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Effects of particulate air pollution and ozone on lung function in non-asthmatic children

Chi-Hsien Chen [a], Chang-Chuan Chan [a,b], Bing-Yu Chen [b], Tsun-Jen Cheng [b], Yue Leon Guo [a,b,*]

[a] Department of Environmental and Occupational Medicine, National Taiwan University (NTU) College of Medicine and NTU Hospital, Taipei 100, Taiwan
[b] Institute of Occupational Medicine and Industrial Hygiene, National Taiwan University, Taipei 100, Taiwan

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ABSTRACT

Introduction: Information on the long-term effects of different air pollutant levels on lung function is relatively lacking in Asia and still inconclusive in the world. Age differential effects of air pollution are not known.
Objectives: To assess the acute and subchronic effects of ambient air pollution on lung function and compared among children of different ages.
Methods: From April to May 2011, a nationwide study was conducted on schoolchildren aged 6–15 years in 44 schools of 24 districts in Taiwan. Spirograms were obtained from 1494 non-asthmatic children. Air pollution data were retrieved from air monitoring stations within one kilometre of the schools. Using three-level hierarchical linear models, individual lung function was fitted to air pollution, with adjustments for demographics, indoor exposures, outdoor activity, and districts.
Results: Lung function changes per inter-quartile increase of the past two-months average levels of particulate matter <2.5 μm ($PM_{2.5}$) and ozone (12 μg/m^3, 32–44 and 6.7 ppb, 32–38, respectively) were −103 and −142 ml on FVC, −86 and −131 on FEV1, and −102 and −188 ml/s on MMEF, respectively. Lag-1-day ozone exposure was associated with decreased MMEF. In children aged 6–10, $PM_{2.5}$ was associated with decreased FEV1/FVC and MMEF/FVC ratios.
Conclusions: In children aged 6–15 years, sub-chronic exposure to ambient $PM_{2.5}$ and ozone leads to reduced lung capacity, whereas acute exposure to ozone decreases mid-expiratory flow. In children aged 6–10 years, additional airway obstructive patterns in lung function may be associated with $PM_{2.5}$ exposure.

1. Introduction

Lung function is an objective marker for assessing the type and severity of respiratory problems (Pellegrino et al., 2005). In children, it also provides insights into respiratory development (Miller and Marty, 2010). To assess the health effects of air pollution, lung function tests have been widely used as an effect marker. A most widely utilized measurement of lung function, spirometry provides information on lung capacity by forced vital capacity (FVC) and forced expiratory volume in one second (FEV1), airway obstruction by the ratio of FEV1 to FVC, and small airway function by the maximum mid-expiratory flow (MMEF) (Pellegrino et al., 2005). A review article concludes that long-term exposure to ambient air pollution causes adverse effects on children's lung function (Gotschi et al., 2008). Various effects have been associated with air pollution in lung function measurements, including FVC (Frye et al., 2003; Raizenne et al., 1996), FEV1 (Brunekreef et al., 1997; Galizia and Kinney, 1999), and MMEF (Galizia and Kinney, 1999; Kunzli et al., 1997; Tager et al., 2005).

The respiratory effects of exposure to particulate matter <2.5 μm ($PM_{2.5}$) have gained much attention among health workers and policy makers. Several studies have focused on long-term $PM_{2.5}$ effects in children of elementary or middle school

Abbreviations: PM, particulate matter; $PM_{2.5}$, particulate matter with an aerodynamic diameter of ≤2.5 um; PM_{10}, particulate matter with an aerodynamic diameter of ≤10 um or less; $PM_{2.5-10}$, particulate matter with an aerodynamic diameter of 2.5–10 um; SO_2, sulphur dioxide; O_3, ozone; CO, carbon monoxide; NO_2, nitrogen dioxide; EPA, Taiwan Environmental Protection Administration; PFT, pulmonary function tests; FVC, forced vital capacity; FEV1, forced expiratory volume in one second; MMEF, maximum mid-expiratory flow; IQR, inter-quartile range; Lag-1-day, first day before the PFT; Lag-2-day, second day before the PFT; 2-m, two months before the PFT

* Corresponding author at: Department of Environmental and Occupational Medicine, College of Medicine, National Taiwan University and National Taiwan University Hospital, Rm 339, 17 Syujhou Road, Taipei 100, Taiwan.
Fax: +886 2 3322 8214.
E-mail address: leonguo@ntu.edu.tw (Y. Leon Guo).

