Association of Air Pollution and Lung Function of Young Adult Females in New Delhi

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Introduction

Lung function tests help to evaluate the respiratory health of an individual as they reflect the underlying physiological condition of the airways and the alveoli. Lung function is compromised far before appearance of signs and symptoms of chronic respiratory diseases. Air pollution adversely affects lung function. Exposure to sources of pollution differ between men and women due to commuting and smoking habits. The present study was carried out in Delhi to assess the association of exposure to air pollution sources with lung function of young adult females, as this younger age group is expected to have a different exposure profile than older women.

Methods. The present study was conducted on the campus of a central university in Delhi among 18- to 25-year old females (n=200). A pre-tested, close-ended and interviewer-administered questionnaire was used that consisted of information on sociodemographic details of the participants and self-reported exposure to air pollution sources at the residence of participants, during their commute to and from college, and at school. Both active and passive smoking status were recorded. Lung function was assessed using a digital spirometer.

Results. A significant association was observed between percentage of predicted value of forced expiratory volume in one second (FEV₁)/forced vital capacity (FVC) and peak expiratory flow (PEF) with the number of years the participant had resided in Delhi (p<0.05). Forced vital capacity and FEV₁ of those using closed transport methods such as car, metro, and air-conditioned (A/C) bus were significantly better than those who used open transport methods such as non-A/C bus and scooter (p<0.05). Forced vital capacity and FEV₁ were significantly decreased among those who had a smoke-producing factory in the vicinity of their residence (p<0.05). A significant decrease in FVC and FEV₁ was observed among active smokers and among those who were exposed to passive smoking by family members in comparison to those who were not exposed (p<0.05).

Conclusions. The results of the present study suggest that air pollution exposure plays a role in determining the lung function profile of young adult females. This study provides baseline data on lung function of young adult females which could be used in future longitudinal cohort studies.

Participant Consent. Obtained
Ethics Approval. The study was approved by the Institutional Ethics Committee of University College of Medical Sciences.
Competing Interests. The authors declare no completing financial interests.

Keywords. spirometry, lung function, PFTs, air pollution, young adults, passive smoking

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females were selected for the present study. There is a gap in knowledge regarding sources of air pollution exposure and its association with lung function in young women in particular. This study was carried out in Delhi to assess the association of exposure to air pollution sources with lung function of young adult females.

**Methods**

This cross-sectional study was conducted on the campus of a central university in Delhi between November 2016 and April 2018. Two hundred female students who were enrolled in regular courses at the university were recruited for the present study. The participants were adult females between 18 to 25 years age who were enrolled in undergraduate, postgraduate or PhD courses on a regular basis. Inclusion criteria included residence in Delhi for the past six months or more. Women who were being treated for chronic diseases like COPD, asthma, tuberculosis, heart and kidney ailments, musculoskeletal disorders affecting respiratory functions, pregnant and lactating females, and those with a body mass index greater than 30 kg/m² were excluded, as these conditions might modify the measured respiratory parameters. The study was approved by the Institutional Ethics Committee of University College of Medical Sciences. Each eligible student was solicited for participation in the present study and those who gave written informed consent were included in the study until the desired sample size was reached. An attempt was made to include day-scholars (students who live off-campus) and hostel residents in equal proportion. Students were informed that performing spirometry might cause hypoxia, resulting in giddiness. After data collection, study participants were encouraged to seek professional help for their respiratory ailments, if any were identified. Lung function measurements were disclosed to the participants on demand.

**Questionnaire**

A pre-tested, close ended and interviewer-administered questionnaire was used for recording information. The questionnaire consisted of information on sociodemographic details of the participants and self-reported exposure to potential sources of air pollution at the respondent’s residence, during their commute, and at school. Details were collected regarding distance of commute to school, mode of transport, extent and nature of residential pollution as determined by overcrowding, ventilation, method of cooking, presence of air-conditioner (A/C) and heavy rugs/carpets, etc. The questionnaire also inquired about the presence of smoke-producing factories, construction sites, gas stations, or petrol pumps in the vicinity of residence (within 1 km). Presence of any one or more of the above was considered to be a source of residential pollution. Questions were asked regarding smoking and exposure to environmental tobacco smoke due to overcrowding, ventilation, method of cooking, presence of air-conditioner (A/C) and heavy rugs/carpets, etc. Overcrowding is said to occur if persons per room exceed these numbers. Ventilation was assessed by presence or absence of windows. For assessment of smoke exposure, active smoker was defined as smoking tobacco in the past 30 days. Passive smoker was defined as exposure to environmental tobacco smoke due to smoking by either family members or friends in the past 30 days. Frequent exposure to tobacco smoke was defined as exposure to tobacco smoke more than two times a week and non-frequent exposure as less than once a week. The questionnaire can be found in Supplemental Material.

