The effect of particulate matter reduction by indoor air filter use on respiratory symptoms and lung function: A systemic review and meta-analysis

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Research

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Abstract

Background

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-studied interventions, and respiratory outcomes in patients with chronic respiratory disease.

Methods

We systemically reviewed intervention studies on PM using Pubmed, EMBASE, and Cochrane databases up to September 2019. Studies that included data on PM level 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

Seven studies were included in our study. Air filter use reduced indoor $PM_{2.5}$ by 11.45 μg/m^3 (95% confidence interval [CI]: 6.88–16.01 μg/m^3). Air filter use improved predicted forced expiratory volume in one second (FEV_1) by 3.60% (95% CI: 0.29–6.90%). Air filter use was not associated with a significant change in respiratory symptoms (odds ratio: 0.82; 95% CI: 0.62–1.08).

Conclusion

The findings from this systematic review suggest that a role for air filter with respect to reduced indoor PM and increased lung function. Further studies in high density PM regions may provide additional information on this role.

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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 $PM_{2.5}$ concentration continues to increase annually, mainly due to the contribution of developing countries, particularly East Asia (6).

As an increased level of PM is considered to aggravate respiratory diseases by decreasing lung function (7) and exacerbating respiratory symptoms (8), effective interventions are required. A national reduction in $PM_{2.5}$ concentration was shown to be associated with reduced mortality risk (9, 10). At an individual level, most studies evaluated the use of air filters. Morishita et al. demonstrated that indoor air filtration may improve cardiovascular health outcomes (11). 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. 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 (13). 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 levels, 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 systemic review and meta-analysis to determine the effect of reducing PM through the use of air filters on patients with chronic respiratory diseases.

Methods

Search strategy and selection criteria

A systematic search of the PubMed, EMBASE, and Cochrane databases was performed to identify studies of 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 “$PM_{2.5}$” 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 of our search strategy is provided in Supplementary Appendix 1. 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 of this meta-analysis. (17) (Supplement Table 1) Following the PRISMA guidelines, article titles and abstracts were extracted (CH Suh) and reviewed independently by two researchers (HJ Park, HY Lee) to include intervention studies. The full text was evaluated, and the inclusion criteria were applied; any disagreement was resolved by another researcher (SW Lee). 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 trial and randomized cross-over study; 3) air filter should be filtering more than 99% of particles which is greater than 0.3 μm; 4) they were published in a peer-reviewed journal in English; 5) they were conducted in patients diagnosed with a chronic respiratory diseases including asthma, COPD interstitial lung disease and bronchiectasis. Quality assessment of the studies was performed by two researchers (HJ Park, HY Lee). When a duplicate publication of the same trial was identified, the study with the most complete, recent, and updated report was included.

Table 1
Characteristics of studies evaluating the effect of air filter use on respiratory disease

References	Study design	N	Duration of follow-up	Population	Mean $PM_{2.5}$ density pre-intervention	Location	Intervention/Comparison	Outcomes
Jhun 2017 (25)	Double-blind RCT	25	6 months	Asthma	6.2 μg/m^3	Northeastern USA	Air filter/Sham filter	Self-reporting asthma symptoms, lung function (FEV_1)
Park 2017 (15)	Randomized case-control	16	3 months	Asthma	7.42 μg/m^3	Fresco, California, USA	Air filter/Sham filter	Childhood ACT score, lung function (PEF)
Noonan 2017 (14)	Randomized case-control	92	2 weeks	Asthma	17.1 μg/m^3	Montana, Idaho, and Alaska, USA	Air filter/No filter	PAQLQ score, lung function (FEV_1, PEF)
Eggleston 2005 (24)	Randomized case-control	100	12 months	Asthma	38.0 μg/m^3	Baltimore, Maryland, USA	Air filter/No filter	Self-reporting asthma symptoms, lung function (FEV_1)
Butz 2011 (23)	Randomized case-control	123	6 months	Asthma	39.5 μg/m^3	Baltimore, Maryland, USA	Air filter/No filter (with education)	Self-reporting asthma symptoms
Lanphear 2011 (26)	Double-blind RCT	225	12 months	Asthma	4.0 × 10^6/ft^3 (number of particles)	Cincinnati, Ohio, USA	Air filter/Sham filter	Asthma symptoms assessed with Child Health Asthma Survey
Shao 2017 (27)	Randomized cross-over	20	2 weeks	COPD	60.0 μg/m^3	Beijing, China	Air filter/Sham filter	Lung function (FEV_1), inflammation marker, blood pressure

ACT, asthma-control test; COPD, chronic obstructive pulmonary disease; FEV_1, forced expiratory volume in the first second; PAQLQ, pediatric asthma quality of life questionnaire; PEF, peak expiratory flow; RCT, randomized, controlled trial.

