RESEARCH PAPER

Lung Function in Adolescents Exposed to Environmental Contamination and Brickworks in Guadalajara, Mexico

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Objective: To compare the pulmonary function in adolescents exposed to different concentrations of air pollutants in two different zones. **Methods:** Two zones based on monitoring of environmental pollutant concentration as high (zone 1) and low (zone 2) were chosen. The lung functions of apparently healthy adolescents (12-15 years) residing in two zones were measured for forced vital capacity (FVC), forced expiratory volume in first second (FEV1), FEV1/FVC ratio, and forced expiratory flow $(FEF)_{25-75}$. **Results:** A total of 302 adolescents (142, zone 1 and 160, zone 2) resided in the study area, with higher than permissible concentrations of PM10 and ozone at both places. Abnormal lung functions were seen in a higher proportion of adolescents in zone 1 than zone 2 (23% and 14%; *P*=0.04). A significantly lower mean (SD) FEV1 was seen in adolescents in zone 1 than zone 2 [2.9 (0.5) *vs.* 3.2 (0.4) L, *P* = 0.04]. A higher proportion of abnormal FEV1/FVC ratio% was seen in zone 1 than 2 (12% *vs.* 6%, *P*=0.04), suggestive of an obstructive pattern on spirometry. Higher risk (β 95% CI) for abnormal lung functions was seen with the zone [2.2 (1.1-4.2)], diagnosis of asthma [5.74 (2.4-13.2)], and living within 500 meters from a brickwork [1.8 (1.0-2.5)]. **Conclusion:** High exposure to PM10, ozone and living near brickwork were associated with reduced lung function in adolescents.

Keywords: *Air pollution, Asthma, Ozone, Particulate matter, Spirometry.*

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Around 92% of the global population lives in areas with environmental contamination that exceeds the limits recommended by the World Health Organization (WHO), which includes 300 million children [1,2]. The last phase of pulmonary development occurs during adolescence with the lungs being vulnerable to the effects of environmental contami-nation [3]. This may be associated with chronic obstructive pulmonary disease and lung cancer if persis-tent in adulthood, including among non-smokers [2,4].

Previous studies [5-7] have demonstrated the link between environmental contamination and decrease in lung function in children, with scarce data in adolescents. In the metropolitan area of Guadalajara, located in the western region of Mexico, environmental contamination related to automobile traffic is the primary source of ozone and particulate matter with an aerodynamic diameter of<10µm (PM10), which exceed the WHO limits in few areas [8]. The objectives of this study were to compare the lung functions of adolescents exposed to different concentrations of atmospheric pollutants and associate with the proximity to artisan brick factories (brickworks) and major roadways.

METHODS

This cross-sectional study was conducted during 2016-2017 in the metropolitan area of Guadalajara, Mexico. Adolescents between 12 to 15 years of age of either gender who were attending public secondary schools were enrolled. Those with active smoking, acute exacerbation of asthma or acute respiratory infection in the last two weeks were excluded. The protocol was approved by the Research and Ethics Committee of the Mexican Social Security Institute.

The metropolitan area of Guadalajara has ten fixed stations for environmental monitoring which measure PM10, ozone, nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO). Two stations were selected centered on their concentrations of air pollution (the highest and lowest), based on the 2016 official report of air quality [8]. Google earth was used to locate the schools within a 2 km radius from the monitoring station, and to measure the distance between the subjects' homes and brickwork or a major roadway. The adolescents were randomly selected from a list obtained from the district's Department of Education. The study period was from

September to October, 2016 and March to June, 2017 as the mean values of ozone and PM10 remained stable with maximum of 10% variation during this period [8].

Written informed consent was obtained from the parents and assent from the adolescents. Parents completed an ad hoc questionnaire which included demographic details, clinical details for chronic diseases, asthma and allergies, and environmental exposures like prenatal smoke, secondhand tobacco smoke, wood and charcoal smoke, proximity (<500 meters) to a major roadway and/or brickworks from their house.

