Exposure to Greater Air Pollution when Traveling Abroad Is Associated with Decreased Lung Function

To the Editor:

Global travel numbers have been increasing worldwide, by 3.3% per year since 2010, and are expected to reach 1.8 billion travelers by 2030 (1). More travelers from the United States are now visiting cities in Asia and Africa, and megacities in these regions are known to have high levels of particulate matter (PM) pollution, at times resulting in major air pollution episodes. Therefore, international travelers can be exposed to very high levels of PM pollution if they arrive in these cities during an air pollution episode, and they lack the necessary adaptation and precautionary measures to minimize the associated health risks (2).

To date, we have not found any published studies that have researched the respiratory impacts of acute exposure to high levels of air pollution when individuals travel abroad to cities with significantly higher PM concentrations than their city of residence. To examine this issue, we measured and analyzed health and indoor PM exposure data from individuals who traveled from the United States to selected cities abroad, to test the hypothesis that when individuals travel abroad, exposure to higher levels of PM $\leq$2.5 μm in aerodynamic diameter ($PM_{2.5}$) than are encountered in their home city will adversely impact their lung function.

Our study initially enrolled 42 nonsmoking, healthy young adults who traveled from the New York City metropolitan area to selected cities abroad, which were categorized into four regions: Europe, South Asia, East Asia, and Africa. Eight subjects were excluded from the analyses because of confounding activities and/or insufficient data (i.e., if they provided less than 5 days of data for baseline or when abroad). To be included in the study, subjects were required to *1*) have traveled to a city abroad for at least a week, *2*) be $\geq$21 years old, and *3*) be a nonsmoker (self-reported). The New York University School of Medicine Institutional Review Board approved the study. Participants were pretrained to measure and record their lung function and personal indoor PM exposure levels using a portable spirometer (Koko PeakPro6; Ferraris) (3) and a low-cost $PM_{2.5}$ sensor (AirBeam; Habitatmap), respectively. Health and $PM_{2.5}$ data were obtained in the morning and evening of each day for 1 week before travel, 1 week during the stay abroad, and 1 week after the subjects returned to their home city (each subject provided at least 5 days of morning and evening measurements at each location). Lung function measurements were obtained in accordance with American Thoracic Society guidelines (4), and the highest value of three consecutive efforts was used for analyses. AirBeams were individually precalibrated using concentrated ambient particles at the New York University Sterling Forest laboratory. The measured $PM_{2.5}$ concentrations were used to categorize cities into "polluted cities" categories (low [0–35 $\mu g/m^3$], medium [36–100 $\mu g/m^3$], and high [>100 $\mu g/m^3$]), and lung function was assessed by the observed change in FEV_1 by low, medium, or highly polluted categories. A mixed-effects statistical model was applied to repeated-measures longitudinal data for lung function and indoor $PM_{2.5}$ measurements (total n of >700 data points) to study the association between FEV_1 and $PM_{2.5}$ exposure concentrations, using a subject-specific random intercept term (subject as random effect), along with covariates (age and height), and fixed terms (pollution level).

The study population consisted of healthy young adults (based on age, height, weight, and body mass index) who were mostly university students based in the New York City metropolitan area and New Jersey. In some regions, mean indoor $PM_{2.5}$ concentrations in cities abroad were significantly higher than pretravel New York concentrations, particularly in South and East Asia. Cities in East Asia, as a group, had the highest (mean $\pm$ SD) indoor $PM_{2.5}$ measurements (73 ± 96 $\mu g/m^3$ and 95 ± 114 $\mu g/m^3$ for morning and evening measurements, respectively). The mean $PM_{2.5}$ concentrations in European cities were significantly lower than those in East and South Asia (Figure 1).

Results from the mixed-effects analysis showed that travel to a "high" polluted city was associated with a statistically significant mean decrement of 235 ml (95% confidence interval, -365 to -112 ml) in evening FEV_1. Main effects plots showing the fitted (predicted) means of evening FEV_1 for low, medium, and high polluted cities are given in Figure 2) (based on indoor $PM_{2.5}$). When further analyzed using the maximum percentage change of FEV_1, where maximum change = (minimum FEV_1 abroad $-$ mean pretravel FEV_1/mean FEV_1 in pretravel New York) $\times$ 100, travel to a highly polluted city was associated with a 6.5% reduction in evening FEV_1 compared with the overall population mean.

