.Were carers and people delivering the interventions aware of participants' assigned intervention during the trial? | N | |
| | 2.3. If Y/PY/NI to 2.1 or 2.2: Were there deviations from the intended intervention that arose because of the experimental context? | NA | |
| | 2.4 If Y/PY to 2.3: Were these deviations likely to have affected the outcome? | NA | |
| | 2.5. If Y/PY/NI to 2.4: Were these deviations from intended intervention balanced between groups? | NA | |
| | 2.6 Was an appropriate analysis used to estimate the effect of assignment | Y | |

| | | | |
|---|---|---|---|
| | to intervention? | | |
| | 2.7 If N/PN/NI to 2.6: Was there potential for a substantial impact (on the result) of the failure to analyse participants in the group to which they were randomized? | NA | |
| | **Risk of bias judgement** | **Low** | |
| **Bias due to missing outcome data** | 3.1 Were data for this outcome available for all, or nearly all, participants randomized? | Y | |
| | 3.2 If N/PN/NI to 3.1: Is there evidence that result was not biased by missing outcome data? | NA | |
| | 3.3 If N/PN to 3.2: Could missingness in the outcome depend on its true value? | NA | |
| | 3.4 If Y/PY/NI to 3.3: Is it likely that missingness in the outcome depended on its true value? | NA | |
| | **Risk of bias judgement** | **Low** | |
| **Bias in measurement of the outcome** | 4.1 Was the method of measuring the outcome inappropriate? | N | |
| | 4.2 Could measurement or ascertainment of the outcome have differed between intervention groups? | N | |
| | 4.3 Were outcome assessors aware of the intervention received by study participants? | N | |
| | 4.4 If Y/PY/NI to 4.3: Could assessment of the outcome have been influenced by knowledge of intervention received? | NA | |
| | 4.5 If Y/PY/NI to 4.4: Is it likely that assessment of the outcome was influenced by knowledge of intervention received? | NA | |
| | **Risk of bias judgement** | **Low** | |
| **Bias in selection of the reported result** | 5.1 Were the data that produced this result analysed in accordance with a pre-specified analysis plan that was finalized before unblinded outcome data were available for analysis? | Y | |
| | 5.2 ... multiple eligible outcome measurements (e.g. scales, definitions, | N | |

| | | | |
|---|---|---|---|
| | time points) within the outcome domain? | | |
| | 5.3 ... multiple eligible analyses of the data? | N | |
| | **Risk of bias judgement** | **Low** | |
| **Overall bias** | **Risk of bias judgement** | **Low** | |

| | | | | | |
|---|---|---|---|---|---|
| **Unique ID** | 5 | **Study ID** | Eggleston et al 2005 | **Assessor** | HJ Park, H Lee |
| **Ref or Label** | | **Aim** | assignment to intervention (the 'intention-to-treat' effect) | | |
| **Experimental** | Air filter | **Comparator** | no filter | **Source** | Journal article(s) with results of the trial |
| **Outcome** | asthma symptoms/FEV1 | **Results** | | **Weight** | 1 |
| **Domain** | **Signalling question** | | | **Response** | **Comments** |
| **Bias arising from the randomization process** | 1.1 Was the allocation sequence random? | | | Y | Families were randomized to the treatment group, which received intervention immediately, or to the control group, which received the intervention at the end of the study.<br>The study treatment assignment was not blinded because it included a large behavioral component that could not be masked. |
| | 1.2 Was the allocation sequence concealed until participants were enrolled and assigned to interventions? | | | N | |
| | 1.3 Did baseline differences between intervention groups suggest a problem with the randomization process? | | | N | |
| | **Risk of bias judgement** | | | **High** | |
| **Bias due to deviations from intended interventions** | 2.1.Were participants aware of their assigned intervention during the trial? | | | Y | |
| | 2.2.Were carers and people delivering the interventions aware of participants' assigned intervention during the trial? | | | Y | |
| | 2.3. If Y/PY/NI to 2.1 or 2.2: Were there deviations from the intended | | | PY | |