Data extraction

The study design, location, sample size, population size, study characteristics, PM concentration, spirometry, and clinical outcomes were extracted from each study. All of the estimates were calculated by Comprehensive Meta-Analysis, version 3 (Biostat, Englewood, NJ, USA). If the estimates of a study were presented in figures without specific descriptions in the text, the investigators were contacted to obtain the relevant estimates. If no response was received after three emails, the articles were excluded from the quantitative analysis, but data that could be extracted from any accompanying graphs were included.

For the case-crossover studies, if the observation period was less than 3 months, the last value of effect was extracted to compare among the studies. Included studies used different criteria for estimating symptoms of asthma. (Supplement Table 2) Therefore, if the estimates of respiratory symptoms were reported separately, we pooled the estimates in each study and compared the estimates with other respiratory outcomes.

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 (18). 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 five components: randomization process, deviation from intended interventions, missing outcomes data, measurement of the outcome, and selection of the reported result. In a randomized cross-over trial, additional consideration was used in the risk of bias tool 2.0. Where bias was due to deviation from the intended intervention, the tool included an additional consideration regarding carry-over effect, which remains from the previous experimental condition.

Statistical analysis

All statistical analyses were carried out using Comprehensive Meta-Analysis, version 3. The metric of the analysis for primary outcome was clarified as follows: reduced PM (effect measure: difference in means), change of symptoms (effect measure: odds ratio), changed forced expiratory volume in 1 second (FEV_1, effect measure: differences in mean values).

Heterogeneity among studies was estimated using the I^2-based Cochrane Q test. I^2 values of 25%, 50%, and 75% were considered to represent low, moderate, and high heterogeneity, respectively (19). 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 (19). To assess publication bias, funnel plots and Egger’s weighted linear regression results were reviewed visually (20). Where statistically significant publication bias was present, the “trim and fill” approach was employed to obtain an unbiased summary effect estimate (21). Given that the Egger’s test may be underpowered in meta-analyses with a low number of studies (22), 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 1,522 related articles; 229 duplicates were removed. Among the remaining 1,293 articles, 1,220 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 study (n = 18), interventions other than air filter (n = 30), no respiratory outcomes (n = 8), or abstract only (n = 9).

Of the seven eligible studies, six were randomized controlled trials (14, 15, 23–26) and one was a randomized cross-over study (27). The study population included asthmatics (14, 15, 23–26) and patients with COPD (27); the study about interstitial lung disease or bronchiectasis was not identified. Six of the identified studies were conducted in North America (14, 15, 23–26); the remaining study was conducted in Beijing, China (27).

The mean density of baseline indoor $PM_{2.5}$ ranged from 6.2 to 60.0 $\mu g/m^3$ (Table 1).

Effect of air filters on particulate matter

The studies had differing baseline PM concentrations and sequestrating effect of air filters. Therefore, the pooled estimate was calculated with an absolute difference in means. Five of included studies (15, 23, 25, 26, 28) used high-efficiency particulate air (HEPA) filter which can eliminate PM 2.5 more than 99.9% and two of included studies did not describe a filter model (24, 27) (Supplement Table 3). All enrolled studies reported that air filers resulted in a significant reduction in $PM_{2.5}$ (Fig. 2). When studies were categorized by baseline $PM_{2.5}$ concentration, the analysis showed that the higher the baseline concentration, the greater the $PM_{2.5}$ reduction, with the exception of one study

that used different measures 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 $PM_{2.5}$ of -11.45 μg/m^3 (95% confidence interval [CI]: -16.02 to -6.88 ug/m^3) with the use of an air filter. There was a high level of heterogeneity (I^2 = 96.63%) among the enrolled studies, and statistical evidence of publication bias was present (Egger's regression test; p = 0.04). The trim and fill method identified two unpublished studies and yielded an unbiased estimate of a change in $PM_{2.5}$ of -5.59 μg/m^3 (95% CI: -9.98 to -1.29 ug/m^3) with the use of air filters.