We show, for the first time, that exposure to increased levels of indoor $PM_{2.5}$ in cities abroad is associated with statistically significant acute changes in pulmonary function in healthy young adults. Together with increases in respiratory symptoms (data not shown), travelers to heavily polluted cities can be considered to encounter adverse health effects according to American Thoracic Society guidelines (5, 6). Similar results were obtained for outdoor $PM_{2.5}$ (central monitor) concentrations and lung function reductions. It is important to note that the higher indoor concentrations recorded in some polluted cities abroad suggest that the traditional approach of staying indoors during high outdoor pollution episodes may not be effective. Although previous human chamber studies that exposed volunteers to fine PM showed no or very small decrements in lung function (7, 8), it is important to consider that owing to institutional review board and ethical considerations, chamber studies typically have limitations with respect to how high the PM concentrations can go. However, the subjects in this study were exposed to much higher PM levels in polluted cities abroad and for longer hours/days, and therefore their doses could have been much higher than those reported in chamber studies. Thus, travel provided a natural

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Author Contributions: M.J.R.V. and T.G. planned the project. M.J.R.V. conducted subject training, acquired data, and performed the statistical analyses. M.J.R.V., G.D.T., and T.G. advised on the study design and analysis, and edited the manuscript. L.-C.C. contributed with experimental methods and equipment. C.C.L. contributed to equipment calibrations and reviewed the statistical analyses. All of the authors approved the work and final version of the manuscript.

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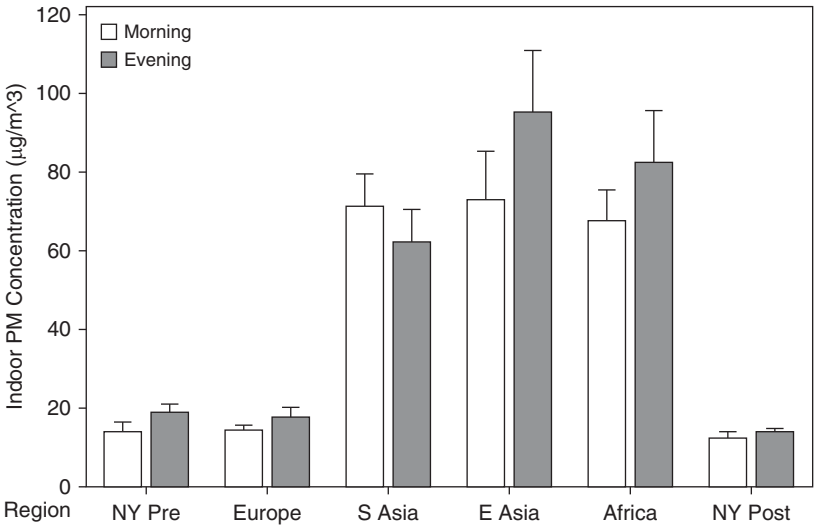

Figure 1. Mean indoor (AirBeam measured) $PM_{2.5}$ concentrations by region. Error bars are 1 SE from the mean. NY Post = after returning to resident city; NY Pre = before travel; PM = particulate matter; $PM_{2.5}$ = PM ≤2.5 μm in aerodynamic diameter.

experiment in which individuals were exposed to high PM concentrations for long periods of time. The limitations of this study include not having a balanced number of subjects for each city, lack of time/activity pattern data for the subjects, and the possible influence of weather, although we believe that the results indicate that PM has greater impacts on lung function than these other potentially confounding factors.

In conclusion, our study suggests that travel-related exposure to increased PM adversely impacts individuals' pulmonary function and health, which can be particularly important for travelers with a preexisting respiratory or cardiac disease. Recommendations from physicians may include avoiding travel to highly polluted cities, carrying asthma medication, and using suitable particle masks (e.g., with physician guidance) while abroad.

Some of the data used in this study have been previously analyzed and reported in the form of abstracts (9, 10). ■

