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Consumption of fruit and vegetables might mitigate the adverse effects of ambient $PM_{2.5}$ on lung function among adults

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ABSTRACT

Background: Evidence on the effects of ambient $PM_{2.5}$ on lung function is limited among adults and the effect modification by dietary fruit and vegetables remains largely unknown.
Methods: We interviewed 29,032 participants aged 50 years and older from the WHO Study on global AGEing and adult health. Annual average $PM_{2.5}$ levels were estimated for each community using satellite data. We applied multi-level linear regressions to examine the association between ambient $PM_{2.5}$ and lung function (forced vital capacity (FVC), forced expiratory volume in 1-sec (FEV_1), FEV_1/FVC ratio, peak expiratory flow (PEF), and forced expiratory flow between 25th and 75th percentiles of FVC ($FEF_{25–75}$)).
Results: We found that ambient $PM_{2.5}$ was associated with lower lung functions. Each 10 μg/m^3 increase in $PM_{2.5}$ corresponded to reductions of 123.58 ml in FVC (95% CI: −185.21, −61.95), 126.64 ml in FEV_1 (95% CI: −186.04, −67.23) and 178.93 ml/s $FEV_{25–75}$ (95% CI: −249.20, −108.66). Lower effect estimates were observed among those with higher consumption of fruit and vegetables.
Conclusion: Our study suggests that exposure to ambient $PM_{2.5}$ might be one risk factor of reduced lung function in adults and that higher consumption of fruit and vegetables may mitigate this effect.

1. Introduction

Both short-term and long-term exposures to $PM_{2.5}$ (particles smaller than or equal to 2.5 μm in aerodynamic diameters) have been linked with respiratory morbidity and mortality (Kubesch et al., 2015; Neupane et al., 2010). Lung function is one important indicator of respiratory effects of air pollution (Trenga et al., 2006). Multiple air pollutants have been associated with decreased lung function growth among children and decreased lung function among adults. Long-term exposure to ozone (O_3), for example, has been associated with decreased lung function in several cohort studies (Frischer et al., 1999; Tager et al., 2005). Nitrogen dioxide (NO_2) and PM_{10} have also been reported to have similar effects (Menni et al., 2015; Zeng et al., 2016). Additionally, improved air quality was associated with improved lung function (Downs et al., 2007). However, only a few studies have examined the effect of long-term exposure to ambient $PM_{2.5}$ on lung function among adults (Goss et al., 2004).

The airborne fine particles, following inhalation in the respiratory tract, could trigger oxidative reactions in the respiratory system leading to oxidative stress and damage due to the pro-oxidant-antioxidant imbalance (Romieu et al., 2008). Antioxidants play a critical role in defense against the inflammation and oxidative stress induced by air pollutants (Kelly et al., 2003). Fruit and vegetables are important dietary sources of antioxidants and related compounds, in particular, vitamin C, carotenoids, and other phytochemicals. A higher intake of these compounds has been associated with increased lung function among adults (Balsano and Alisi, 2009). We thus hypothesize that higher intake of fruit and vegetables may mitigate the adverse effects of air pollutants.

We conducted this study using the survey data in six low- and

Abbreviations: $PM_{2.5}$, particles smaller than or equal to 2.5 μm in aerodynamic diameters; FVC, forced vital capacity; FEV_1, forced expiratory volume in 1-second; PEF, peak expiratory flow; $FEF_{25–75}$, forced expiratory flow between 25th and 75th percentiles of FVC; NO_2, nitrogen dioxide; WHO, World Health Organization; BMI, body mass index; 95% CI, 95% confidence interval

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middle-income countries with two specific objectives: 1) to examine whether long-term exposure to ambient $PM_{2.5}$ is associated with decreased lung function; 2) to investigate whether higher consumption of fruit and vegetables could modify the associations.

2. Methods

2.1. Study population

The WHO Study on global AGEing and adult health (SAGE) is an ongoing cohort study with participants aged 50 years and older from six low- and middle-income countries: China, Ghana, India, Mexico, Russia and South Africa, the details have been described previously (Kowal et al., 2012). The current analysis was derived from SAGE Wave 1 survey, which was implemented through a face-to-face interview using a stratified multistage random cluster sampling design (Lin et al., 2017a).

2.2. Lung function measurement

In a sitting position with a nose clip, each participant was asked to perform the test until three satisfactory spirometric measurements were obtained (Kowal et al., 2012). The average of the three readings was chosen for our analysis. Five metrics were considered: forced vital capacity (FVC), forced expiratory volume in 1-sec (FEV_1), FEV_1/FVC ratio, peak expiratory flow (PEF), and forced expiratory flow between 25th and 75th percentile of FVC ($FEF_{25–75}$).