Two studies (23, 24) showed the cleaning effect of air filters on PM_{10}. A random-effects model yielded a pooled estimate of the absolute difference in PM_{10} of -15.01 μg/m^3 (95% CI: -24.95 to -5.06 μg/m^3) with the use of air filters. These two 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 intervention by air filter use. (14, 15, 23–26) Although a low heterogeneity was noted (I^2 = 22.03%, p = 0.268), the random-effects model was used because of the heterogeneity of the baseline concentrations and absolute differences in PM which had different effects on asthma symptoms. The random-effects model yielded a pooled estimate of an odds ratio in symptom change of 0.82 (95% CI: 0.62–1.08) with the use of air filters (Fig. 3). There was statistically significant evidence of publication bias (Egger's regression test; p = 0.02). The trim and fill method identified three unpublished studies and yielded an unbiased estimate of an odds ratio in symptom change of 0.93 (95% CI: 0.69–1.26) associated with the use of air filters. The effect of air filter use was also analyzed based on the period of usage, but this analysis showed no notable effect on symptom change (Supplementary Fig. 1).

Effect of air filter use on lung function

Four studies analyzed the change in FEV_1 after air filter intervention (14, 24, 25, 27). A random-effects model yielded a pooled estimate of change in predicted FEV_1 of 3.60% (95% CI: 0.29–6.90%; Fig. 4). I^2 was 0.0, indicating no statistically significant heterogeneity among the studies, and no differences in the pooled estimates between random and fixed models were seen. No evidence of publication bias was observed (Egger's regression test; p = 0.41). The pooled estimate was greater when there was a longer duration of air filter use (absolute difference in means: 6.54% [95% CI: -0.32–13.38%] for 12 months vs. 2.70% [95% CI: -0.93–6.33%] for ≤ 6 months), although this difference did not reach statistical significance (Supplementary Fig. 2).

Quality assessment and sensitivity analysis

Three studies were judged to have a low risk of bias (14, 25, 26), two raised some concerns, (15, 27). Risk of bias in included studies were described in Supplement Table 4. Two studies compared the groups with and without air filter intervention (24, 29). These studies had a high risk of bias for respiratory symptoms (Fig. 5). With the exception of these two studies, pooled estimates of respiratory symptoms showed no statistically significant change. One study had a high risk of bias for lung function (24), and excluding this study also showed no statistically significant changes in lung function.

Discussion

In this 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 $PM_{2.5}$, and that a higher baseline PM concentration was associated with greater reductions. PM reduction improved predicted FEV_1, but showed no significant effect on respiratory symptoms. No study about other respiratory diseases such as interstitial lung disease or bronchiectasis was founded in our searching strategy.

Although two studies showed significant changes in respiratory symptoms with air filter use, (15, 24) the remaining studies showed no statistically significant improvement, and the pooled estimate failed to reach statistical significance in this review. Previous meta-analyses have shown that short-term exposure to $PM_{2.5}$ could aggravate respiratory symptoms and reduce peak expiratory flow in patients with COPD (8) and asthma (8, 30). The odds ratio of the respiratory symptoms was 1.22–1.57 with a 50 μg/m^3 increase in $PM_{2.5}$, depending on the model used (8). The baseline concentration of $PM_{2.5}$ (6.2–39.5 μg/m^3) was relatively low in the studies evaluated here (14, 15, 24–26, 29), and the pooled change in $PM_{2.5}$ was − 11.45 μg/m^3. A minimal reduction in PM due to low baseline levels may have influenced the results and caused the lack of statistical significance. The measure of respiratory symptoms was differing between studies (14, 15, 24–26) such as from cough to emotional function. The previous systemic review (8) used cough and wheeze as measure of respiratory symptoms. However, for the estimates of respiratory symptoms as a whole asthma status in this review, there is no significant change by using air filters.

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 (31, 32) evaluated the effect of long-term PM (decades of year) exposure on respiratory symptoms. The current study evaluates the effect of PM reduction (less than 6 weeks to 12 months) in various periods. In subgroup analysis, however, there was no tendency or significant difference in respiratory symptoms by the duration of air filter use (Supplementary Fig. 1).