| | | | |
|---|---|---|---|
| | intervention that arose because of the experimental context? | | |
| | 2.4 If Y/PY to 2.3: Were these deviations likely to have affected the outcome? | PY | |
| | 2.5. If Y/PY/NI to 2.4: Were these deviations from intended intervention balanced between groups? | N | |
| | 2.6 Was an appropriate analysis used to estimate the effect of assignment to intervention? | Y | |
| | 2.7 If N/PN/NI to 2.6: Was there potential for a substantial impact (on the result) of the failure to analyse participants in the group to which they were randomized? | NA | |
| | **Risk of bias judgement** | **High** | |
| **Bias due to missing outcome data** | 3.1 Were data for this outcome available for all, or nearly all, participants randomized? | Y | |
| | 3.2 If N/PN/NI to 3.1: Is there evidence that result was not biased by missing outcome data? | NA | |
| | 3.3 If N/PN to 3.2: Could missingness in the outcome depend on its true value? | NA | |
| | 3.4 If Y/PY/NI to 3.3: Is it likely that missingness in the outcome depended on its true value? | NA | |
| | **Risk of bias judgement** | **Low** | |
| **Bias in measurement of the outcome** | 4.1 Was the method of measuring the outcome inappropriate? | N | |
| | 4.2 Could measurement or ascertainment of the outcome have differed between intervention groups? | N | |
| | 4.3 Were outcome assessors aware of the intervention received by study participants? | Y | |
| | 4.4 If Y/PY/NI to 4.3: Could assessment of the outcome have been influenced by knowledge of intervention received? | N | |
| | 4.5 If Y/PY/NI to 4.4: Is it likely that assessment of the outcome was | NA | |

| | | | |
|---|---|---|---|
| | influenced by knowledge of intervention received? | | |
| | **Risk of bias judgement** | **Low** | |
| **Bias in selection of the reported result** | 5.1 Were the data that produced this result analysed in accordance with a pre-specified analysis plan that was finalized before unblinded outcome data were available for analysis? | Y | |
| | 5.2 ... multiple eligible outcome measurements (e.g. scales, definitions, time points) within the outcome domain? | N | |
| | 5.3 ... multiple eligible analyses of the data? | N | |
| | **Risk of bias judgement** | **Low** | |
| **Overall bias** | **Risk of bias judgement** | **High** | |

| | | | | | |
|---|---|---|---|---|---|
| **Unique ID** | 6 | **Study ID** | Butz 2011 | **Assessor** | HJ Park, H Lee |
| **Ref or Label** | | **Aim** | assignment to intervention (the 'intention-to-treat' effect) | | |
| **Experimental** | Air filter | **Comparator** | no filter | **Source** | Journal article(s) with results of the trial |
| **Outcome** | asthma symptoms | **Results** | | **Weight** | 1 |

| **Domain** | **Signalling question** | **Response** | **Comments** |
|---|---|---|---|
| **Bias arising from the randomization process** | 1.1 Was the allocation sequence random? | Y | In this randomized 3-arm controlled trial, randomization was performed by the study coordinator who activated a randomization function embedded in the study database.<br>All study staff, including all investigators, were blinded to subsequent group assignments. |
| | 1.2 Was the allocation sequence concealed until participants were enrolled and assigned to interventions? | PY | |
| | 1.3 Did baseline differences between intervention groups suggest a problem with the randomization process? | N | |
| | **Risk of bias judgement** | **Low** | |
| **Bias due to** | 2.1.Were participants aware of their assigned intervention during the | Y | |

| | | | |
|---|---|---|---|
| **deviations from intended interventions** | trial? | | |
| | 2.2.Were carers and people delivering the interventions aware of participants' assigned intervention during the trial? | Y | |
| | 2.3. If Y/PY/NI to 2.1 or 2.2: Were there deviations from the intended intervention that arose because of the experimental context? | PY | |
| | 2.4 If Y/PY to 2.3: Were these deviations likely to have affected the outcome? | PY | |
| | 2.5. If Y/PY/NI to 2.4: Were these deviations from intended intervention balanced between groups? | N | |
| | 2.6 Was an appropriate analysis used to estimate the effect of assignment to intervention? | Y | |
| | 2.7 If N/PN/NI to 2.6: Was there potential for a substantial impact (on the result) of the failure to analyse participants in the group to which they were randomized? | NA | |
| | **Risk of bias judgement** | **High** | |
| **Bias due to missing outcome data** | 3.1 Were data for this outcome available for all, or nearly all, participants randomized? | PY | |
| | 3.2 If N/PN/NI to 3.1: Is there evidence that result was not biased by missing outcome data? | NA | |
| | 3.3 If N/PN to 3.2: Could missingness in the outcome depend on its true value? | NA | |
| | 3.4 If Y/PY/NI to 3.3: Is it likely that missingness in the outcome depended on its true value? | NA | |
| | **Risk of bias judgement** | **Low** | |
| **Bias in measurement of the outcome** | 4.1 Was the method of measuring the outcome inappropriate? | N | |
| | 4.2 Could measurement or ascertainment of the outcome have differed between intervention groups? | N | |
| | 4.3 Were outcome assessors aware of the intervention received by study | Y | |

