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Cardiopulmonary effects of overnight indoor air filtration in healthy non-smoking adults: A double-blind randomized crossover study

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ABSTRACT

Background: More than 90% of the world's population lives in areas where outdoor air pollution levels exceed health-based limits. In these areas, individuals may use indoor air filtration, often on a sporadic basis, in their residences to reduce exposure to respirable particles ($PM_{2.5}$). Whether this intervention can lead to improvements in health outcomes has not been evaluated.

Methods: Seventy non-smoking healthy adults, aged 19 to 26 years, received both true and sham indoor air filtration in a double-blinded randomized crossover study. Each filtration session was approximately 13 h long. True and sham filtration sessions were separated by a two-week washout interval. The study was carried out in a suburb of Shanghai.

Results: During the study period, outdoor $PM_{2.5}$ concentrations ranged from 18.6 to 106.9 μg/m^3, which overlapped with levels measured in Western Europe and North America. Compared to sham filtration, true filtration on average decreased indoor $PM_{2.5}$ concentration by 72.4% to 10.0 μg/m^3 and particle number concentration by 59.2% to 2316/cm^3. For lung function measured immediately after the end of filtration, true filtration significantly lowered airway impedance at 5 Hz (Z_5) by 7.1% [95% CI: 2.4%, 11.9%], airway resistance at 5 Hz (R_5) by 7.4% [95% CI: 2.4%, 12.5%], and small airway resistance (R_5-R_{20}) by 20.3% [95% CI: 0.1%, 40.5%], reflecting improved airway mechanics especially for the small airways. However, no significant improvements for spirometry indicators (FEV_1, FVC) were observed. True filtration also significantly lowered von Willebrand factor (VWF) by 26.9% [95% CI: 7.3%, 46.4%] 24 h after the end of filtration, indicating reduced risk for thrombosis. Stratified analysis in male and female participants showed that true filtration significantly decreased pulse pressure by 3.3% [95% CI: 0.8%, 7.4%] in females, and significantly reduced VWF by 42.4% [95% CI: 17.4%, 67.4%] and interleukin-6 by 22.6% [95% CI: 0.4%, 44.9%] in males. Effect

Abbreviations: AI, Augmentation index; dBP, Diastolic blood pressure; FeNO, Fractional exhaled nitric oxide; FEV_1, Forced expiratory volume during the first second; Fres, Resonant frequency; FVC, Forced vital capacity; HEPA filter, High efficiency particulate air filter; HR, Heart rate; IL-6, Interleukin-6; MDA, Malondialdehyde; $PM_{2.5}$, Particles with aerodynamic diameters less than or equal to 2.5 μm; PP, Pulse pressure; PWV, Pulse wave velocity; R_5, Airway resistance at 5 Hz; R_5-R_{20}, Airway resistance at 5 Hz minus airway resistance at 20 Hz; sBP, Systolic blood pressure; sCD62P, Soluble P-selectin; SEVR, Subendocardial viability ratio; SG, Specific gravity; URI, Upper respiratory tract infection; VWF, von Willebrand factor; X_5, Airway reactance at 5 Hz, indicator of distal capacitive reactance; Z_5, Airway impedance at 5 Hz, indicating the magnitude of respiratory impedance

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modification analyses indicated that filtration effects in male and female participants were not significantly different.

Conclusion: A single overnight residential air filtration, capable of reducing indoor particle concentrations substantially, can lead to improved airway mechanics and reduced thrombosis risk.

1. Introduction

The adverse cardiorespiratory effects of air pollution are now well known, including lung function impairment, airway inflammation, cardiac autonomic function disruption, and endothelial dysfunction (World Health Organization (WHO), 2011; Brook et al., 2010; Adam et al., 2014; Di et al., 2017). The World Health Organization (WHO) estimated that 92% of the world's population lived in areas with outdoor air pollution levels exceeding the WHO guidelines in 2014 (World Health Organization (WHO), 2016a). Although the ultimate solution is to control emission sources, exposure reduction strategies at the individual level address more immediate needs. As people typically spend approximately 80% of their time indoors (Ministry of Environmental Protection of China, 2013; United States Environmental Protection Agency (US EPA), 1997; Klepeis et al., 2001), improvement of indoor air quality has been proposed to reduce total exposure to each resident. However, evidence is limited to support the effectiveness of air filtration in bringing beneficial health effects to the users.