Edginton et al. reviewed the effect of PM on FEV_1 in healthy adults (33). Short-term exposure (over several days) resulted in FEV_1 changes of -7.02 mL with an increase of 10 μg/m^3 $PM_{2.5}$. Gauderman et al. (34) evaluated the effect of PM on lung development in adolescents over an 8 year period and showed that high $PM_{2.5}$ concentration could reduce lung growth, measured by FEV_1 and FVC. In another study, long-term exposure to $PM_{2.5}$ reduced FEV_1 by 0.24% each year (35). Our data support the previous exposure studies and suggest that reducing PM can improve lung development in polluted areas. Subgroup analysis showed that longer duration of use (1 year) had a greater effect on FEV_1 than shorter duration of use (less than 6 months), although these results were not statistically significant. A greater number of studies with an observation period of more than 6 months is required to confirm the significance of these data.

Other interventions can ameliorate the adverse effect of PM, such as facial mask, omega-3, and vitamin D. A facial mask is an easy way to avoid exposure to PM, and Langrish et al. demonstrated that the use of facial masks in healthy subjects exposed to PM results in lower systolic blood pressure than in those without facial masks (36). During the study period, the concentration of $PM_{2.5}$ 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 (27, 36, 37), even when considering the confounding effect of traffic noise (38). However, the observation period of the studies was just a few weeks and none of the studies showed the effect on respiratory outcomes such as lung function and symptom. In one review article, omega-3 oil was shown to have an anti-inflammation effect and reduced asthma symptoms (39). Brigham et al. (40) demonstrated a correlation between omega-3 intake and $PM_{2.5}$, and showed a marginal effect in reducing respiratory symptoms in children with asthma. Vitamin D is also reported to help control asthma. (39) Bose et al. demonstrated that a decreased level of vitamin D in obese children with asthma is associated with a higher level of symptoms following a 10 unit increase in $PM_{2.5}$. (41) However, these studies were observational study 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, the studies included in this analysis were primarily conducted in the USA, where PM concentration is relatively low. It is possible that studies conducted in areas of high PM concentration may have shown a greater effect with air filter use. Second, some studies (23, 24) may have deviated from the intended intervention to allow comparison with a control group (Supplementary Fig. 3). Third, since evaluating respiratory symptoms are easy to be affected by a placebo effect, some of the subjects in studies (23, 24) might favor reporting their symptoms when they are using an air filter. However, there was no tendency to see high estimates in these groups so that the result of respiratory symptom is free from this bias.

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 baseline PM concentration, air filter use duration, and study design.

In conclusion, indoor air filter use successfully reduced indoor PM levels, and this reduction had a beneficial effect on lung function in patients with chronic respiratory disease including asthma and COPD. Further studies of varying duration are required in areas of high PM concentration to confirm these observations.

Abbreviations

CI
confidence interval
COPD
chronic obstructive pulmonary disease
FEV_1
forced expiratory volume in the first second
FVC
forced vital capacity
HEPA
high-efficiency particulate air
ILD
interstitial lung disease

PM
particulate matter
$PM_{2.5}$
particulate matter that has a diameter < 2.5 micrometers
PM_{10}
particulate matter that has a diameter < 10 micrometers

Declarations

Ethical Approval and Consent to participate

This study is a meta-analysis of anonymized data in the public domain, so that there is no chance for a person's private medical information to leak. Therefore, ethical approval is waived in this study.

Consent for publication

Not applicable

Availability of supporting data

All data in this study can be accessed with searching in PubMed, Cochrane, Embase. Specific requests to access the estimate data can be sent to iseiwon@gmail.com

Competing interest

The authors declare no competing interest. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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Author Contribution

Hyung Jun Park: Data Curation, Software, Data Curation, Writing. Ho Young Lee: Data Curation, Investigation. Chong Hyun Suh: Methodology Ho Cheol Kim: Investication, Supervision. Hwan Cheol Kim, Young-Jun Park: supervision Sei Won Lee: Conceptualization, Writing- Review and editing