**Spirometry**

Pulmonary functions were assessed according to American Thoracic Society criteria using a digital, portable spirometer (Spiromin, Universal Medical Equipment). A bronchodilator was not administered prior to spirometry.

**Procedure**

One of the study investigators was trained in performing spirometry. Each participant was shown how to perform a spirometry test. Height and weight of the participants were measured with shoes removed. The breathing tube with a disposable mouthpiece was inserted into the participant’s mouth so that the lips were sealed around the mouthpiece.
A nose clip was used or nares were manually occluded before starting the maneuver. For safety reasons, testing was done in a seated position, using a chair with arms and without wheels. Each participant was instructed to perform at least three forced expiratory maneuvers. Using a computer assisted quantitative assessment, the best maneuver was determined. The data was compared with predicted values based on age, sex, height, and weight. Flow volume loops were generated. Flow was plotted against volume to display a continuous loop from inspiration to expiration and the results were interpreted.

Recorded lung function parameters included forced vital capacity (FVC), i.e. the maximum amount of air that can be expired after a maximal inspiratory effort; forced expiratory volume in one second (FEV<sub>1</sub>), i.e. the volume of air expired during the first second of a forced expiration; ratio of FEV<sub>1</sub> to FVC (FEV<sub>1</sub>/FVC) expressed as percentage; forced expiratory flow at 25-75% (FEF 25-75%), the average expiration flow rate during the middle 50% of the FVC; and peak expiratory flow (PEF), the peak flow rate during

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| Ambient air pollution | N | % |
|-----------------------|---|---|
| Number of years in Delhi |
| Less than five years | 79 | 39.5 |
| Five to eighteen years | 45 | 22.5 |
| More than eighteen years | 76 | 38 |
| Commuting distance between residence and university |
| One km or less | 86 | 43 |
| More than one km | 114 | 57 |
| Mode of transport (those commuting a distance of more than one km between residence and university) |
| Closed (car, metro, A/C bus) | 70 | 61.4 |
| Open (two or three-wheeler, non-A/C bus) | 44 | 38.6 |

| Source of pollution exposure in vicinity of residence |
| Smoke producing factory | 17 | 8.5 |
| Gas station | 61 | 30.5 |
| Construction site | 90 | 45 |

| Indoor air pollution |
| Presence of overcrowding (person/ room criteria) (21) | 56 | 28 |
| Presence of artificial ventilation | 52 | 26 |
| Cooking method |
| Liquefied petroleum gas | 188 | 94 |
| Others | 12 | 6 |
| A/C at residence | 129 | 64.5 |
| Heavy rugs/ Carpets | 71 | 35.5 |
| Smoking status |
| Active smoking | 14 | 7 |
| Passive smoking (either family or friends) |
| From family members | 46 | 23 |
| From friends | 57 | 28.5 |

Table 1 — Air Pollution Exposure and Smoking Status of Study Participants (N=200)
expiration. The percentage predicted values of FEV₁, FVC, FEV₁/FVC ratio, FEF and PEF were determined.

Statistical analysis

Data were entered in a Microsoft Excel spreadsheet which was checked for errors and cleaned before analysis. The Statistical Package for the Social Sciences (SPSS) 20.0 software was used for statistical computations and simple descriptive tabulations were made. Exploratory data analysis was performed to determine distribution of different variables. Continuous variables such as lung function values were presented as means and standard deviations. Bivariate analysis was performed to determine the association of air pollution exposure and smoking status with lung function. Significance tests such as the t-test and analysis of variance (ANOVA) were used. All tests were two-tailed and a P-value of less than 0.05 was considered to be statistically significant.

Results

The mean age of the participants was 20.1±1.9 years. The participation rate among eligible subjects was 96%. Only two subjects were married. The majority of the participants identified as Hindu (87.5%). Most of the respondents (85.5%) were classified as upper middle socio-economic status as per the revised Kuppuswamy scale. Table 1 summarizes the sources of exposure to air pollution and smoking status of the participants. Thirty-eight percent (38%) of the participants had resided in Delhi for eighteen years or more. Almost two-thirds of the participants were commuters (lived over one km from the school). Two-thirds of the commuters used closed