| | | | |
|---|---|---|---|
| | participants? | | |
| | 4.4 If Y/PY/NI to 4.3: Could assessment of the outcome have been influenced by knowledge of intervention received? | PY | |
| | 4.5 If Y/PY/NI to 4.4: Is it likely that assessment of the outcome was influenced by knowledge of intervention received? | PY | |
| | **Risk of bias judgement** | **Low** | |
| **Bias in selection of the reported result** | 5.1 Were the data that produced this result analysed in accordance with a pre-specified analysis plan that was finalized before unblinded outcome data were available for analysis? | Y | |
| | 5.2 ... multiple eligible outcome measurements (e.g. scales, definitions, time points) within the outcome domain? | N | |
| | 5.3 ... multiple eligible analyses of the data? | N | |
| | **Risk of bias judgement** | **Low** | |
| **Overall bias** | **Risk of bias judgement** | **High** | |

| | | | | | |
|---|---|---|---|---|---|
| **Unique ID** | 7 | **Study ID** | Noonan 2017 | **Assessor** | HJ Park, H Lee |
| **Ref or Label** | | **Aim** | assignment to intervention (the 'intention-to-treat' effect) | | |
| **Experimental** | Air filter | **Comparator** | sham filter | **Source** | Journal article(s) with results of the trial |
| **Outcome** | asthma symptoms/FEV1 | **Results** | | **Weight** | 1 |
| **Domain** | **Signalling question** | | | **Response** | **Comments** |
| **Bias arising from the randomization process** | 1.1 Was the allocation sequence random? | | | Y | ARTIS was a three-arm randomized placebo-controlled intervention trial with two intervention strategies for reducing in-home woodsmoke PM. |
| | 1.2 Was the allocation sequence concealed until participants were enrolled and assigned to interventions? | | | PY | |
| | 1.3 Did baseline differences between intervention groups suggest a problem with the randomization process? | | | N | |
| | **Risk of bias judgement** | | | **Low** | |
| **Bias due to** | 2.1.Were participants aware of their assigned intervention during the | | | Y | This blinding was not possible for the homes |

| | | | |
|---|---|---|---|
| **deviations from intended interventions** | trial? | | receiving the woodstove intervention. |
| | 2.2.Were carers and people delivering the interventions aware of participants' assigned intervention during the trial? | Y | Moreover, field staff responsible for collecting exposure and health data were not blinded. |
| | 2.3. If Y/PY/NI to 2.1 or 2.2: Were there deviations from the intended intervention that arose because of the experimental context? | N | |
| | 2.4 If Y/PY to 2.3: Were these deviations likely to have affected the outcome? | NA | |
| | 2.5. If Y/PY/NI to 2.4: Were these deviations from intended intervention balanced between groups? | NA | |
| | 2.6 Was an appropriate analysis used to estimate the effect of assignment to intervention? | Y | |
| | 2.7 If N/PN/NI to 2.6: Was there potential for a substantial impact (on the result) of the failure to analyse participants in the group to which they were randomized? | NA | |
| | **Risk of bias judgement** | **Low** | |
| **Bias due to missing outcome data** | 3.1 Were data for this outcome available for all, or nearly all, participants randomized? | Y | |
| | 3.2 If N/PN/NI to 3.1: Is there evidence that result was not biased by missing outcome data? | NA | |
| | 3.3 If N/PN to 3.2: Could missingness in the outcome depend on its true value? | NA | |
| | 3.4 If Y/PY/NI to 3.3: Is it likely that missingness in the outcome depended on its true value? | NA | |
| | **Risk of bias judgement** | **Low** | |
| **Bias in measurement of** | 4.1 Was the method of measuring the outcome inappropriate? | N | |
| | 4.2 Could measurement or ascertainment of the outcome have differed between intervention groups? | N | |