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None

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Figures

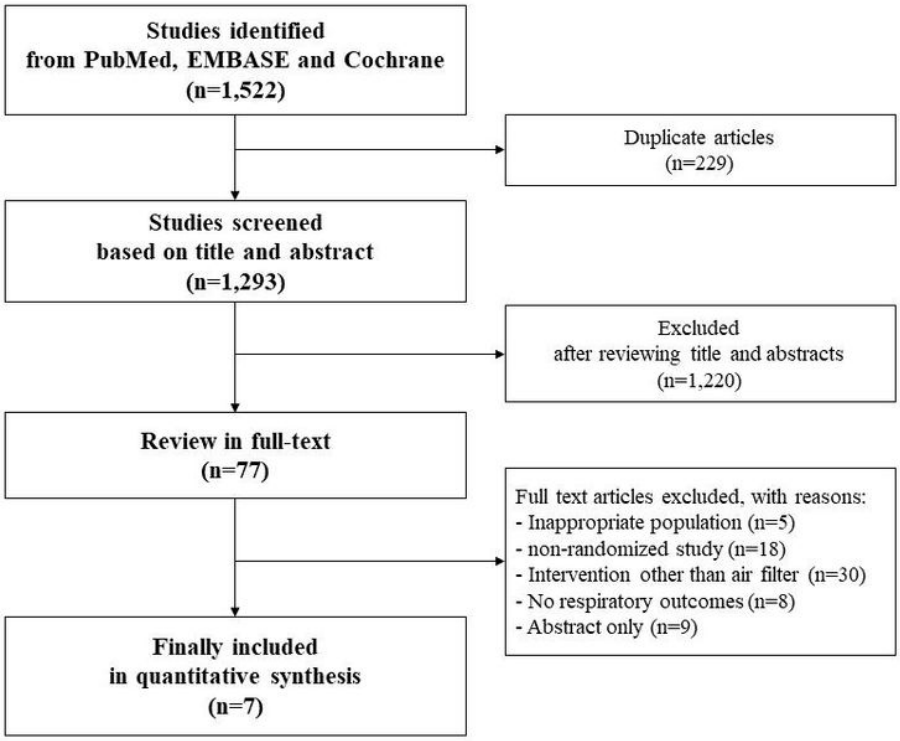
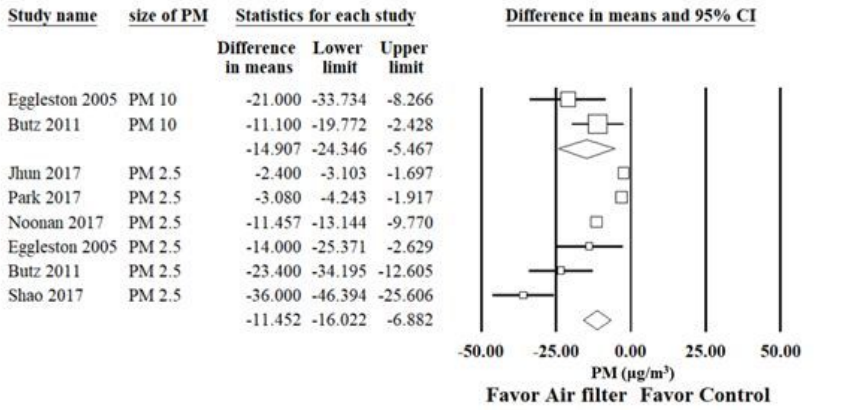


Figure 1

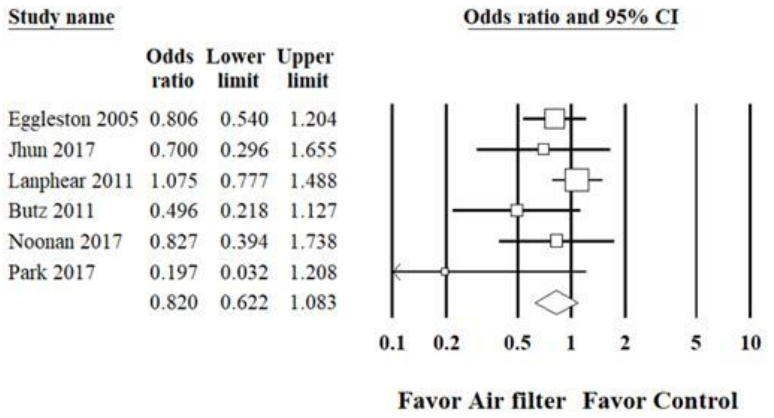
PRISMA flow diagram



The forest plot shows the reduction of PM in studies. The studies are sorted along with the baseline concentration of PM; the higher reduction was noted as the baseline PM 2.5 increased.