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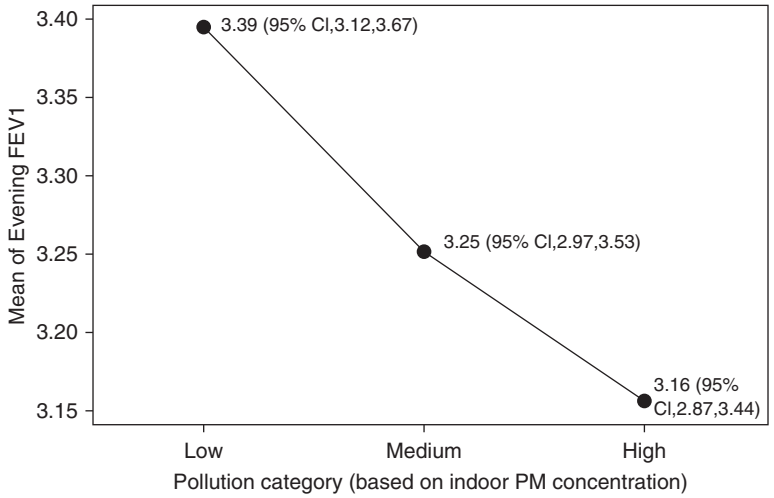

Figure 2. Main effects plot of fitted means for evening FEV_1 with an indoor pollution category assigned to each city: low (0–35 μg/m^3), medium (36–100 μg/m^3), and high (>100 μg/m^3). CI = confidence interval; PM = particulate matter.

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Changes in Electrical Impedance Tomography Findings of ICU Patients during Rapid Infusion of a Fluid Bolus: A Prospective Observational Study

To the Editor:

Electrical impedance tomography (EIT) is a noninvasive, radiation-free imaging tool for critically ill patients suffering from acute respiratory failure. During bedside EIT monitoring, differences between end-expiratory lung impedance and end-inspiratory lung impedance, commonly referred to as tidal impedance variation (TV), are used to assess regional ventilation distribution (1), whereas changes in end-expiratory lung impedance over time are frequently used to track changes in end-expiratory lung volume (EELV) (2–5).

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However, although they are highly correlated with changes in air content, changes in pulmonary bioimpedance may also be influenced by intrathoracic fluid volume and electrolyte concentrations (6). This may affect the interpretation of changes in end-expiratory lung impedance and TV, which could be influenced by fluid and blood volume shifts.

The aim of this study was to assess the effects of routine clinical fluid administration on end-expiratory lung impedance and TV in critically ill patients requiring mechanical ventilation. Some results of this study have been previously reported in the form of abstracts (7, 8).

Methods

We conducted a prospective observational study (NCT02992002) of 25 mechanically ventilated ICU patients with EIT (PulmoVista 500; Dräger) and transpulmonary thermodilution $\dot{Q}$ monitoring (PiCCO; Pulsion), in whom a fluid challenge (9) with 500 ml of balanced crystalloid solution (Sterofundin ISO; Braun) over approximately 15 minutes was performed to assess fluid responsiveness as per clinical decision. Exclusion criteria were age < 18 years, body mass index > 35 kg/m^2, open chest lesions, and presence of metal implants. Owing to the observational nature of the study, informed consent was waived by the Ethics Committee of Christian Albrechts University Kiel (D486/16).

EIT data were recorded continuously throughout the study period. Transpulmonary thermodilution data were acquired at four predefined time points: *1*) 15 minutes before the start of fluid administration (T1), *2*) immediately before the start of fluid administration (T2), *3*) immediately after the end of fluid administration (T3), and *4*) 30 minutes after the end of fluid administration (T4).

The exact time points (T1–T4) were registered on the EIT device using the device's "mark event" function. Ventilator settings and patient position remained unchanged during the study period.

Changes in end-expiratory lung impedance and end-inspiratory lung impedance, as well as TV, were determined globally in the whole image and regionally for the ventral and dorsal image regions using the Dräger EIT data analysis tool 6.1 (Dräger). Changes in end-expiratory lung impedance were assessed in comparison with T1 and normalized to the TV at T1. To assess changes in end-expiratory lung impedance, a reference was automatically defined as the minimum impedance during the first 5 minutes of measurements by loading the first file of the recording as a "reference file" in the EIT data analysis tool. All subsequent changes in end-expiratory lung impedance for the time points T1–T4 were compared with this reference. To assess changes in TV, the average tidal image was calculated as the difference between end-inspiratory lung impedance and end-expiratory lung impedance, taking into account all breaths during a 1-minute period at time points T1, T2, T3, and T4, respectively.

Statistical analysis was performed with GraphPad Prism 5.0 (GraphPad Software) using one-way ANOVA for repeated measures with Bonferroni's multiple comparison test for normally distributed variables and Friedman's test with Dunn's multiple comparison test for nonnormally distributed variables. Normal distribution was assessed with the D'Agostino-Pearson omnibus normality test. Normally distributed results are presented as the mean ± SD, and nonnormally distributed results are presented as the median (25th–75th percentile).