Height was measured using SECA portable stadiometer (SECA GMBH & Co., Hamburg, Germany; model 206), and weight by Tanita scale (Tanita UK Ltd Middlesex, United Kingdom; model UM-061) to calculate the body mass index (BMI). The spirometer equipment used was Easy-One Spirometer (NDD, Techopark, Zurich Switzerland) which was calibrated daily with a 3L syringe (Sensor Medics) prior to data collection. Forced vital capacity (FVC), forced expiratory volume in the first second (FEV1), FEV1/FVC ratio, and forced expiratory flow 25-75 (FEF25-75) were measured. Readings were performed at the school during morning and early afternoon to record at least three acceptable spirograms which were reproducible. The spirometric measurements were checked with the 2019 American Thoracic Society (ATS) criteria for acceptability and reproducibility [9]. The lung function parameters were calculated as mean (SD) and percentage of the predicted value. Reference values of National Health and Nutrition Examination Survey III for Mexican-Americans were used to calculate the percentage of predicted values [10].

Air pollutant concentrations were measured for ozone as 8-hour means in parts per million (ppm), PM10 as 24-hour means ($\mu m/m^3$), NO_2 as 1-hour means (ppm), SO_2 as 24-hour means (ppm), and CO as 8-hour means (ppm). The permissible concentrations were defined as per WHO [11], for ozone, PM10, NO_2, SO_2, and CO as <0.050 ppm, <50 $\mu m/m^3$, <0.106 ppm, <0.008 ppm and <8.73 ppm, respectively. Environmental air pollution was considered high (zone 1) or low (zone 2) according to the median concentrations of pollutants in the two respective zones.

Sample size and statistical analysis: The sample size based on a power of >80% and a two-tailed α of 0.05, to detect at least an 11% difference [12] in predicted percentage of FEV1, FVC, and FEV1/FVC ratio between the two zones was 129 adolescents in each zone.

The analysis was conducted using SPSS V.22 (License by IBM). Comparisons for continuous data between groups were done with Student t-test, and for proportions by chi-square test. Logistic regression analysis was done for risk of abnormal lung functions for factors like zone, diagnosis of asthma, and living <500 meters from a brickwork. A *P*-value of less than 0.05 was considered statistically significant.

RESULTS

A total of 317 adolescents were enrolled, out of which four children with asthma, two with active smoking and nine with poor reproducibility on spirometry were excluded to finally include 302 adolescents. The mean (SD) age in zone 1 (*n*=142) and zone 2 (*n*=160) was 13 (1) and 13 (0.9) years, respectively, with BMI of 21 (3) and 21 (4) kg/m^2, respectively.

The mean (SD) concentrations of pollutants in both zones are shown in ***Web Table* I.** The levels of PM10 and ozone were higher than the permissible limits in both zones. A higher proportion of adolescents lived within 500 meters from brickworks in zone 1 than zone 2 (31% *vs.* 16%, *P*= 0.001), respectively. A lesser proportion of those with allergic rhinitis (2% and 7%, *P*=0.03) and asthma (6% and 14%, *P*=0.03), respectively were reported in zone 1 than zone 2. There were no significant differences for any other environmental exposures.

The lung functions of adolescents in both groups are shown in ***Table* I.** A higher proportion of adolescents in zone 1 had abnormal spirometry results than zone 2 [23% *vs*. 14%, OR (95% CI) 1.8 (1.0-3.2); *P*=0.04]. Significantly

Table I Lung Function in Adolescents According to Air Pollution Exposure Zone in Guadalajara, Mexico

Spirometry variables	*Zone 1 (n=142)*	*Zone 2 (n=160)*	*P value*
FEV_1, L	2.9 (0.5)	3.2 (0.4)	0.04
FVC, L	3.4 (0.6)	3.3 (0.6)	0.08
FEF_{25-75}, L/s	3.7 (0.6)	3.9 (0.5)	0.4
% Predicted			
FEV_1 %	91.2 (9)	93.6 (10)	0.03
FVC %	90.4 (10)	91 (0.9)	0.2
FEV_1/FVC %	86.3 (6)	86.2 (5)	0.9
FEF_{25-75}%	89.2 (3)	90.1 (4)	0.6
n (%)			
FVC <80	16 (11)	9 (6)	0.07
FEV1 <80	14 (10)	6 (4)	0.03
FEV1/FVC ratio	17 (12)	9 (6)	0.04
FEF_{25-75} <80	12 (8)	8 (5)	0.3

Continuous data expressed as mean (SD); FEV_1: Forced expiratory volume in the first second; FVC: Forced vital capacity; FEF 25-75: Forced expiratory flow 25-75.