Figure 2

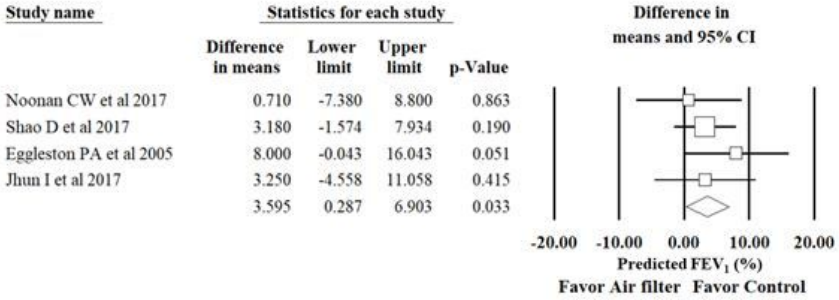
The pooled effect estimates on the reduction of particulate matter by air filter



The studies are sorted in order of baseline and the corresponding decrease of PM concentration. There was no consistent effect on symptoms along with the baseline and reduction of PM concentration. The pooled estimates did not show statistical significance in reducing symptoms by air filter.

Figure 3

The effect of air filter on respiratory symptoms



The studies are sorted studies in order of the baseline concentration of PM. The effect size of increasing FEV_1 by air filter is shown with higher reduction of PM and the longer period of usage of air filer.

Figure 4

The effect of air filter on FEV1

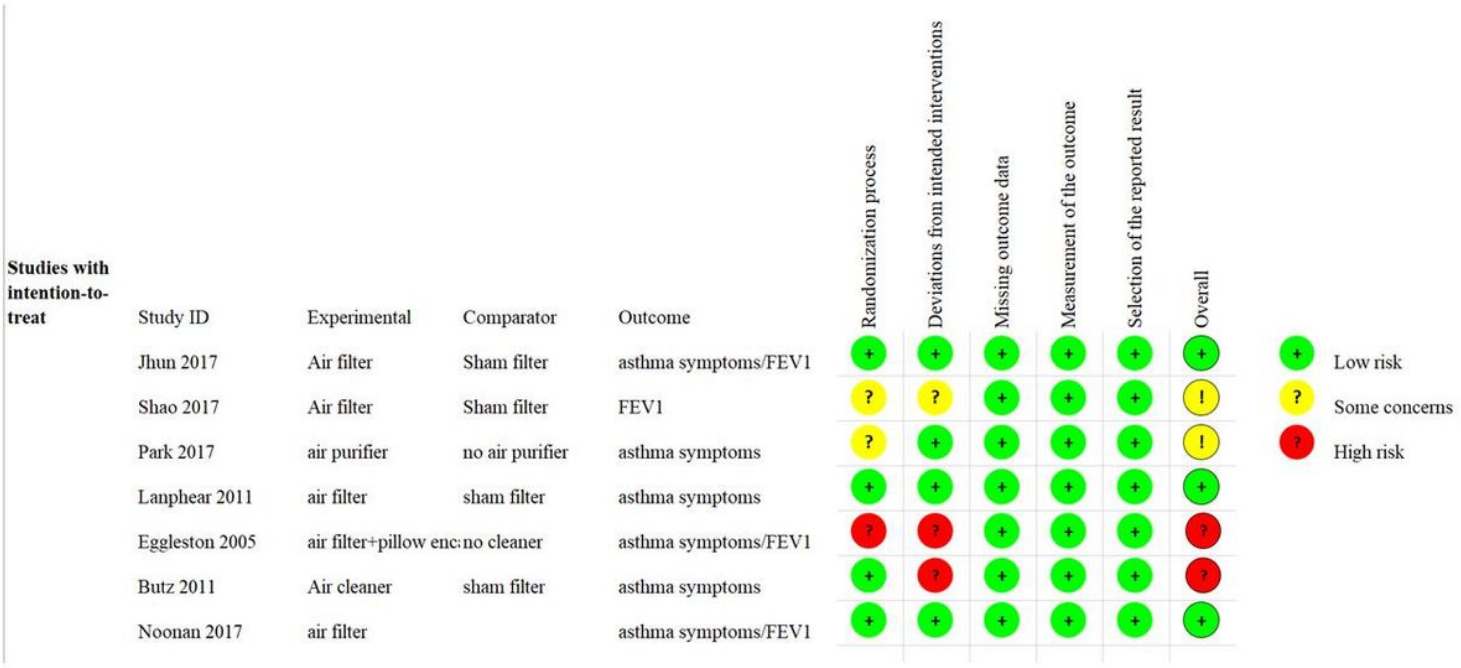


Figure 5

The summary of risk of bias about respiratory symptoms, showing each risk of bias item for every included study

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryAppendix20200406.docx
- SupplementaryAppendix20200406.docx