| Lung function parameters | Percentage of predicted value (Mean ± SD) |
|--------------------------|------------------------------------------|
|                          | Residence *                               |
|                          | p value (Mean ± SD)                        |
|                          | Commuting distance                        |
|                          | p value (Mean ± SD)                        |
|                          | Mode of transport                         |
|                          | p value (Mean ± SD)                        |

|                          | Less than five years | Five to eighteen years | More than eighteen years |
|--------------------------|----------------------|------------------------|--------------------------|
|                          | (n=79)               | (n=45)                 | (n=76)                   |
| FVC                     | 66.37±11.82          | 68.52±13.18            | 66.82±14.66              |
| FEV₁                    | 72.09±12.07          | 73.13±13.2             | 70.94±14.97              |
| FEV₁/FVC                | 108.93±4.4           | 107.22±6.77            | 106.38±5.99              |
| PEF                     | 72.5±13.81           | 70.52±19.91            | 68.63±15.84              |
| FEF (25-75%)            | 79.36±18.6           | 82.31±24.23            | 73.9±19.43               |

Table 2a — Association of Ambient Pollution Exposure (Residence, Commuting Distance and Mode of Transport) with Lung Function

* ANOVA, Post hoc Test (Tukey’s) was used.

# The post hoc test is presented using the superscripts a and b. Categories with the same superscript are not significantly different whereas categories with different superscripts are significantly different.

**Bold** signifies p value less than 0.05

In the rest of the variables, unpaired t test was used.

Abbreviation: SD, standard deviation.
transport methods such as the metro, car or an air conditioned (A/C) bus and one-third used open transport methods such as a two- or three-wheeler or non-A/C bus. None of the participants reported use of unclean fuels (i.e. those that produce smoke like wood and kerosene) for cooking purposes at their residence. The majority reported the use of A/C at their residence and of these, one-third reported spending more than eight hours per day in air-conditioned rooms. One-third reported the presence of heavy rugs or carpets at the residence.

The prevalence of cigarette smoking among respondents was 7% (n=14). Of these, thirteen reported hookah smoking as well, but it was practiced infrequently. Half of the cigarette smokers were frequent smokers.

Twenty-three percent (23%, N=46) of respondents were exposed to passive smoking from family members and 28.5% (N=57) were exposed from friends.

Table 2a depicts the association of ambient pollution exposure (residence, commuting distance and mode of transport) with lung function. Study participants who had resided in Delhi for 18 years or more showed significantly lower values of FEV₁/FVC and PEF in comparison to those who had resided in Delhi for five years or less. Participants who used open transport methods for commuting from home to college had significantly lower values of FVC and FEV₁ compared to those who used closed transport. Table 2b depicts the association of ambient pollution exposure (source of pollution exposure in vicinity of residence) with lung function. A similar decrease in FVC and FEV₁ was observed among those who reported that a factory was located near their residence.

Table 3a shows the association of indoor pollution exposure (overcrowding and ventilation) with lung function and Table 3b depicts the association of indoor pollution exposure (cooking method, A/C at residence and heavy rugs/ carpets) with lung function. No significant association was observed between various possible sources of indoor pollution exposure and lung function.

Table 4 depicts the association of participant smoking status with lung function. Participants who were active smokers showed a significant decrease
Second-hand smoke exposure from family members was also associated with a significant decrease in FVC and FEV$_1$. Among those who were exposed to second-hand smoke in comparison to those who were not.

**Discussion**

Delhi is one of the most polluted cities in India. The levels of pollutants in ambient air as well as in indoor environments have increased substantially due to an increase in vehicles and construction activity. Longer durations of exposure were found to be associated with decreased FEV$_1$/FVC in the present study. Those who had resided in Delhi for less than five years had better lung function values compared to those who had been in Delhi for 18 years or more. In 2008, Bran et al. reported an annual mean PM 2.5 of 72±4 µg/m$^3$ in Delhi, indicating that those who had lived in Delhi for 18 years or more had comparatively higher exposures to pollution. Similar findings were observed in a study by the Central Pollution Control Board (CPCB) in India that found that those residing in Delhi for at least 18 years had an increased prevalence of restrictive, obstructive, and combined lung function deficits compared to the residents of West Bengal (controls). In the present study, no statistically significant association was observed between lung function and distance between college and residence, but better FVC and FEV$_1$ values were observed among those who resided near campus. Among those who resided over one kilometer from college, a significant association was found between mode of transport for commuting and FVC and FEV$_1$ values. Those who used closed transport methods such as car, metro, or air-conditioned bus had better values than those who used open transport vehicles such as a two- or three-wheeler or non-A/C bus. This may be because those travelling by open transport have higher exposures to pollution in comparison to those who use closed transport. Vehicular exhaust contributes greatly to particulate matter in ambient atmosphere and is a matter of concern. Studies have shown that high to critical levels of pollutants are present at traffic intersections. Residing close to busy roads with high traffic volume has been associated with acute respiratory