| | | | |
|---|---|---|---|
| **the outcome** | 4.3 Were outcome assessors aware of the intervention received by study participants? | PN | |
| | 4.4 If Y/PY/NI to 4.3: Could assessment of the outcome have been influenced by knowledge of intervention received? | NA | |
| | 4.5 If Y/PY/NI to 4.4: Is it likely that assessment of the outcome was influenced by knowledge of intervention received? | NA | |
| | **Risk of bias judgement** | **Low** | |
| **Bias in selection of the reported result** | 5.1 Were the data that produced this result analysed in accordance with a pre-specified analysis plan that was finalized before unblinded outcome data were available for analysis? | Y | |
| | 5.2 ... multiple eligible outcome measurements (e.g. scales, definitions, time points) within the outcome domain? | N | |
| | 5.3 ... multiple eligible analyses of the data? | N | |
| | **Risk of bias judgement** | **Low** | |
| **Overall bias** | **Risk of bias judgement** | **Low** | |

FEV1, forced expiratory volume in one second; HEPA, high-efficiency particulate air; NA, not applicable; Y, yes; N, no; PY, probably yes; NI, no information; PM, particulate matter.

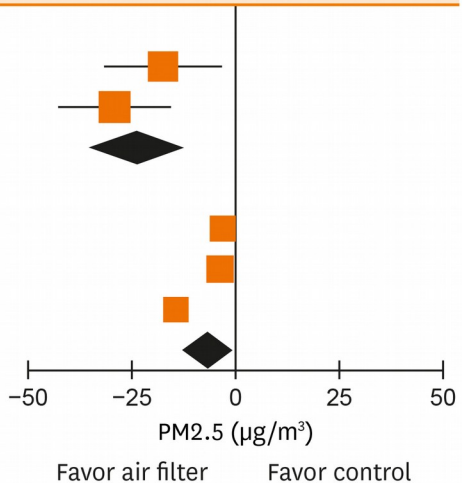
**Supplementary Table S3.** Air cleaners used in each study

| References | Air cleaner | Efficacy of the filter in reducing PM2.5 |
|---|---|---|
| Jhun *et al.*[27] | AP-1013A; Coway, Seoul, Korea | 99.98% |
| Park *et al.*[14] | Model AX9000 and AX7000; Samsung, Suwon, Korea | 99.95% |
| Noonan *et al.*[15] | FAP02-RS model 3M Filtrete; 3M, St. Paul, MN, USA | 99.90% |
| Eggleston *et al.*[25] | Holmes Products Inc., Milford, MA, USA | HEPA filter model not specified |
| Butz *et al.*[24] | Holmes Harmony Air Purifier HAP650; Holmes Products Inc., Milford, MA, USA | 99.97% |
| Lanphear *et al.*[26] | Austin Healthmate, Buffalo, NY, USA | 99.00% |
| Shao *et al.*[18] | AC4374 and AC4016; Philips Lifestyle Ltd., Amsterdam, Netherlands (HEPA and activated carbon filter) | HEPA filter model not specified |

PM, particulate matter; HEPA, high-efficiency particulate air.

**Supplementary Fig. S1. Forest plot of the effect of air filters on PM reduction according to baseline concentration.**

| Study or subgroup | Statistics for each study | | | *P*-value |
|---|---|---|---|---|
| | Difference in means | Lower limit | Upper limit | |
| Heavily polluted | | | | |
| Eggleston *et al.* (2005)[25] | −14.000 | −25.371 | −2.629 | 0.016 |
| Butz *et al.* (2011)[24] | −23.400 | −34.195 | −12.605 | 0.000 |
| | −18.877 | −28.082 | −9.671 | 0.000 |
| Less polluted | | | | |
| Jhun *et al.* (2017)[27] | −2.400 | −3.103 | −1.697 | 0.000 |
| Park *et al.* (2017)[15] | −3.080 | −4.243 | −1.917 | 0.000 |
| Noonan *et al.* (2017)[14] | −11.457 | −13.144 | −9.770 | 0.000 |
| | −5.583 | −10.072 | −1.094 | 0.015 |