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ages. Two studies with low background mean $PM_{2.5}$ (13.3 and 14.5 μg/m^3) have demonstrated significant adverse effect on lung function. These studies reveal that for each 10 μg/m^3 increment in $PM_{2.5}$, FVC is reduced by 1.69% and 2.15% and FEV1 by 2.18% and 1.89%, respectively (Raizenne et al., 1996; Urman et al., 2014). However, three other studies with higher mean $PM_{2.5}$ levels (15.6, 19.0, and 24.9 μg/m^3) do not observe similar findings (Dales et al., 2008; Hogervorst et al., 2006; Lee et al., 2011). Thus, the dose–response relationship of higher $PM_{2.5}$ concentrations remains unclear. In Taiwan, ambient $PM_{2.5}$ levels are >20 μg/m^3. The observed dose–response relationship at this concentration range may be informative for policy makers in areas with relatively high ambient $PM_{2.5}$ concentrations.

Based on previous experimental studies, smaller children have higher nasal to oral breathing ratio and higher minute ventilation to their lung volume, rendering them more susceptible to inhalational hazards (Becquemin et al., 1999; Bennett et al., 2008; Zeman, 1998). Smaller children also have greater tracheo-bronchial particle deposition than older individuals, suggesting that the airways may be the target for particulate air pollutant (Phalen et al., 1985). However, most of the previous epidemiologic studies have enroled relatively narrow age ranges and are unable to evaluate the effects of air pollution on lung function in children with different ages (Gotschi et al., 2008). Thus, it is still unknown whether the current ambient air pollution causes different adverse effects on children of different ages.

The present study investigated the association between acute (lag-1-day and lag-2-day) and sub-chronic (prior 2 months) exposures of ambient air pollution and lung function in children with no known asthma in 24 communities around Taiwan. The study subjects were schoolchildren aged 6–15 from 22 elementary and 22 middle schools, thus enabling the evaluation of differences in lung function effects of air pollution, especially $PM_{2.5}$, between children younger and older than 10 years.

Fig. 1. The 24 air monitoring stations in this study in Taiwan, 2011.

2. Methods

2.1. Design and study population

Between April and May 2011, a nationwide cross-sectional study in Taiwan was conducted using a modified Chinese version of the International Study of Asthma and Allergies in Childhood (ISSAC-C) questionnaire. The questionnaire, which collected information on children's respiratory health, allergic conditions, demographic characteristics, and environmental exposures, was taken home by students and answered by parents. Questions related to atopic conditions were unchanged from those used in 1995–96 (Guo et al., 1999) and in 2001 (Lee et al., 2007).

To evaluate the effect of ambient air pollution on children's health, the study population was limited to students whose schools were located within one km of Taiwan Environmental Protection Agency (EPA) air-monitoring stations (Fig. 1). In our 2001 survey, 22 monitoring stations were randomly sampled, one of the monitoring stations in each county. The 22 monitoring stations were located in 22 cities or townships (districts), which were maintained in the research structure of our current (2011) survey, and 22 elementary schools and 22 middle schools were used from these districts. In 20 out of the 22 districts, the middle school and elementary school were near each other. The air pollutant data used was from one EPA monitoring station within one kilometre of the schools. In the other two districts, the elementary school was not near to the middle school, and one monitoring station within one kilometre of each school was randomly selected from another district in the same county. Thus, the pollutant data from a total of 24 monitoring stations (districts) were used.

In Taiwan, students were classified into six grades in elementary school (aged 6–12 years) and three grades in the middle school (aged 13–16 years). A stratified sampling of students was conducted by randomly selecting one class per grade from the elementary schools and three classes per grade from the middle schools. A total of 7154 children aged 6–15 years were approached and 6346 (88.7%) completed the questionnaire, with response rates of 86–93%. Six children in each class who were never diagnosed with asthma, had no asthmatic symptoms in the past 12 months, or had never smoked were randomly selected for pulmonary function test (PFT). The institutional review board of the National Taiwan University Medical Centre approved the study and the parents of each participant provided informed consent.

2.2. Health outcomes

After excluding subjects with symptomatic respiratory tract infection, 1561 children were eligible for PFT. Three well-trained technicians performed the test using spirometres (Chest-graph HI-101; CHEST MI, Tokyo, Japan). The standardized spirometry of the American Thoracic Society was adapted. Children received spirometry in the standing position, in the morning, and inside buildings. The FVC, FEV1, MMEF, and ratio of FEV1 to FVC (FEV1/FVC) were recorded. The ratio of MMEF to FVC was also calculated as an indicator of small airway function (Tager et al., 2005). Each subject was asked to perform at least three acceptable spirograms, defined as extrapolation volume $<5\%$ of FVC or 150 ml, smooth flow–volume curve without artefacts, and satisfactory exhalation with forced expiratory duration >6 s (3 s for children younger than 10 years), or with a plateau more than 1 s in the volume–time curve. If the difference between the two largest FVC and FEV1 was within