| Lung function parameters | Percentage of predicted value (Mean ± SD) | p value | Percentage of predicted value (Mean ± SD) | p value |
|--------------------------|----------------------------------------|--------|----------------------------------------|--------|
|                          | Overcrowding                           |        | Ventilation                            |        |
|                          | Present (n=148)                        |        | Present (n=52)                         |        |
|                          | Absent (n=56)                          |        | Absent (n=144)                         |        |
| FVC                     | 68.64±14.33                            | 0.286  | 67.83±13.61                            | 0.149  |
| FEV$_1$                 | 72.96±13.57                            | 0.479  | 72.6±13.89                             | 0.199  |
| FEV$_1$/FVC             | 106.9±16.98                            | 0.369  | 107.3±15.67                            | 0.325  |
| PEF                     | 72.06±15.62                            | 0.921  | 72.49±16.81                            | 0.374  |
| FEF (25-75%)            | 76.37±20.99                            | 0.521  | 77.53±20.38                            | 0.695  |

Abbreviation: SD, standard deviation.

**Table 3a — Association of Indoor Pollution Exposure (Overcrowding and Ventilation) with Lung Function**

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|--------------------------|----------------------------------------|--------|----------------------------------------|--------|
|                          | Overcrowding                           |        | Ventilation                            |        |
|                          | Present (n=148)                        |        | Present (n=52)                         |        |
|                          | Absent (n=56)                          |        | Absent (n=144)                         |        |
| FVC                     | 68.64±14.33                            | 0.286  | 67.83±13.61                            | 0.149  |
| FEV$_1$                 | 72.96±13.57                            | 0.479  | 72.6±13.89                             | 0.199  |
| FEV$_1$/FVC             | 106.9±16.98                            | 0.369  | 107.3±15.67                            | 0.325  |
| PEF                     | 72.06±15.62                            | 0.921  | 72.49±16.81                            | 0.374  |
| FEF (25-75%)            | 76.37±20.99                            | 0.521  | 77.53±20.38                            | 0.695  |

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**Table 3a — Association of Indoor Pollution Exposure (Overcrowding and Ventilation) with Lung Function**

| Lung function parameters | Percentage of predicted value (Mean ± SD) | p value | Percentage of predicted value (Mean ± SD) | p value |
|--------------------------|----------------------------------------|--------|----------------------------------------|--------|
|                          | Overcrowding                           |        | Ventilation                            |        |
|                          | Present (n=148)                        |        | Present (n=52)                         |        |
|                          | Absent (n=56)                          |        | Absent (n=144)                         |        |
| FVC                     | 68.64±14.33                            | 0.286  | 67.83±13.61                            | 0.149  |
| FEV$_1$                 | 72.96±13.57                            | 0.479  | 72.6±13.89                             | 0.199  |
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| PEF                     | 72.06±15.62                            | 0.921  | 72.49±16.81                            | 0.374  |
| FEF (25-75%)            | 76.37±20.99                            | 0.521  | 77.53±20.38                            | 0.695  |

Abbreviation: SD, standard deviation.

**Table 3a — Association of Indoor Pollution Exposure (Overcrowding and Ventilation) with Lung Function**
infections and diseases like asthma, COPD, and chronic bronchitis.\textsuperscript{11-13,15,16} Individuals with occupational exposure to vehicular pollution such as traffic police have been found to have significantly deteriorated lung function in comparison to the normal population, as demonstrated by Gupta et al.\textsuperscript{17,18} Hence, there is strong evidence of decline in lung function among those exposed to vehicular exhaust. In the present study, both FVC and FEV\textsubscript{1} of the participants were significantly associated with the presence of a factory near their residence. This could be because smoke contains harmful pollutants which contaminate the air and lead to air quality deterioration, eventually harming respiratory health. Patel et al. reported that those living in proximity to an industrial area had higher prevalence of respiratory symptoms, lower FVC and FEV\textsubscript{1} values, and restrictive lung abnormalities.\textsuperscript{19} Presence of an industrial site was identified as a predictor of asthma and respiratory symptoms by Barakat et al.\textsuperscript{20} No association was observed between lung function and presence of a construction site near the residence of participants in the present study.