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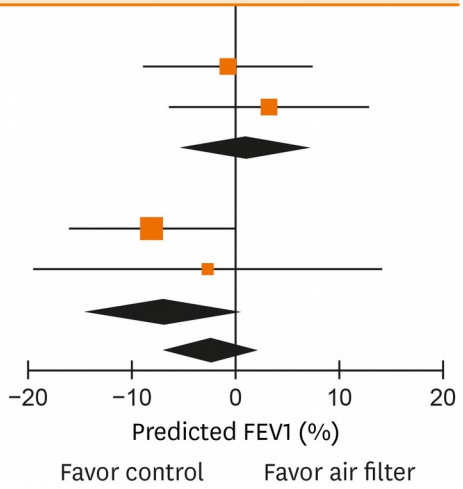
**Supplementary Fig. S2. Forest plot of the effect of air filters on FEV1 according to the duration of follow-up.**

| Study or subgroup | Statistics for each study | | | *P*-value |
|---|---|---|---|---|
| | Difference in means | Lower limit | Upper limit | |
| < 6 months | | | | |
| Noonan *et al.* (2017)[14] | −0.710 | −8.800 | 7.380 | 0.863 |
| Jhun *et al.* (2017)[27] | 3.250 | −6.393 | 12.893 | 0.509 |
| | 0.926 | −5.272 | 7.123 | 0.770 |
| 12 months | | | | |
| Eggleston *et al.* (2005)[25] | −8.000 | −16.043 | 0.043 | 0.051 |
| Jhun *et al.* (2017)[27] | −2.663 | −19.421 | 14.096 | 0.756 |
| | −7.001 | −14.252 | 0.250 | 0.058 |
| **Overall** | **−2.420** | **−7.132** | **2.291** | **0.314** |

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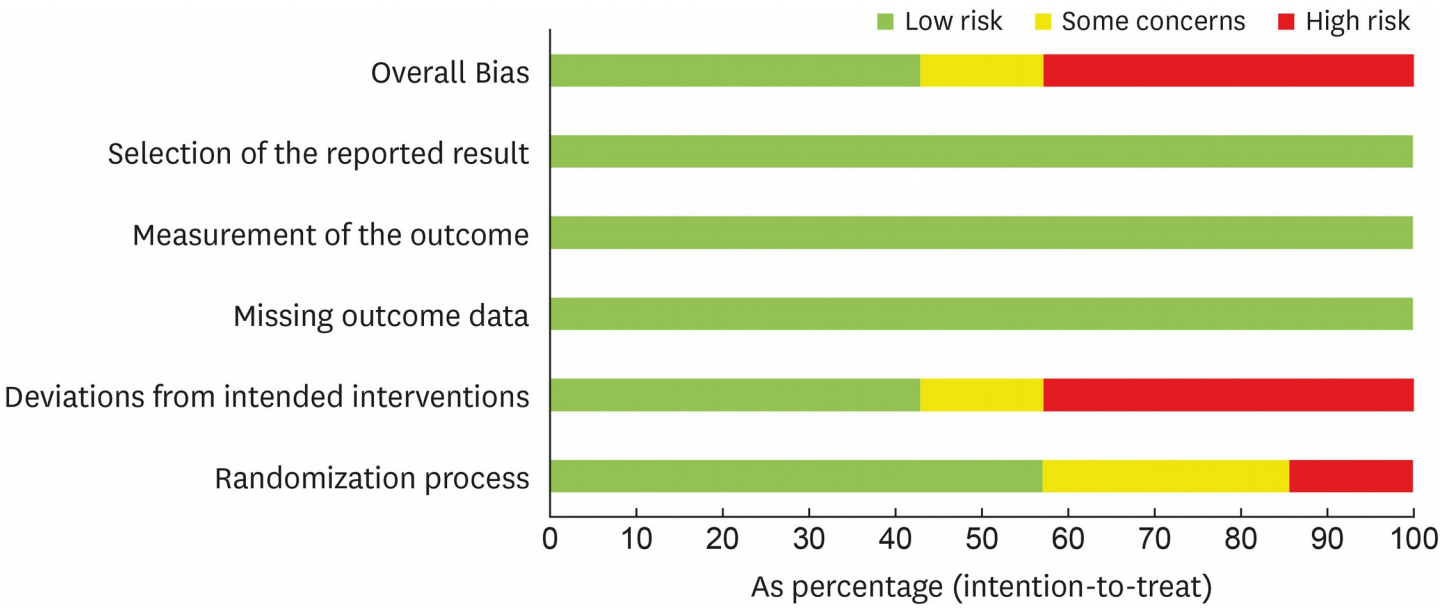
**Supplementary Fig. S3. Bar graph presenting the risk of each bias item as percentages across all included studies.**

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