WHAT THIS STUDY ADDS?

- Adolescents exposed to high concentrations of PM10, ozone, and living <500 m from a brickwork have reduced lung function.

higher odds ratio (95% CI) for abnormal lung function were recorded for the zone, diagnosis of asthma, and living <500 meters from a brickwork as [2.2 (1.1-4.2)], [5.7 (2.4-13.2)], and [1.8 (1.0-2.5)], respectively.

DISCUSSION

Almost one-third of the adolescents presented abnormalities on spirometry, chiefly as a decrease in FEV1 and predicted FEV1%, which represents obstruction of the medium and large airways. The pollutants in both the zones were predominantly PM10 and ozone, both exceeding the WHO recommendations.

Our study has several limitations. First, we relied on fixed-site environmental measurements which could introduce exposure misclassifications. Second, we did not measure PM 2.5, which accounts for a larger proportion of the combined effects of PM10 and PM 2.5 [13]. PM 2.5 contains more small particles that can absorb toxic components from the air and penetrate deep in the lungs [14]. Third, socioeconomic status might be a determinant of lung function in our population which was not assessed. Fourth, the questionnaire for pollutant exposure was not validated. Fifth, we did not perform the reversibility test on spirometry. Six, multilevel logistic models should have been adjusted for potential confounders like height, BMI, sex, age, and passive smoking.

In this study, up to one third of the adolescents in zone 1 lived <500 meters from a brickwork. The brickworks are an artisanal and unregulated industry, initially located on the periphery, but nowadays found alongside inhabited zones which emit contaminants like SO_2, NO_2, CO, particulate matter (PM10 and PM2.5), and black carbon. These can cause health problems for their workers, in the nearby surrounding and even distant communities [15]. The generated gases induce an inflam-matory response in the airways, with excessive mucous production, broncho-constriction, and deterio-ration of lung function [16]. The exposure to PM10 and ozone induces oxidative stress and inflammation of the airway generating a decrease in lung function in children [17].

Our results are pertinent when compared to the ESCAPE study [6], from Europe which observed spirometry alterations in 6.8% to 10.4% children with an annual PM10 ranging from 3.0-31.4 μg/m^3. The decrease in FEV1 % was associated with high concentrations of NO_2 and PM2.5 [6]. Similarly, the Southern California Children's Health Study [5], confirmed alterations in FEV1 and FVC, and progressive loss of FEV1 <80% of predicted at 15 years of age in 3.6% to 6.3% and 7.9% adolescents on follow-up [5]. Similar reductions in FEV1 and FVC were associated with exposure to ozone, PM10, and NO_2 in children in an earlier study [12], as also reported by us. Exposure to higher NO_2 and PM levels during preschool was associated with reduced FEV1 at 16 years of age, but not with FVC which was not modified by asthma. This suggested that pollutant exposure during early life was influential to cause increased airway obstruction but not reduced lung volume in adolescence [18]. The increase in morbidity and mortality associated with brief exposure to environmental contamination is also documented [19].

To conclude, the high exposure to PM10, ozone, and living in close proximity to brickwork was associated with reduction in lung function in adolescents from the metropolitan area of Guadalajara. Follow-up studies to determine the impact of air pollution on lung function during adulthood are required.

Ethics approval: Comité Local de Investigación en Salud (CLIS); No. R-2016-1302-031, dated March 06, 2016.
Contributors: RHR, ATP: conception and designed of the study; RHR, VM: collected the data; RHR, OMC: analyzed the data; RHR, ATP: wrote the manuscript. All authors read and approved the final manuscript.
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