No significant association between lung function parameters with presence or absence of windows or presence of overcrowding at the residence of the respondents was observed. However, a trend of better indicators of lung function among those with windows and without overcrowding in their residences was observed, especially for FVC and FEV\textsubscript{1}. This may be due to the fact that lack of windows and overcrowding result in the accumulation of indoor pollutants, which in turn may harm lung function.\textsuperscript{21-23} In addition, FVC and FEV\textsubscript{1} were significantly lower in smokers compared to non-smokers. This may be because smoking is a major risk factor for COPD, as reported in studies by Mahmood et al.\textsuperscript{24} and Hooper et al.\textsuperscript{25} This in turn affects respiratory health.\textsuperscript{24,25} No significant association between lung function and presence of A/C or heavy rugs or carpets at participants’ residences was found. In a study among adolescents in the United Arab Emirates, similar results were observed by Barakat et al.,\textsuperscript{20} even though heavy rugs and carpets have a tendency to accumulate dust and resuspend it during anthropogenic activity.\textsuperscript{20}

### Table 3b — Association of Indoor Pollution Exposure (Cooking method, A/C at residence and heavy rugs/ carpets) with Lung Function

| Lung function parameters | Cooking method | Percentage of predicted value (Mean ± SD) | Heavy rugs/ carpets | p value |
|--------------------------|----------------|------------------------------------------|---------------------|---------|
|                          | Liquefied petroleum gas (n=188) | Present (n=129) | Absent (n=71) | Present (n=71) | Absent (n=129) |
| FVC                      | 66.54±12.69 | 74.72±19.46 | 0.177 | 67.21±13.29 | 66.71±13.32 | 0.8 | 67.53±12.97 | 66.75±13.47 | 0.692 |
| FEV\textsubscript{1}     | 71.37±12.99 | 79.67±18.75 | 0.158 | 72.1±13.48 | 71.46±13.58 | 0.747 | 72.08±12.87 | 71.76±13.86 | 0.872 |
| FEV\textsubscript{1}/FVC  | 107.57±5.78 | 107.09±4.93 | 0.778 | 107.62±5.33 | 107.39±6.42 | 0.784 | 107.1±5.59 | 107.78±5.81 | 0.419 |
| PEF                      | 71.36±16.22 | 80.03±16.74 | 0.075 | 72.11±16.86 | 71.45±15.47 | 0.784 | 71.75±17.32 | 71.95±15.85 | 0.935 |
| FEF (25-75%)             | 77.37±20.18 | 85.72±24.49 | 0.171 | 78.76±20.54 | 76.25±20.44 | 0.408 | 75.4±18.67 | 79.23±21.37 | 0.207 |

Abbreviation: SD, standard deviation.
Unpaired t test was used.
In addition to active smoking, passive smoking also has a serious impact on respiratory health. In the present study, a highly significant decrease in FVC and FEV\textsubscript{1} was observed among those who were exposed to passive smoking by family members in comparison to those without this exposure. Among participants who were exposed to passive smoking from their friends, no significant decrease in lung function was observed. This could be because participants spend more time with their family members compared to with their friends at university, and therefore exposure to second-hand smoke may be greater at the participants' residence compared to at school. Passive smoking results in the accumulation of indoor air pollutants, and an increase in sulfur dioxide and suspended particulate matter has been observed in homes where there was a positive history of smoking by any family members.\textsuperscript{21,22} Those households where smoking took place inside the house had a higher prevalence of respiratory symptoms among women and children.\textsuperscript{26}

**Limitations**

This study was conducted among female college students in an urban area, therefore the results cannot be extrapolated to the community at large. A self-designed pretested questionnaire was used. Air pollution exposure was empirically assessed and was not quantified using a monitoring instrument. The study was conducted in Delhi where all households were using liquid petroleum gas for cooking and no unclean fuels were used. The exposure of smoke produced from combustion of biomass fuels affecting indoor air quality could not be assessed. The present study was cross-sectional in design, hence the temporal association of risk factors with pulmonary function could not be assessed.

**Conclusions**

Significant differences in lung function parameters were observed based on duration of residence, mode of transport, proximity of residence to a factory, as well as active and passive...
smoking. A similar study of young men and pulmonary function is currently being conducted. Additional analyses examining these factors as independent predictors of lung function are under way and gender will be included in these future studies.

The present study was a cross-sectional study. Thus, the changes in different lung function parameters due to various sources of pollution exposure were not able to be detected. Further longitudinal studies are recommended for future research. The present study provides baseline data on lung function of young adult females which could be used for longitudinal cohort studies in the future. Actual observation and quantitative monitoring and personal monitoring of actual pollution data is also recommended.

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