A few recent studies have evaluated the health impacts of removing $PM_{2.5}$ of outdoor origin with filtration technologies in places with outdoor air pollution (Chen et al., 2015; Chuang et al., 2017; Lin et al., 2011; Li et al., 2017). One study conducted in Shanghai found that a 9-day residential intervention using a commercially available filter-based air purifier was associated with reduced levels of blood pressure, stress hormones, insulin, glucose, and indicators of oxidative stress and inflammation (Li et al., 2017). Earlier another study conducted in the same city using the same filter-based air purifier found that a continuous 48-hour indoor air filtration resulted in significant reductions in airway inflammation as well as circulatory inflammation and thrombogenic biomarkers in healthy young adults (Chen et al., 2015). However, in both studies participants stayed in the same room with the indoor air purifiers for either the entirety of the 48-hour period or as much time as possible during the 9-day intervention. These studies imposed time-activity patterns on study participants that were unrepresentative of real-world conditions, in which people may only have access to air filtration devices for part of the day in their homes. In addition, people may not use air purifiers in their homes on consecutive days as was done in the 9-day intervention trial (Li et al., 2017). It is necessary to know whether a sporadic filtration intervention as short as overnight can bring health benefits.

This study aims to examine the cardiorespiratory response to an overnight home use of a portable air filtration device in healthy non-smoking young adults living in Shanghai. As the study focuses on an intervention representative of daily activity, mimicking the scenario in which people return home in the evening and stay through the night until the next morning, we assessed parameters of airway and cardiovascular function and biomarkers reflecting cardiorespiratory pathophysiology that have been shown previously to respond rapidly to acute changes in air pollution levels (Rich et al., 2012; Chen et al., 2012). Given that gender may modify cardiovascular pathophysiological processes (Joyner et al., 2016; Reckelhoff, 2001), we also aim to examine the health response to the air filtration intervention in men and women separately.

2. Materials and methods

Further details are available in the Appendix.

2.1. Study design and participants

The study protocol was approved by the Ethics Committee of Shanghai First People's Hospital and registered at ClinicalTrials.gov (NCT02736487). We conducted this cluster-randomized double-blind crossover study at Shanghai First People's Hospital in a suburb (Songjiang District) of Shanghai, China. We recruited non-smoking adults free from chronic diseases from a pool of medical and nursing students through word-of-mouth and advertisements on hospital bulletin boards. Smokers and individuals that exhibited abnormal levels of health indicators in the blood routine and biochemistry tests during the screening visit were excluded from the study. All participants provided written consent.

2.2. Indoor air filtration

Each participant underwent two indoor air filtration sessions in his/her dormitory room during the period of November 7 to December 13, 2015. A commercially-available air purifier (Atmosphere®, Amway, USA), which contained a pre-filter (made of polypropylene mesh fabric), a high efficiency particulate air (HEPA) filter, and an activated carbon filter, was used in the study at a flow rate of 2.8 m^3/min. All three filters were newly installed for the study, and this condition is referred to as “true filtration”. In contrast, the “sham filtration” refers to the use of the same air purifiers with all the three filters removed. During each filtration intervention session, multiple filtration devices were used so that the participating dormitory rooms underwent filtration interventions simultaneously. Each session started at 6 pm on a Saturday, participants stayed and slept in their dorms with its doors and windows closed until the next morning. The duration of filtration captured by different health indicators was slightly different (Table 1, Appendix Table S2, and Fig. S1). During the time between the measurements of health indicators of post-intervention visit 1, study participants were encouraged to return to their dormitory room to resume filtration intervention. Their compliance was recorded in time activity questionnaires and taken into consideration when calculating the duration of filtration. The average duration of filtration was 13 h.

The order of true filtration and sham filtration was determined using cluster-randomization with individuals residing in the same dormitory room as a group. The true and sham filtration devices looked identical, the participants and research staff members that assessed health indicators were blinded to the order of true and sham filtration interventions.

2.3. Exposure assessment

We monitored concentrations of airborne pollutants ($PM_{2.5}$ mass concentration, particle number concentration, ozone, nitrogen dioxide) and ambient conditions (temperature and relative humidity) before, during, and after the indoor air filtration interventions (see Appendix Table S1 for details on the location and instrumentation of