2.3. Air pollution

We used the satellite-derived annual mean $PM_{2.5}$ estimation to assess the long-term exposures to $PM_{2.5}$, the method has been described elsewhere (van Donkelaar et al., 2015). In brief, aerosol optical depth data were retrieved from the Moderate Resolution Imaging Spectroradiometer and Multiangle Imaging Spectroradiometer instruments from the Terra satellite, which measures the light extinction due to aerosol (Levy et al., 2007). Combined with the vertical profile of aerosol from a chemical transport model (Bey et al., 2001), we can estimate ground-level $PM_{2.5}$ concentrations. The $PM_{2.5}$ concentrations were estimated for each community with the assumption of a similar air pollution concentration within the same community. We used a three-year averaged concentration before the survey as the independent variable.

2.4. Consumption of fruit and vegetables

Two questions were used to solicit information pertaining to the consumption of fruit (such as apple, pear, peach, banana, orange, watermelon) and vegetables (such as cabbage, spinach, leek, bok choy, cucumber, celery, capsicum) (Wu et al., 2015): “How many servings of fruit do you eat on a typical day?” and “How many servings of vegetables do you eat on a typical day?”. For each question, the respondents were shown a card with samples of a standard portion of fruit or vegetables relevant for typical diets; one serving was about 80 g (Rivas Marino et al., 2015).

2.5. Covariates

Covariates included demographic, socioeconomic, and lifestyle factors, such as age, sex, weight, height, body mass index (BMI), education, marital status, smoking, alcohol consumption, physical activity, education, and annual household income. Weight and height were measured to calculate BMI, expressed as weight/height^2 (kg/m^2). Marital status was divided into married (currently married or cohabiting) and unmarried (never married, separated, divorced, or widowed). Two metrics were used for tobacco smoking: smoking status (never or ever) and smoking amount (none, less or more than eight cigarette equivalents per day). Alcohol drinking was grouped into two broad categories, drinker and non-drinker. Household income was categorized into two levels (low or high) using median income as the threshold. Three levels of physical activity (low, moderate, and high physical activity) were considered using the participants' responses to the questions about moderate or vigorous physical activities during work, their movement to and from places, and recreational/leisure time activities (Hallal et al., 2012). Domestic fuel type and ventilation apparatus for cooking were included as indicators of indoor air pollution. Two fuel types were mainly used: solid fuels, such as coal, wood, dung and agricultural residues; and liquid and gas fuels, including electricity, liquefied petroleum gas and natural gas. Ventilation was defined as presence of an indoor ventilation apparatus in the cooking area (chimney, fan, extraction hood or none).

2.6. Statistical analysis

The lung function measurements for participants from the same community may be correlated with each other, violating the independence assumption of regression models. To account for the data clustering, we considered a three-level linear mixed effect model with participants being the first-level unit, the community being the second-level unit, and the country being the third-level unit (Lin et al., 2017b). The effect estimates were expressed as absolute differences in lung function measures associated with each 10 μg/m^3 increases in ambient $PM_{2.5}$ concentrations.

We selected covariates in the final models based on three criteria: 1) the variables were known or hypothesized risk factors for ambient $PM_{2.5}$ and lung function or they were significant associated with ambient $PM_{2.5}$ and lung function in the univariate models; 2) the association changed by more than 10% when additionally including the variable in the model (Beelen et al., 2014); 3) some important covariates, such as age, sex, height, and smoking were included in the models even if they were not significant in the univariate models. Therefore, the final model included age, sex, height, education, marital status, smoking, alcohol drinking, household income and indoor air pollution (fuel type and ventilation).

To examine potential effect modifiers, stratified analyses were conducted in terms of sex (males and females), smoking (smokers and never-smokers), and intakes of fruit and vegetables. Consumption of fruit and vegetables were classified into sufficient or insufficient levels: two or more servings of fruit per day and 3.5 or more servings of vegetables per day were considered sufficient, fewer servings were considered insufficient in keeping with previous definitions (Wu et al., 2015). The statistical difference of the associations between the subgroups was examined by calculating the 95% confidence interval of the difference using the formula: $(\beta_1 - \beta_2) \pm 1.96\sqrt{(SE_1)^2 + (SE_2)^2}$; where β_1 and β_2 were the effect estimates for each subgroup (such as smokers and never-smokers), and SE_1 and SE_2 were the standard errors (Schenker and Gentleman, 2001).

A series of sensitivity analyses were also conducted to assess the robustness of the effect estimations obtained in the main model. First, additional country-level covariates were incorporated into the models to control for potential confounding at the country level, such as GDP, percentage of urban population, health care expenditure, and Gini coefficient. Second, the average $PM_{2.5}$ concentrations for one, two, four and five years before the survey were used as the exposure variable. Third, sensitivity analysis was also conducted by excluding individuals with existing cardiovascular and respiratory conditions. Fourth, we also examined the country-specific association, and pooled them to obtained an overall effect estimate using a random-effect meta-analysis approach (Berkey et al., 1995). Approval to conduct this study was granted by the Ethics Committee of the Chinese Centre for Disease Control and Prevention. Informed consent was obtained from each participant before the interview.